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# The trilemma of advanced societies: health, environment and diet

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# THE TRILEMMA OF ADVANCED SOCIETIES: HEALTH, ENVIRONMENT AND DIET

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# LIST OF PUBLICATIONS

This PhD thesis is based on the following scientific articles, a register of intellectual property and a book chapter. More details on scientific publications, journal metrics, and copyright can be found in Annex I.

1. **Cambeses-Franco, C.**, González-García, S., Feijoo, G., Moreira, M. T., 2022. ***Driving commitment to sustainable food policies within the framework of American and European dietary guidelines***. Science of The Total Environment, 807, 150894. https://doi.org/10.1016/j.scitotenv.2021.150894
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# NOTATION

| | |
|---|---|
| **A** | |
| AESAN | Spanish Agency for Food Safety and Nutrition |
| **B** | |
| BEDCA | Spanish Food Consumption database |
| BMI | Body mass index |
| **C** | |
| CED | Cumulative Energy Demand |
| CF | Carbon footprint |
| CI | Confidence interval |
| CONSORT | Consolidated Standards of Reporting Trials |
| COSI | European Childhood Obesity Surveillance Initiative |
| CRCA | Colorectal cancer |
| CREA | Council of Agricultural Research and Economics |
| CVD | Cardiovascular disease |
| **D** | |
| DDG | Dutch dietary guidelines |
| DGA | Dietary Guidelines for Americans |
| DHA | Docosahexaenoic acid |
| DIPASI | Dietary pattern sustainability index |
| **E** | |
| EFSA | European Food Safety Authority |
| EPA | Eicosapentaenoic acid |
| EPD | Environmental Product Declaration |
| EROI | Energy return on investment ratio |
| **F** | |
| FAO | Food and Agricultural Organisation |
| FBDG | Food-based dietary guidelines |
| **G** | |
| GALIAT | Galician Atlantic diet |
| GHG | Greenhouse gas |
| GMO | Genetically modified organism |
| **H** | |
| HDL | High-density lipoprotein |
| HEPA active | Health-enhancing physical activity |
| HHS | Department of Health and Human Services |
| HR | Hazard ratio |
| **I** | |
| ICC | Intraclass correlation coefficient |
| IDG | Italian Dietary Guidelines |
| INDIGOO | Individual Diet Including Global Objectives Optimisation |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Incidence rate ratio |
| ISO | International Organisation for Standardisation |
| **L** | |
| LCA | Life cycle assessment |
| LCI | Life cycle inventory |

| | |
|---|---|
| LCIA | Life cycle impact assessment |
| LDL | Low-density lipoprotein |
| LU | Land use |
| LULUC | Land-use and land-use change activities |
| **M** | |
| MAPA | Ministry of Agriculture, Fisheries and Food |
| MD | Mediterranean diet |
| MetS | Metabolic syndrome |
| MSC | Marine Stewardship Council |
| MUFA | Monounsaturated fatty acids |
| **N** | |
| NAOS | Spanish strategy for nutrition, physical activity and obesity prevention |
| NCD | Non-communicable disease |
| NEA | Net energy analysis |
| NND | New Nordic Diet |
| NRD9.3 | Nutrient Rich Diet 9.3 |
| NRF9.3 | Nutrient Rich Food 9.3 |
| **O** | |
| OEC | Observatory of Economic Complexity |
| OR | Odd ratio |
| **P** | |
| PAHO | Pan American Health Organisation |
| POR | Proportional Odds Ratio |
| PUFA | Polyunsaturated fatty acids |
| **R** | |
| RCT | Randomised controlled trial |
| RR | Relative risk |
| RVD | Recommended daily values |
| **S** | |
| SD | Standard deviation |
| SDG | Sustainable Development Goal |
| SFA | Saturated fatty acids |
| SNND | Southern version of the New Nordic Diet |
| **T** | |
| TIDieR | Template for Intervention Description and Replication |
| T2D | Type 2 diabetes mellitus |
| **U** | |
| UNESCO | United Nations Educational, Scientific and Cultural Organisation |
| USDA | United States Department of Agriculture |
| **W** | |
| WCRF | World Cancer Research Fund |
| WF | Water footprint |
| WFA | Water footprint assessment |
| WFN | Water footprint network |
| WHO | World Health Organisation |

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# RESUMO

O noso planeta atópase nun punto de inflexión. Unha complexa rede de desafíos – o crecemento da poboación, os avances tecnolóxicos, a inestabilidade económica, os desastres naturais, os efectos da COVID-19 na cadeas mundiais de subministro, os conflitos rexionais e nacionais – somerxen ao mundo nunha crise alimentaria sen precedentes e obstaculizan o logro dos Obxectivos de Desenvolvemento Sustentable para 2030.

Os sistemas alimentarios contribúen de maneira significativa á degradación do medio ambiente. A agricultura e actividades afíns representan arredor dun terzo das emisións de gases de efecto invernadoiro a nivel global, afectando negativamente á calidade do solo, ó consumo de auga e á biodiversidade. Aínda que a maior parte dos impactos ambientais proveñen da produción primaria de alimentos (ou da recolección no caso da pesca), unha parte significativa destes impactos tamén se xera nos procesos de post-produción e post-colleita ao longo das cadeas de subministro. Por iso, resulta fundamental avaliar de forma integral os impactos ambientais asociados a cada fase do sistema alimentario.

Por outra banda, as crecentes desigualdades poñen a proba a capacidade dos sistemas alimentarios para ofrecer alimentos nutritivos e accesibles a toda a poboación. En consecuencia, a fame e as dietas pouco saudables están socavando a saúde pública a nivel mundial, e moitos países enfróntanse agora a unha carga tripla de malnutrición: sobrenutrición (sobrepeso e obesidade), desnutrición (retraso do crecemento e insuficiencia de peso respecto da talla) e deficiencias de micronutrientes. Esta situación está provocando un incremento de enfermidades non transmisibles, como a diabetes, enfermidades cardiovasculares e certos tipos de cancro, ao tempo que limita o desenvolvemento físico e cognitivo, especialmente na infancia.

Ante estes desafíos, a perspectiva global sobre como empregar os sistemas alimentarios para mellorar a nutrición evolucionou cara dietas saudables e sustentables. Estas dietas non so promoven a saúde individual, senón tamén a do planeta. Son accesibles, seguras e equitativas e, ademais, son culturalmente apropiadas e xeran un baixo impacto ambiental. Asegurar todas estas características só e posible se se analizan as dietas no contexto máis amplo do sistema alimentario na súa totalidade, abarcando dende a produción na granxa ata o consumidor, así como as súas conexións con diversos sectores, que van dende a educación ata a infraestrutura.

Por iso, o obxectivo principal desta tese é avaliar a sustentabilidade de diversos patróns dietéticos, dende as recomendacións oficiais ata as prácticas alimentarias da poboación. Analizarase o seu impacto na saúde, na nutrición, no medio ambiente e na accesibilidade económica. Ademais, examinaranse os factores que determinan as decisións alimentarias, incluíndo aspectos socioculturais como a estratificación social, as crises alimentarias globais e as tendencias alimentarias. Incorporar este enfoque multidisciplinario serve como base para que os gobernos deseñen políticas alimentarias efectivas e integren a educación ambiental nos programas escolares, promovendo así a conciencia sobre o impacto das eleccións alimentarias. A tese estrutúrase como se indica nas seguintes liñas.

A **Sección I** describe unha visión xeral do estado da arte do problema abordado nesta tese, así como dos obxectivos e ferramentas metodolóxicas empregadas para este fin. O **capítulo 1** explora os desafíos do sistema alimentario global, que inclúen a perda de biodiversidade, a contaminación dos solos e da auga, o cambio climático, a degradación ambiental, a inseguridade alimentaria, a obesidade e a malnutrición. É urxente avanzar cara un sistema alimentario sustentable para cumprir cos Obxectivos da Axenda 2030. Para iso, resulta fundamental promover a educación ambiental, o etiquetado ecolóxico e a adopción de dietas baseadas en alimentos, e recuperar as dietas tradicionais. No **capítulo 2** preséntanse os obxectivos da tese,

mentres que o **capítulo 3** céntrase en metodoloxías para avaliar a sustentabilidade dos patróns dietéticos. Destácase a Análise de Ciclo de Vida como unha ferramenta metodolóxica estandarizada para medir o impacto ambiental das nosas eleccións alimentarias, xunto co uso de índices específicos para avaliar a calidade nutricional como son o NRD9.3 e o índice de saúde. Así mesmo, abórdanse ensaios controlados aleatorios e estudos de cohorte que examinan a relación entre intervencións dietéticas e saúde, especialmente no contexto de enfermidades non transmisibles coma a diabetes tipo II, a obesidade, o cancro, as enfermidades cardiovasculares ou o síndrome metabólico. Por último, a análise de conglomerados preséntase como unha técnica estatística multivariante clave para integrar as dimensións ambientais, de saúde e socioeconómicas na toma de decisións.

Na **Sección II** abórdase a análise multicriterio das guías alimentarias baseadas en alimentos de diversas entidades nacionais e internacionais, reafirmando o compromiso de avanzar cara un futuro saudable e sustentable para todos e todas. As guías alimentarias baseadas en alimentos constitúen un marco de referencia para deseñar políticas públicas de alimentación e nutrición. Proporcionan recomendacións sobre alimentos, grupos de alimentos e patróns dietéticos co fin de garantir unha inxestión axeitada de nutrientes para a poboación en xeral, promovendo a saúde e previndo enfermidades crónicas. No **capítulo 4** comparáronse as guías alimentarias de varios países europeos (Holanda, España e Italia), as guías americanas e dietas rexionais (mediterránea e Nova Dieta Nórdica) dende a perspectiva ambiental (pegada de carbono e hídrica) e calidade nutricional (NRD9.3 e índice de saúde). As dietas máis ricas en contido vexetal, como a italiana e a mediterránea, presentaron unha menor pegada de carbono, mentres que as guías americanas, ricas en carne e lácteos, foron as peores neste aspecto. En termos de pegada hídrica, as guías dietéticas que tomaron España como lugar de referencia (a dieta mediterránea e as guías españolas relativas á Estratexia para a nutrición, actividade física e prevención da obesidade) foron as que presentaron valores máis elevados, o cal se pode atribuír ás condicións climáticas, factores agrícolas e sistemas de produción. No referido á calidade nutricional, a dieta mediterránea sobresae, especialmente na comparación coas dietas holandesa e americana. Estas disparidades son motivadas pola inclusión limitada de froitas, verduras e fibra nas guías dietéticas holandesas, así como polo alto contido de graxas saturadas e sodio nas guías dietéticas americanas.

O **capítulo 5** centra a súa atención na dieta EAT-Lancet, considerada un referente global de saúde planetaria. A través dunha análise comparativa, contrástase o patrón alimentario español con esta dieta universal e explóranse as diferencias con outras guías alimentarias europeas e americanas, todo baixo a lenta da nutrición e o medioambiente. A dieta EAT-Lancet é unha dieta flexitariana que inclúe principalmente alimentos de orixe vexetal como verduras, froitas, cereais integrais, legumes, froitos secos e sementes, limitando o consumo de produtos de orixe animal (principalmente carne vermella e procesada), azucres engadidos e cereais refinados. Se ben o patrón alimentario español cumpre coas recomendacións nutricionais, o estudo revela unha brecha significativa en termos de sustentabilidade ambiental. Os produtos a base de amidón, así como os aceites e as graxas, foron os principais contribuíntes nos dous indicadores ambientais na dieta proposta pola comisión EAT-Lancet. Por outra banda, a carne e os produtos lácteos destacaron como os maiores factores de impacto ambiental dentro do patrón dietético español. Polo tanto, a redución do consumo de carne e lácteos, tal e como propón a dieta EAT-Lancet, é fundamental para que os españois avancen na loita contra o cambio climático, preserven os recursos naturais e melloren a súa propia saúde.

No **capítulo 6** a Nova Dieta Nórdica reformúlase no sur de Europa. A través dunha análise multidisciplinaria, avalíase se esta proposta pode converterse nunha alternativa viable á dieta mediterránea. A Nova Dieta Nórdica promove unha alimentación saudable baseada en

alimentos locais e de temporada dos países nórdicos, dando prioridade a produtos orgánicos e rexionais, e fomentando o uso de ingredientes do campo e do mar. O capítulo revela que tanto a dieta mediterránea como a Nova Dieta Nórdica adaptada ao sur de Europa protexen contra enfermidades non transmisibles (cardiovasculares, diabetes e cancro colorrectal) e axudan a manter un peso saudable. Ademais, ámbalas dúas dietas son accesibles economicamente. Con todo, cando se trata de coidar o planeta e ofrecer unha maior calidade nutricional, a dieta mediterránea álzase como a mellor opción.

A **Sección III** céntrase na dieta atlántica, arraigada na tradición culinaria de Galicia e o norte de Portugal. Esta dieta aposta por receitas con ingredientes frescos e de tempada, adaptadas aos sabores e hábitos propios da rexión. Un aspecto clave é a forma de preparación, preferindo métodos como a cociña a vapor ou a cocción en auga, en lugar da fritura. O peixe e o marisco son alimentos fundamentais que se consumen de maneira habitual, mentres que os produtos lácteos tamén teñen un papel relevante, xunto co aceite de oliva, que é a principal fonte de graxa. Ademais, a dieta inclúe o consumo diario de froitas e hortalizas. No **capítulo 7** preséntase unha investigación pioneira que analiza os beneficios da dieta atlántica dende unha perspectiva dual: saúde e medio ambiente. Este estudo baséase nun ensaio clínico de intervención nutricional, controlado e aleatorizado, deseñado dende un enfoque comunitario (estudo GALIAT). As principais características deste enfoque son: (1) centrarse na familia como unidade clave de intervención (2) basearse nunha dieta que respecta o patrimonio cultural e gastronómico da zona, a dieta atlántica (3) incluír a educación nutricional tanto a nivel individual como comunitario (4) levarse a cabo no marco da atención primaria (5) contar coa participación de empresas alimentarias locais, varios grupos de investigación, os medios de comunicación, o concello e restaurantes, entre outros actores. Os resultados amosan que a intervención nutricional de 6 meses conseguiu reducir o risco de desenvolver síndrome metabólico entre os participantes do grupo de intervención, en comparación co grupo de control. Ademais, os individuos do grupo de intervención tiveron un 42% menos de probabilidade de presentar un compoñente adicional de síndrome metabólico en relación co grupo de control, aínda que non se observou unha redución significativa dos riscos relativos de presión arterial alta, hipertrigliceridemia ou hiperglicemia por separado. Non obstante, o grupo de intervención non amosou unha redución significativa no impacto ambiental en termos de pegada de carbono en comparación co grupo control. O tamaño da mostra de estudo podería non ter o poder estatístico suficiente para detectar unha redución significativa neste indicador ambiental, o que suxire a necesidade de realizar estudos a maior escala.

O **capítulo 8** busca revolucionar a gastronomía galega mediante unha análise de conglomerados xerárquica para avaliar a pegada de carbono, a eficiencia enerxética e o custo de cada receita galega. Conclúese que as receitas con maior proporción de produtos animais, especialmente carne vermella, teñen maiores custos e pegadas de carbono, así como unha menor taxa de retorno enerxética. Esta análise permite a consumidores tomar decisións informadas, apoiando a produción local e sustentable e fomentando a creación de menús máis ecolóxicos. Ademais, proporciona a base para o desenvolvemento de ecoetiquetas nos menús dos restaurantes, o que lles permitiría diferenciarse no mercado, mellorar a súa imaxe de marca e fomentar a lealdade e confianza dos clientes.

A **Sección IV** amosa como as nosas eleccións dietéticas son o resultado dunha complexa rede de factores socioculturais, sanitarios, políticos e económicos. Estes factores interactúan para influír nas preferencias individuais, nas prácticas culturais e nas decisións alimentarias a nivel de poboación. Eventos críticos, como unha pandemia, poden alterar esta rede, modificando de forma significativa os motivos subxacentes á elección de alimentos e, por conseguinte, cambiando os hábitos alimentarios xerais.

O **capítulo 9** busca entender como as medidas de saúde pública implementadas durante a COVID-19 modificaron os patróns de consumo alimentario en España. Examínase o impacto destes cambios na pegada de carbono e na pegada hídrica, así como a súa repercusión no cumprimento dos Obxectivos de Desenvolvemento Sustentable 2 (fame cero), 6 (auga potable e saneamento), 12 (produción e consumo responsables) e 13 (acción polo clima). As medidas de confinamento provocaron un aumento significativo no consumo de alimentos nos fogares, o que se reflexou nun incremento da pegada de carbono e hídrica, especialmente entre marzo e abril de 2020. Este pico foi seguido dunha tendencia á baixa a medida que se avanzaba na vacinación e se relaxaban as restricións. Ademais, observouse un aumento estacional do consumo durante as festividades de Nadal. A crise sanitaria evidenciou a importancia de contar cun sistema alimentario resiliente, capaz de xestionar cambios rápidos nas demandas de consumo, nas cadeas de subministración e nos comportamentos da poboación, ao tempo que se manteñen os principios de sustentabilidade e xustiza social.

O **capítulo 10** investiga como o nivel socioeconómico inflúe no custo, a calidade nutricional e a pegada ambiental das eleccións dietéticas dos chilenos. Os fogares de maiores ingresos teñen acceso a dietas mellores a nivel nutricional, pero pouco sustentables dende o punto de vista ambiental. Os residentes chilenos no quintil socioeconómico máis alto consumen máis carne e menos produtos a base de amidón, sendo a carne o principal contribuínte ás pegadas de carbono e hídrica. Con todo, a desnutrición é un problema que transcende ás clases sociais en Chile. Esta realidade subliña a necesidade de implementar políticas alimentarias que garantan o acceso a unha alimentación saudable e sustentable para toda a poboación, especialmente no contexto de cambio climático, escaseza hídrica e prevalencia de factores de risco metabólico que incrementan a probabilidade de enfermidades non transmisibles en América Latina.

O **capítulo 11** analiza a dieta paleolítica dende unha perspectiva integral que abarca aspectos ambientais, nutricionais e de saúde pública, comparándoa con outros patróns dietéticos máis convencionais. Esta dieta do home das cavernas baséase en alimentos que se podían obter a través da caza e a recolección, como froitas, verduras, carnes magras, peixe, ovos, froitos secos e sementes. Deste modo, exclúe produtos que se popularizaron co desenvolvemento da agricultura, como os grans, as legumes e os lácteos. Aínda que a dieta paleolítica é rica en proteínas e baixa en carbohidratos, o que pode facilitar a perda de peso e o desenvolvemento muscular, trae consigo riscos significativos. En particular, os altos niveis de colesterol e certos ácidos graxos asociados a esta dieta incrementan o risco de enfermidades coma o cancro e problemas cardiovasculares. Ademais, o seu alto custo e o seu considerable impacto ambiental, debido ao consumo de carnes e mariscos, convértena nunha opción pouco sustentable e con posibles consecuencias negativas para a saúde a longo prazo.

A **Sección V** presenta dous xogos que permiten plantar as sementes dunha xeración máis consciente e comprometida co coidado do medio ambiente. Baseados no marco do Deseño Universal da Aprendizaxe, integran a dimensión ambiental no currículo, favorecendo a formación integral do alumnado, e nutrindo a súa personalidade, pensamento crítico, creatividade e capacidade de resolución de problemas.

O **capítulo 12** somérxenos no deseño dun xogo de cartas que promove a aprendizaxe cooperativa e ensina aos nenos e nenas de educación primaria a calcular a pegada hídrica e de carbono asociadas ás súas dietas persoais, ademais de explorar os Obxectivos de Desenvolvemento Sustentable 3 (saúde e benestar), 4 (educación de calidade), 6 (auga limpa e saneamento), 12 (produción e consumo responsables) e 13 (acción polo clima). A actividade inclúe fases de traballo individual, reflexión grupal e deseño dun plan de dieta sustentable. Este xogo encaixa cos obxectivos xerais, contidos e criterios de avaliación de áreas como Ciencias

da Natureza, Ciencias Sociais, Matemáticas, Educación Física e Educación en Valores Cívicos e Éticos. Coa práctica deste xogo favorécense ademais competencias clave para a aprendizaxe permanente como son a competencia persoal, social e de aprender a aprender, a competencia matemática e competencia en ciencia, tecnoloxía e enxeñaría, a competencia cidadá, a competencia en conciencia e expresións culturais, e a competencia plurilingüe. "Come san...come sustentable" non só axuda aos nenos e nenas a desenvolver hábitos alimentarios saudables para toda a vida, senón que tamén fomenta unha conciencia ambiental dende unha idade temperá.

O **capítulo 13** presenta Ecorush, un xogo de mesa deseñado para estudantes de secundaria que ensina aos participantes a pensar como consumidores responsables. Este xogo resulta especialmente relevante na adolescencia, unha etapa de cambios significativos a nivel físico, biolóxico, psicolóxico e social, cuxas implicacións teñen un impacto directo na saúde e no benestar a longo prazo. Ao igual que un agricultor seleccionando sementes, os xogadores deberán tomar decisións estratéxicas para adquirir produtos que minimicen a súa pegada de carbono, sen descoidar unha dieta equilibrada. Utilizando o $CO_2$ como moeda de cambio, cada estudante móvese por un taboleiro que representa diferentes categorías de alimentos. Durante o xogo, tamén se producen eventos imprevistos que introducen impostos ambientais, subvencións ecolóxicas e outras variables, poñendo a proba a capacidade dos xogadores para xestionar tanto o aspecto ambiental como o financeiro. Ao final do xogo, non so teremos un gañador, senón tamén unha maior conciencia sobre a importancia da alimentación sustentable.

Esta tese, desenvolvida nun marco interdisciplinario que reúne profesionais da saúde e da nutrición, expertos en medio ambiente e profesionais da educación, propón un cambio de paradigma na nosa alimentación. En lugar de antepoñer o prezo, a conveniencia e o sabor, busca balancear a atención na saúde, a sustentabilidade e a equidade. Serve como un paso adiante no impulso e fomento de dietas saudables e sustentables, dentro do contexto de converxencia entre o crecemento demográfico, o incremento de enfermidades non transmisibles e a presión ambiental derivada da produción e consumo de alimentos. Ademais, propón iniciativas educativas gamificadas para sensibilizar aos grupos máis novos sobre a pegada de carbono dos alimentos, as metas do desenvolvemento sustentable, a diversidade alimentaria e a importancia de consumir produtos locais e de tempada.

Porén, a aplicabilidade desta tese demanda un marco sólido de políticas, regulacións e asignacións orzamentarias suficientes que promovan a transición cara  sistemas alimentarios sustentables, xunto con estruturas institucionais que faciliten a coordinación efectiva entre diferentes actores implicados, como os gobernos, as empresas, as organizacións non gobernamentais, as comunidades e o sector privado. So a través dunha colaboración intersectorial será posible abordar a complexidade dos retos que implica a sustentabilidade alimentaria. Ademais, a cooperación internacional e a solidariedade entre países permitirán compartir coñecemento, recursos e mellores prácticas, así como establecer alianzas estratéxicas que fortalezan a capacidade global de facer fronte aos desafíos alimentarios e ambientais.

En definitiva, esta investigación abre un camiño prometedor cara un futuro no que a saúde, a sustentabilidade e a xustiza alimentaria se convertan en pezas clave dunha forma de entender a nosa relación coa comida e co medio ambiente. A visión que se propón é ambiciosa pero necesaria, pois as accións de hoxe determinarán a saúde das xeracións futuras e o benestar do noso planeta.

# RESUMEN

Nuestro planeta se encuentra en un punto de inflexión. Un complejo entramado de desafíos – el crecimiento de la población, los avances tecnológicos, la creciente inflación, los desastres naturales, los efectos del COVID-19 en las cadenas mundiales de suministro, los conflictos regionales y nacionales – sumergen al mundo en una crisis alimentaria sin precedentes y obstaculizan el logro de los Objetivos de Desarrollo Sostenibles para 2030.

Los sistemas alimentarios contribuyen significativamente a la degradación del medio ambiente. La agricultura y actividades afines representan alrededor de un tercio de las emisiones de gases de efecto invernadero a nivel global, afectando negativamente la calidad del suelo, el consumo de agua y la biodiversidad. Aunque la mayor parte de los impactos ambientales provienen de la producción primaria de alimentos (o de la recolección en el caso de la pesca), una parte significativa de estos impactos también se genera en los procesos de post-producción y post-cosecha a lo largo de las cadenas de suministro. Por ello, resulta fundamental evaluar de forma integral los aspectos ambientales asociados a cada fase del sistema alimentario.

Por otra parte, las crecientes desigualdades han puesto a prueba la capacidad de los sistemas alimentarios para ofrecer alimentos nutritivos y asequibles a toda la población. En consecuencia, el hambre y las dietas poco saludables están socavando la salud pública a nivel mundial, y muchos países enfrentan ahora una triple carga de malnutrición: sobrenutrición (sobrepeso y obesidad), desnutrición (retraso del crecimiento y emaciación) y deficiencias de micronutrientes. Esta situación está provocando un incremento de las enfermedades no transmisibles, como la diabetes, las enfermedades cardiovasculares o ciertos tipos de cáncer, al mismo tiempo que limita el desarrollo físico y cognitivo, especialmente en la infancia.

Ante estos desafíos interconectados, la perspectiva global sobre cómo utilizar los sistemas alimentarios para mejorar la nutrición ha evolucionado hacia dietas saludables y sostenibles. Estas dietas no solo promueven la salud individual, sino también la del planeta. Son accesibles, seguras y equitativas, y, además, son culturalmente apropiadas y generan un bajo impacto ambiental. Asegurar todas estas características solo es posible si se analizan las dietas en el contexto más amplio del sistema alimentario en su totalidad, abarcando desde la producción en la granja hasta el consumidor, así como sus conexiones con diversos sectores, que van desde la educación hasta la infraestructura.

Por ello, el objetivo principal de esta tesis es evaluar la sostenibilidad de diversos patrones dietéticos, desde las recomendaciones oficiales hasta las prácticas alimentarias de la población. Se analizará su impacto en la salud, la nutrición, el medio ambiente y la accesibilidad económica. Además, se examinarán los factores que determinan las decisiones alimentarias, incluyendo aspectos socioculturales como la estratificación social, las crisis alimentarias globales y las tendencias alimentarias. Incorporar este enfoque multidisciplinario sirve como base para que los gobiernos diseñen políticas alimentarias efectivas e integren la educación ambiental en los programas escolares, promoviendo así la conciencia sobre el impacto de las elecciones alimentarias. La tesis se estructura como se indica en las siguientes líneas.

La **Sección I** describe una visión general del estado del arte del problema abordado en esta tesis, así como de los objetivos y herramientas metodológicas empleadas para este fin. El **capítulo 1** explora los desafíos del sistema alimentario global, que incluyen la pérdida de biodiversidad, la contaminación de los suelos y del agua, el cambio climático, la degradación ambiental, la inseguridad alimentaria, la obesidad y la malnutrición. Es urgente avanzar hacia un sistema alimentario sostenible para cumplir con los objetivos de la Agenda 2030. Para ello, resulta fundamental promover la educación ambiental, el etiquetado ecológico y la adopción de

dietas basadas en alimentos, y recuperar las dietas tradicionales. En el **capítulo 2** se presentan los objetivos de la tesis, mientras que el **capítulo 3** se enfoca en metodologías para evaluar la sostenibilidad de los patrones dietéticos. Se resalta el Análisis de Ciclo de Vida como una metodología estandarizada para medir el impacto ambiental de nuestras elecciones alimentarias, junto con el uso de índices específicos para evaluar la calidad nutricional como son el NRD9.3 y el índice de salud. Asimismo, se abordan ensayos controlados aleatorios y estudios de cohorte que examinan la relación entre intervenciones dietéticas y salud, especialmente en el contexto de enfermedades no transmisibles como la diabetes tipo II, la obesidad, el cáncer, las enfermedades cardiovasculares o el síndrome metabólico. Por último, el análisis de conglomerados se presenta como una técnica estadística multivariante clave para integrar las dimensiones ambientales, de salud y socioeconómicas en la toma de decisiones.

La **Sección II** aborda el análisis multicriterio de las guías alimentarias basadas en alimentos de diversas entidades nacionales e internacionales, reafirmando el compromiso de avanzar hacia un futuro saludable y sostenible para todos y todas. Las guías alimentarias basadas en alimentos constituyen un marco de referencia para diseñar políticas públicas de alimentación y nutrición. Proporcionan recomendaciones sobre alimentos, grupos de alimentos y patrones dietéticos con el fin de garantizar una ingesta adecuada de nutrientes para la población en general, promoviendo la salud y previniendo enfermedades crónicas. En el **capítulo 4** se compararon las guías alimentarias de varios países europeos (Holanda, España e Italia), las guías americanas y dietas regionales (mediterránea y Nueva Dieta Nórdica) desde la perspectiva ambiental (huella de carbono e hídrica) y la calidad nutricional (NRD9.3 e índice de salud). Las dietas más ricas en contenido vegetal, como la italiana y la mediterránea, presentaron una menor huella de carbono, mientras que las guías americanas, ricas en carne y lácteos, fueron las peores en este aspecto. En términos de huella hídrica, las guías dietéticas que tomaron España como lugar de referencia (la dieta mediterránea y las guías españolas relativas a la Estrategia para la nutrición, actividad física y prevención de la obesidad) fueron las que presentaron valores más elevados, lo cual se puede atribuir a las condiciones climáticas, factores agrícolas y sistemas de producción. En cuanto a calidad nutricional, la dieta mediterránea sobresale, especialmente en comparación con las dietas holandesa y americana. Estas disparidades son motivadas por la inclusión limitada de frutas, verduras y fibra en las guías dietéticas holandesas, así como por el alto contenido de grasas saturadas y sodio en las guías dietéticas americanas.

El **capítulo 5** centra su atención en la dieta EAT-Lancet, considerada un referente global de salud planetaria. A través de un análisis comparativo, se contrasta el patrón alimentario español con esta dieta universal y se exploran las diferencias con otras guías alimentarias europeas y americanas, todo bajo la lente de la nutrición y el medio ambiente. La dieta EAT-Lancet, es una dieta flexitariana que incluye principalmente alimentos de origen vegetal como verduras, frutas, cereales integrales, legumbres, frutos secos y semillas, limitando el consumo de productos de origen animal (principalmente carne roja y procesada), azúcares añadidos y cereales refinados. Si bien el patrón alimentario español cumple con las recomendaciones nutricionales, el estudio revela una brecha significativa en términos de sostenibilidad ambiental. Los productos a base de almidón, así como los aceites y las grasas, fueron los principales contribuyentes en los dos indicadores ambientales en la dieta propuesta por la comisión EAT-Lancet. Por otra parte, la carne y los productos lácteos destacaron como los mayores factores de impacto ambiental dentro del patrón dietético español. Por lo tanto, la reducción del consumo de carne y lácteos, tal y como propone la dieta EAT-Lancet, es fundamental para que los españoles avancen en la lucha contra el cambio climático, preserven los recursos naturales y mejoren su propia salud.

En el **capítulo 6** la Nueva Dieta Nórdica se reinventa en el sur de Europa. A través de un análisis multidisciplinario, se evalúa si esta propuesta puede convertirse en una alternativa viable a la dieta mediterránea. La Nueva Dieta Nórdica promueve una alimentación saludable basada en alimentos locales y de temporada de los países nórdicos, priorizando productos orgánicos y regionales, y fomentando el uso de ingredientes del campo y del mar. El capítulo revela que tanto la dieta mediterránea como la Nueva Dieta Nórdica adaptada al sur de Europa protegen contra enfermedades no transmisibles (cardiovasculares, diabetes y cáncer colorrectal) y ayudan a mantener un peso saludable. Además, ambas dietas son accesibles económicamente. Sin embargo, cuando se trata de cuidar el planeta y ofrecer una mayor calidad nutricional, la dieta mediterránea se alza como la mejor opción.

La **Sección III** se centra en la dieta atlántica, arraigada en la tradición culinaria de Galicia y el norte de Portugal. Esta dieta apuesta por recetas con ingredientes frescos y de temporada, adaptadas a los sabores y hábitos propios de la región. Un aspecto clave es la forma de preparación, prefiriendo métodos como la cocina a vapor o la cocción en agua, en lugar de la fritura. El pescado y el marisco son alimentos fundamentales que se consumen de manera habitual, mientras que los lácteos también tienen un papel relevante, junto con el aceite de oliva, que es la principal fuente de grasa. Además, la dieta incluye el consumo diario de frutas y hortalizas. El **capítulo 7** presenta una investigación pionera que ha analizado los beneficios de la dieta atlántica desde una perspectiva dual: salud y medio ambiente. Este estudio se basa en un ensayo clínico de intervención nutricional, controlado y aleatorizado, diseñado desde un enfoque comunitario (estudio GALIAT). Las principales características de este enfoque son: (1) centrarse en la familia como unidad de intervención (2) basarse en una dieta que respecta el patrimonio cultural y gastronómico de la zona, la dieta atlántica (3) incluir la educación nutricional tanto a nivel individual como comunitario (4) llevarse a cabo en el marco de la atención primaria (5) contar con la participación de empresas alimentarias locales, varios grupos de investigación, los medios de comunicación, el ayuntamiento y restaurantes, entre otros actores. Los resultados mostraron que la intervención nutricional de 6 meses consiguió reducir el riesgo de desarrollar síndrome metabólico entre los participantes del grupo de intervención, en comparación con el grupo de control. Además, los individuos del grupo de intervención tuvieron un 42% menos de probabilidad de presentar un componente adicional de síndrome metabólico en relación con el grupo de control, aunque no se observó una reducción significativa de los riesgos relativos de presión arterial alta, hipertrigliceridemia o hiperglucemia por separado. No obstante, el grupo de intervención no mostró una reducción significativa en el impacto ambiental en términos de huella de carbono en comparación con el grupo de control. El tamaño de la muestra de estudio podría no tener el poder estadístico suficiente para detectar una reducción significativa en este indicador ambiental, lo que sugiere la necesidad de realizar estudios a mayor escala.

El **capítulo 8** busca revolucionar la gastronomía gallega mediante un análisis de conglomerados jerárquico para evaluar la huella de carbono, la eficiencia energética y el coste de cada plato. Se concluye que las recetas con mayor proporción de productos animales, especialmente carne roja, tienen mayores costes y huellas de carbono, así como una menor tasa de retorno energético. Este análisis permite a consumidores tomar decisiones informadas, apoyando la producción local y sostenible y fomentando la creación de menús más ecológicos. Además, proporciona la base para el desarrollo de ecoetiquetas en los menús de los restaurantes, lo que les permitiría diferenciarse en el mercado, mejorar su imagen de marca y fomentar la lealtad y confianza de los clientes.

La **Sección IV** muestra cómo nuestras elecciones dietéticas son el resultado de una compleja red de factores socioculturales, sanitarios, políticos y económicos. Estos factores

interactúan para influir en las preferencias individuales, las prácticas culturales y las decisiones alimentarias a nivel poblacional. Eventos críticos, como una pandemia, pueden alterar esta red, modificando significativamente los motivos que subyacen a la elección de alimentos y, por consiguiente, cambiando los hábitos alimentarios generales.

El **capítulo 9** busca entender cómo las medidas de salud pública implementadas durante la COVID-19 han modificado los patrones de consumo alimentario en España. Se examina el impacto de estos cambios en la huella de carbono y la huella hídrica, así como su repercusión en el cumplimiento de los Objetivos de Desarrollo Sostenible 2 (hambre cero), 6 (agua potable y saneamiento), 12 (producción y consumo responsables) y 13 (acción por el clima). Las medidas de confinamiento provocaron un aumento significativo en el consumo de alimentos en los hogares, lo que se reflejó en un incremento de la huella de carbono e hídrica, especialmente entre marzo y abril de 2020. Este pico fue seguido de una tendencia a la baja a medida que se avanzaba en la vacunación y se relajaban las restricciones. Además, se observó un aumento estacional del consumo durante las festividades navideñas. La crisis sanitaria evidenció la importancia de contar con un sistema alimentario resiliente, capaz de gestionar cambios rápidos en las demandas de consumo, en las cadenas de subministración y en los comportamientos de la población, al tiempo que se mantienen los principios de sostenibilidad y justicia social.

El **capítulo 10** investiga cómo el estatus socioeconómico influye en el coste, la calidad nutricional y la huella ambiental de las elecciones dietéticas de los chilenos. Los hogares de mayores ingresos tienen acceso a dietas mejores a nivel nutricional, y poco sostenibles desde el punto de vista ambiental. Los residentes en el quintil socioeconómico más alto consumen más carne y menos productos a base de almidón, siendo la carne el principal contribuyente a las huellas de carbono e hídrica. Sin embargo, la desnutrición es un problema que trasciende las clases sociales en Chile. Esta realidad subraya la necesidad de implementar políticas alimentarias que garanticen el acceso a una alimentación saludable y sostenible para toda la población, especialmente en el contexto de cambio climático, escasez hídrica y prevalencia de factores de riesgo metabólico que incrementan la probabilidad de enfermedades no transmisibles en América Latina.

El **capítulo 11** analiza la dieta paleolítica desde una perspectiva integral que abarca aspectos ambientales, nutricionales y de salud pública, comparándola con otros patrones dietéticos más convencionales. Esta dieta del hombre de las cavernas se basa en alimentos que se podrían obtener a través de la caza y la recolección, como frutas, verduras, carnes magras, pescado, huevos, frutos secos y semillas. De este modo, se excluyen productos que se popularizaron con el desarrollo de la agricultura, como los granos, las legumbres y los lácteos. Aunque la dieta paleolítica es rica en proteínas y baja en carbohidratos, lo que puede facilitar la pérdida de peso y el desarrollo muscular, conlleva riesgos significativos. En particular, los altos niveles de colesterol y los ácidos grasos asociados a esta dieta incrementan el riesgo de enfermedades como el cáncer o los problemas cardiovasculares. Además, su alto coste y su considerable impacto ambiental, debido al consumo de carnes y mariscos, la convierten en una opción poco sostenible y con posibles consecuencias negativas para la salud a largo plazo.

La **Sección V** presenta dos juegos que permiten plantar las semillas de una generación más consciente y comprometida con el cuidado del medio ambiente. Basados en el marco del Diseño Universal del Aprendizaje, integran la dimensión ambiental en el currículo, favoreciendo la formación integral del alumnado, y nutriendo su personalidad, pensamiento crítico, creatividad y capacidad de resolución de problemas.

El **capítulo 12** nos sumerge en el diseño de un juego de cartas que promueve el aprendizaje cooperativo y enseña a los niños y niñas de educación primaria a calcular la huella hídrica y de carbono asociadas a sus dietas personales, además de explorar los Objetivos de Desarrollo

Sostenible 3 (salud y bienestar), 4 (educación de calidad), 6 (agua limpia y saneamiento), 12 (producción y consumo responsables) y 13 (acción por el clima). La actividad incluye fases de trabajo individual, reflexión grupal y diseño de un plan de dieta sustentable. Este juego encaja con los objetivos generales, contenidos y criterios de evaluación de asignaturas como Ciencias de la Naturaleza, Ciencias Sociales, Matemáticas, Educación Física, y Educación en Valores Cívicos y Éticos. Con la práctica de este juego se favorecen además competencias clave para el aprendizaje permanente como son la competencia personal, social y de aprender a aprender, la competencia matemática y competencia en ciencia, tecnología e ingeniería, la competencia ciudadana, la competencia en conciencia y expresiones culturales, y la competencia plurilingüe. "Come sano... Come sostenible" no solo ayuda a los niños y niñas a desarrollar hábitos alimentarios saludables para toda la vida, sino que también fomenta una conciencia ambiental desde una edad temprana.

El **capítulo 13** nos presenta Ecorush, un juego de mesa diseñado para estudiantes de secundaria que enseña a los participantes a pensar como consumidores responsables. Este juego resulta especialmente relevante en la adolescencia, una etapa de cambios significativos a nivel físico, biológico, psicológico y social, cuyas implicaciones tienen un impacto directo en la salud y el bienestar a largo plazo. Al igual que un agricultor seleccionando sus semillas, los jugadores deberán tomar decisiones estratégicas para adquirir productos que minimicen su huella de carbono, sin descuidar una dieta equilibrada. Utilizando el $CO_2$ como moneda de cambio, cada estudiante se mueve por un tablero que representa diferentes categorías de alimentos. Durante el juego, también se producen eventos imprevistos que introducen impuestos ambientales, subvenciones ecológicas y otras variables, poniendo a prueba la capacidad de los jugadores para gestionar tanto el aspecto ambiental como el financiero. Al final del juego, no solo tendremos un ganador, sino también una mayor conciencia sobre la importancia de la alimentación sostenible.

Esta tesis, desarrollada en un marco interdisciplinario que reúne profesionales de la salud y de la nutrición, expertos en medio ambiente y profesionales de la educación, propone un cambio de paradigma en nuestra alimentación. En lugar de anteponer el precio, la conveniencia y el sabor, busca balancear la atención en la salud, la sostenibilidad y la equidad. Sirve como un paso adelante en el impulso y fomento de dietas saludables y sostenibles, dentro del contexto de convergencia entre el crecimiento demográfico, el incremento de enfermedades no transmisibles y la presión ambiental derivada de la producción y consumo de alimentos. Además, propone iniciativas educativas gamificadas para sensibilizar a los más jóvenes sobre la huella de carbono de los alimentos, las metas de desarrollo sostenible, la diversidad alimentaria y la importancia de consumir productos locales y de temporada.

Sin embargo, la aplicabilidad de esta tesis demanda un marco sólido de políticas, regulaciones y asignaciones presupuestarias suficientes que promuevan la transición hacia sistemas alimentarios sostenibles, junto con estructuras institucionales que faciliten la coordinación efectiva entre diferentes actores implicados, como los gobiernos, las empresas, las organizaciones no gubernamentales, las comunidades y el sector privado. Solo a través de una colaboración intersectorial será posible abordar la complejidad de los retos que implica la sostenibilidad alimentaria. Además, la cooperación internacional y la solidaridad entre países permitirá compartir conocimiento, recursos y mejores prácticas, así como establecer alianzas estratégicas que fortalezcan la capacidad global de hacer frente a los desafíos alimentarios y ambientales.

En definitiva, esta investigación abre un camino prometedor hacia un futuro en el que la salud, la sostenibilidad, y la justicia alimentaria se conviertan en piezas clave de una forma de entender nuestra relación con la comida y con el medioambiente. La visión que se propone es ambiciosa pero necesaria, pues las acciones de hoy determinarán la salud de las generaciones futuras y el bienestar de nuestro planeta.

# ABSTRACT

Our planet is at a breaking point. A wide range of challenges – including population growth, technological advances, economic instability, natural disasters, the impact of COVID-19 on global supply chains and regional and national conflicts – have pushed the world into an unprecedented food crisis, threatening the achievement of the Sustainable Development Goals by 2030.

Current food systems are a key driver of environmental degradation. Agriculture and related activities are responsible for up to one-third of all human-caused greenhouse gas emissions and negatively impact soil quality, water consumption, and biodiversity. Although, the largest share of environmental impacts can be attributed to the primary food production (or harvesting in the case of fisheries), a significant amount of these impacts is also generated in post-production and post-harvest processes along food supply chains. A comprehensive assessment of the environmental impacts associated with each stage of the food supply chain is therefore essential.

Simultaneously, rising inequalities have tested the ability of food systems to provide nutritious and affordable food for all. Consequently, hunger and unhealthy diets undermine public health, resulting in many countries facing a triple burden of malnutrition: overnutrition (overweight and obesity), undernutrition (stunting and wasting), and micronutrient deficiencies. This situation leads to an increase in non-communicable diseases such as diabetes, cardiovascular disease and certain types of cancer, while limiting physical and cognitive development, especially during childhood.

These interconnected challenges have directed global attention toward the urgent need to transform our food systems to promote sustainable, healthy diets. These diets balance the health of people and the planet, being accessible, safe, equitable, culturally appropriate, and environmentally sustainable. Achieving this balance requires a comprehensive analysis of diets within the broader framework of the entire food system, from production to consumption, and their connections to sectors such as education and infrastructure.

The aim of this thesis is to assess the sustainability of various dietary patterns, from official recommendations to real-world consumption habits, and their impacts on health, the environment, and economic accessibility. It also considers socio-cultural factors such as social stratification, global food crises, and current food trends. This multidisciplinary approach provides a basis for governments to develop effective food policies and integrate environmental education into school curricula. This thesis is structured as indicated in the following lines.

**Section I** provides background and context for the research problem, detailing the objectives and methodological tools used. **Chapter 1** explores critical challenges facing food systems, including biodiversity loss, soil and water pollution, climate change, environmental degradation, food insecurity, obesity, and malnutrition. The need to transition toward sustainable food systems is essential for achieving the 2030 Agenda for Sustainable Development, supported by environmental education, eco-labelling, food-based dietary guidelines, and the revival of traditional diets. **Chapter 2** outlines the objectives of the thesis while **Chapter 3** describes the main features of the methodological tools used for assessing dietary sustainability, including the Life Cycle Assessment methodology for environmental impact evaluation and diet quality indices for nutritional analysis (Nutrient Rich Diet 9.3 and the health gain score). Additionally, it reviews randomised controlled trials and cohort studies on dietary interventions related to non-communicable diseases (Type II diabetes mellitus, obesity, cancer, cardiovascular diseases or metabolic syndrome) and highlights the use of

cluster analysis for integrating environmental, health, and socioeconomic factors in decision-making.

**Section II** addresses the multicriteria analysis of national and international food-based dietary guidelines, underlining the commitment to advancing a healthy and sustainable future for all. Food-based dietary guidelines establish a framework for designing public food and nutrition policies. They provide recommendations on foods, food groups and dietary patterns to provide the general population with the necessary nutrients to promote overall health and prevent chronic diseases. **Chapter 4** compares the nutritional quality (Nutrient Rich Diet 9.3 and Health Gain Score) and environmental impacts (carbon and water footprints) of dietary guidelines from Europe (the Netherlands, Spain, and Italy) and America, as well as regional diets like the Mediterranean and New Nordic diets. Plant-based diets, such as the Italian and Mediterranean diets, have a lower carbon footprint than animal-based diets like those suggested by the American guidelines, which emphasize meat and dairy. However, the Mediterranean diet and the Spanish strategy for nutrition, physical activity and the prevention of obesity (NAOS) showed higher water footprint values due to climatic conditions, agricultural practices, and production systems. The Mediterranean diet outperformed the Dutch and American guidelines in nutritional quality. These differences are due to the limited inclusion of fruit, vegetables and fiber in the Dutch dietary guidelines and the high levels of saturated fat and sodium in the American dietary guidelines.

**Chapter 5** focuses on the EAT-Lancet diet as a planetary health diet, comparing the Spanish dietary pattern with it and exploring differences with other European and American food-based dietary guidelines from both nutritional and environmental perspectives. The EAT-Lancet diet is a flexitarian diet that focuses on plant-based foods such as vegetables, fruits, whole grains, legumes, nuts and seeds, while limiting the consumption of animal-based products (mainly red and processed meats), added sugars and refined grains. Although the Spanish dietary pattern meets nutritional recommendations, it evidences significant environmental shortcomings. Starch-based products and oils and fats were the main contributors to carbon and water footprints in the EAT-Lancet diet. In contrast, meat and dairy were responsible for the greatest carbon and water footprints in the Spanish dietary pattern. To address climate change, preserve natural resources, and improve public health, Spaniards should consider the balanced intake of meat and dairy, as recommended by the EAT-Lancet diet.

**Chapter 6** investigates the adaptation of the New Nordic Diet in Southern Europe, assessing its potential as an alternative to the Mediterranean diet through a multidisciplinary lens. New Nordic diet promotes a healthy diet based on local and seasonal foods from the Nordic countries, including organic products and ingredients from the sea, lakes and countryside. Both diets support the prevention of non-communicable diseases and healthy weight maintenance, while also being economically viable. However, the Mediterranean diet holds an edge in environmental sustainability and nutritional quality.

**Section III** focuses on the traditional Atlantic diet, rooted in the coastal cultures of northern Portugal and northwestern Spain. The Atlantic diet focuses on natural, local and seasonal foods, and favours grilling, boiling and stewing as primary cooking methods. The Atlantic diet is characterized by a consumption of fish and seafood, dairy products, and olive oil as the main source of fat. The diet also includes daily consumption of fruit and vegetables. **Chapter 7** presents an analysis of the health and environmental benefits of the Atlantic diet. The study is based on a community-based randomised clinical trial (the GALIAT study). Salient characteristics of the study are: (1) the family as intervention unit (2) the use of the Atlantic diet, a diet congruent with the gastro-cultural heritage of the study area (3) the inclusion of

nutrition education at both individual and community levels (4) fieldwork performed at the primary health care centre (5) involvement of the participation of local food companies, research groups, the media, local governments, restaurants and other stakeholders. The results highlighted that individuals in the intervention group were approximately 42% less likely to develop an additional metabolic syndrome component than those in the control group, although there was no evidence of a reduction in the relative risk for hypertension, hypertriglyceridemia, or hyperglycaemia, separately. However, there was no statistically significant difference in the reduction of the carbon footprint in the intervention group compared to the control group. The sample size of the study may not have sufficient statistical power to detect a significant reduction in this environmental indicator, suggesting the need for larger-scale studies.

The objective of **Chapter 8** is to assess the Galician gastronomy through a hierarchical cluster analysis assessing the carbon footprint, energy efficiency, and cost of Galician recipes. Recipes with higher proportions of animal products, particularly red meat, were linked to higher costs, increased carbon emissions, and lower energy return ratios. These findings help consumers make informed, sustainable choices and support eco-friendly menus. It also facilitates the creation of eco-labels for restaurant menus, helping businesses build a strong brand identity, stand out from the competition, and foster customer loyalty and trust.

**Section IV** illustrates that individual preferences, cultural practices, and food choices at the population level are influenced by complex sociocultural, health, political, and economic factors. Critical events like pandemics can disrupt this network, altering food motivations and overall consumption habits.

**Chapter 9** explores how public health measures during COVID-19 affected food consumption in Spain, analyzing their impact on carbon and water footprints and implications for Sustainable Development Goals 2 (zero hunger), 6 (clean water and sanitation), 12 (responsible consumption and production), and 13 (climate action). Lockdown measures significantly increased at-home food consumption, resulting in higher carbon and water footprints from March to April 2020, followed by a decline as vaccinations progressed and restrictions eased. A seasonal spike was noted during Christmas. The health crisis highlighted the importance of having a resilient food system in the face of rapid changes in consumption demands, supply chains, and population behaviour.

**Chapter 10** examines the impact of family income level on the cost, nutritional quality and environmental footprint of dietary choices in Chile. Higher income correlates with better diet quality but worse environmental outcomes. Chilean residents in the highest socio-economic quintile consumed more meat and fewer starch-based products than those in the lowest quintile, with meat being the main contributor to the carbon and water footprints. Persistent malnutrition across social classes emphasizes the need for policies that ensure access to healthy, sustainable diets, especially in the context of climate change, water scarcity, and the prevalence of metabolic risk factors that increase the likelihood of non-communicable diseases in Latin America.

**Chapter 11** analyses the Palaeolithic diet from a comprehensive perspective, encompassing environmental, nutritional, and health dimensions, and compares it with other traditional dietary patterns. This caveman diet consists of foods that can be hunted and fished such as fruit, vegetables, meat, fish and seafood, eggs, nuts and seeds and excludes grains, pulses and dairy products. While this diet, marked by high protein and low carbohydrates, can aid in weight loss and muscle gain, it is linked to health risks, including elevated cholesterol, and cardiovascular issues. Moreover, the high cost and significant environmental impact associated with the consumption of meat and seafood in this diet, render it an unsustainable choice, with potential long-term health consequences.

**Section V** introduces two educational games aimed at fostering environmental awareness in younger generations. Based on the framework of Universal Design for Learning, they integrate the environmental dimension into the curriculum, promoting the holistic development of students and nurturing their personality, critical thinking, creativity and problem-solving skills.

**Chapter 12** delves into the design of a cooperative card game that teach primary school children how to calculate the water and carbon footprints associated with their personal diets, while learning about the Sustainable Development Goals 3 (good health and well-being), 4 (quality education), 6 (clean water and sanitation), 12 (responsible consumption and production) and 13 (climate action). The activity includes phases of individual work, reflection in the group and the design of a sustainable diet. It is in line with the general objectives, contend and assessment criteria of various subjects, including Natural Sciences, Social Sciences, Mathematics, Physical Education and Education in Civil and Ethical Values. Moreover, the implementation of the game facilitates the development of key competences for lifelong learning: personal, social and learning to learn competence, mathematical competence and competence in science, technology and engineering, citizenship competence, cultural awareness and expression, and multilingual competence. "Eat healthy…Eat sustainably" promotes lifelong healthy eating habits and early environmental consciousness.

**Chapter 13** introduces Ecorush, a board game for high school students to encourage responsible consumer behaviour. This game is particularly relevant during adolescence, a period of significant physical, biological, psychological and social changes that have a direct impact on long-term health and well-being. Players make strategic choices to minimise carbon footprints while maintaining a balanced diet, deepening their understanding of sustainable eating. Using $CO_2$ as a currency, players move across a board representing different food categories. The game incorporates unexpected events such as environmental taxes and subsidies, challenging players to balance environmental and financial considerations.

This interdisciplinary thesis, which brought together experts in health, nutrition, environmental science and education, proposes a radical transformation of food systems. It shifts the focus from taste, price and convenience, to health, sustainability and equity. This radical approach to sustainable healthy diets aims to address global challenges such as population growth, non-communicable diseases and environmental pressures arising from food production and consumption. Moreover, it introduces innovative gamified educational initiatives to enhance awareness among young people about the environmental impact of food choices, Sustainable Development Goals, food diversity, and the importance of consuming local and seasonal products.

A robust policy framework and effective coordination of stakeholders (governments, businesses, non-governmental organisations, communities and the private sector) are needed to ensure the transition to sustainable food systems. Intersectoral cooperation is essential to address the complex challenges of food sustainability. Furthermore, international cooperation and solidarity can facilitate knowledge sharing, resource mobilisation and strategic partnerships to address global food and environmental challenges.

This research paves the way for a future in which health, sustainability and food justice are integral to our relationship with food and the environment. The proposed vision is ambitious but necessary, as the choices made today will have a profound impact on the health and well-being of future generations and the planet.

# SECTION I

## CONTEXTUALIZATION

# 1. RETHINKING THE FOOD SYSTEM FOR HUMAN AND PLANETARY HEALTH

The global food system, involving a complex interplay of production, marketing and consumption, is deeply embedded in the political, social, economic, ecological and cultural fabric of society. Despite its notable achievements, such as keeping pace with population growth and increasing life expectancy, its uneven progress has left significant challenges unaddressed, including persistent hunger, malnutrition, obesity, biodiversity loss, water scarcity, environmental degradation and climate change. The current system, which does more harm than value, is exacerbating global crises.

A sustainable food system requires a paradigm shift in current food consumption patterns, which are characterised by a preponderance of animal-based and ultra-processed foods. To mitigate these problems, policy makers need to prioritise the transition to healthier, more sustainable diets. This can be achieved through strategies such as environmental education in schools, eco-labelling, the development of multi-criteria assessments of dietary patterns, public policies to reduce food waste, and effective communication of sustainable dietary recommendations at the individual and population levels.

Food-based dietary guidelines and traditional diets offer a valuable framework for this transformation. At the national level, food-based dietary guidelines serve as valuable educational resource to promote positive changes among food system actors. Traditional diets, which are often regionally specific, can foster a sense of identity, support local economies and contribute to a more sustainable future. Global initiatives, such as those proposed by the EAT-Lancet Commission and the World Health Organisation, provide practical frameworks for addressing the intertwined issues of environmental harm, human well-being and economic stability. To sum up, evidence-based recommendations can inform policy and individual decisions, leading to more sustainable and equitable food systems in line with the Sustainable Development Goals.

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## 1.1 EXPLORING THE INTERPLAY OF PLANETARY HEALTH AND HUMAN HEALTH IN SOCIETY

Food systems and consumption patterns have played a central role in shaping our society since prehistoric times (Fischer and Garnett, 2016). Over time, human innovation has led to significant advances in agricultural methods and systems of storage, distribution and retailing. The agricultural development has pursued specialization and mechanization, with the extensive use of non-renewable energy sources, fertilizers and chemicals (pesticides) (Daviron and Allaire, 2019). The post-harvest sector has seen the emergence of extensive processing and massive production, the globalization of trade, and the establishment of large-scale distribution channels (Dury et al., 2019). However, these developments are associated with environmental damage (biodiversity loss, misuse of pesticides, nutrient pollution, water scarcity, climate change and overuse of antibiotics), health costs (prevalence of non-communicable diseases (NCDs) such as cardiovascular diseases, cancers, chronic respiratory diseases and diabetes) and social costs (inequalities limiting access to healthy diets) (Rockström et al., 2023).

### 1.1.1 Balancing food production and environmental well-being

Food production systems pose significant environmental risks, including greenhouse gas (GHG) emissions, water pollution and biodiversity loss. Addressing these issues requires concerted efforts by farmers, producers, supply chain actors, consumers and policy makers.

Agriculture is the largest user of freshwater (70% of total freshwater withdrawals) (Mclaren et al., 2021). This can lead to water scarcity in water-stressed regions. In addition, agricultural run-off pollutes rivers, lakes and oceans with excess nutrients.

Food systems are a major contributor to climate change. They are responsible for 94% of all ammonia emissions and about one third of total anthropogenic GHG emissions (European Environment Agency, 2024).

Finally, agriculture dominates 38% of the world's land area, and a third of the world's energy is used for food production and supply (Mclaren et al., 2021). This extensive land use (LU) has led to the conversion of forests and wildlands into agricultural land, resulting in a significant loss of natural habitats. This loss is a major driver of biodiversity loss. Reducing agricultural LU and restoring natural habitats could help wildlife populations recover.

While GHG emissions, LU and freshwater use have been studied extensively, biodiversity and soil carbon have received less attention. In particular, energy use and biodiversity impacts, are under-researched. This includes on-farm biodiversity and the impacts of LU change on biodiversity (Deconinck and Toyama, 2022). Research on the environmental impacts of food systems also tends to focus on high-income countries, with notable gaps in Africa and Central Asia (Cucurachi et al., 2019; Gava et al., 2018) .

On the other hand, agri-food systems pass through different stages in their life cycle, each of which has its own environmental impacts. A comprehensive assessment of the environmental effects of food systems should consider impacts at all stages, including those caused indirectly by input use, LU effects, and waste generation.

One approach to constructing information on environmental impacts along food supply chains is by "downscaling" existing estimates, primarily for GHG emissions and water use. EDGAR-FOOD, a database developed by Crippa et al. (2021) provided consistent coverage of each stage of the food supply chain for each country from 1990 to 2015. A similar approach was used by Tubiello et al. (2022).

These studies revealed that LU and agricultural production account for the majority of GHG emissions from food systems. Crippa et al. (2021) indicated that globally, 71% of food system GHG emissions come from the land-based sector, defined here as agriculture and associated land use and land use change activities (LULUC) (see **Fig. 1.1**). However, the

relative importance of different stages of the supply chain varies considerably between countries. For example, in 59 developed countries and territories, the post-farm supply chain (processing, transport, packaging, retail) accounted for 33% of food-related GHG emissions. In contrast, in 163 developing countries and territories, the post-farm supply chain contributed only 12% to food GHG emissions. Tubiello et al. (2022) highlighted the increasing importance of emissions generated outside of agriculture and land (pre- and post- production processes) in driving overall food system emissions. This trend was observed at global, regional and national levels.

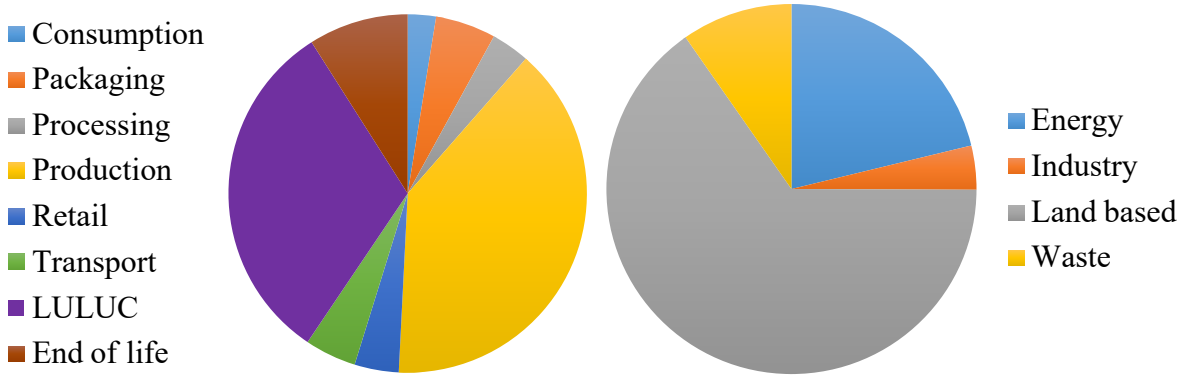


**Fig. 1.1. Global greenhouse gas emissions from the food system including $CO_2$, $CH_4$, $N_2O$ and F-gases expressed as $CO_2$ equivalents. Adapted from Crippa et al. (2021)**

While the downscaling approach provides valuable insights into the relative importance of different supply chain stages, it has limitations. It cannot assess the impact of individual products or production systems and lacks the ability to account for producer heterogeneity. Additionally, the approach focuses on emissions where activities occur, rather than where products are consumed. Complementary methods such as Life Cycle Assessments (LCAs) can address these shortcomings.

LCAs provide a comprehensive view of the environmental impacts associated with food production. Poore and Nemecek (2018) meta-analysis, a landmark study, provided a detailed analysis of 570 LCAs covering 38700 regional or farm-level assessments in 119 countries. Focusing on five environmental indicators: scarcity-weighted freshwater withdrawals, GHG emissions, LU, terrestrial acidification and eutrophication, the study allowed for comparisons across food products, supply chain stages and producers. Their findings revealed that livestock products generally have a greater environmental footprint than plant-based products, and ruminant products have a greater footprint than other livestock products. However, there were significant variation between producers, with 25% of global production accounting for more than half of all environmental impacts. This pattern was consistent across the four categories analysed.

Clark et al. (2022) assessed the environmental impact of 57000 food products using four indicators: GHG emissions, LU, water stress and eutrophication potential. A single estimated composite environmental impact score per 100 g of product was derived to visualise the results and communicate them to time-constrained consumers. This composite score condensed information from the four environmental indicators, assigning equal weight to each, and was presented on a linear scale. The study found that sugary drinks and other beverages composed primarily of water had the lowest environmental impact. This is because these products contain a relatively small amount of sugar and other ingredients (e.g. flavourings, syrups, fruit) compared to the large amount of water. Products such as vegetables, snacks, dairy and meat

alternatives, certain cereals and breads, had an environmental impact score below 2. Many desserts (e.g. cakes, biscuits, pies), other cereals and breads, and prepared meals (e.g. pizzas, ready meals) fell into a moderate impact range, with scores between 2 and 5. Nuts, sweet and savoury spreads, cheese, fish, and some meats (pork and poultry) had a higher environmental impact, with scores ranging from 5 to 10. Beef and lamb products had the highest environmental impacts, with estimated scores greater than 10.

A previous study by Springmann et al. (2018a) found similar results. Animal products, especially meat, were responsible for the majority of food-related GHG emissions (72–78% of total agricultural emissions) due to factors such as low feed conversion efficiency, enteric fermentation and manure-related emissions. In addition, the feed-related impacts of animal products also contributed to blue water use (around 10%) and pressure on cropland, as well as nitrogen and phosphorus applications (20-25% each). While staple crops had lower environmental impacts per kg of product compared to animal products, especially in terms of GHG emissions, their high production volumes led to significant overall environmental impacts. Staple crops grown for human consumption were responsible for a significant proportion (30-50%) of cropland use, blue water use, and nitrogen and phosphorus application. It is anticipated that the projected population growth from 2010 to 2050 will result in increased environmental impacts of all food groups. Projected income growth is expected to change the relative contribution of each food group (**Fig. 1.2**), with a notable shift towards a larger share of impacts from animal products (7-16% increase across all environmental domains) and fruits and vegetables (2-28%). Conversely, the proportion of impacts from staple crops is expected to decrease by 7-19%.

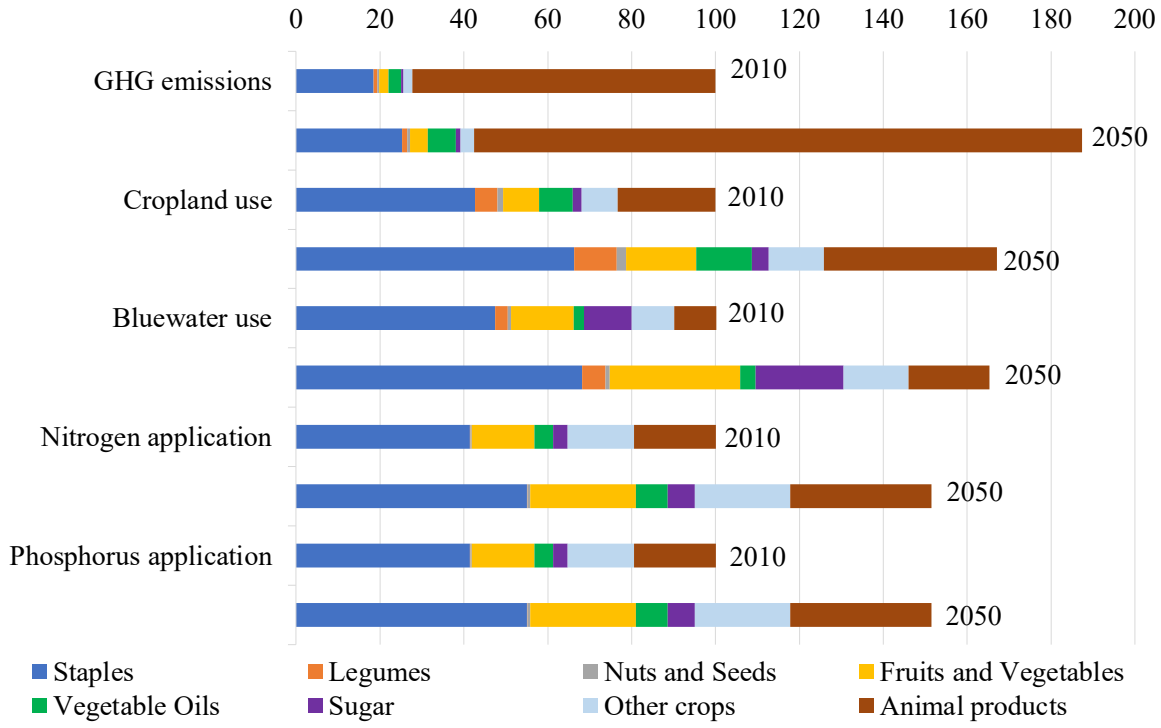


**Fig. 1.2. Environmental pressures of food groups: a comparison of present and projected impacts. Adapted from Springmann et al. (2018a)**

Therefore, a more balanced diet that reduces the consumption of animal products and favours plant proteins, could reduce the environmental impact. In recent years, numerous studies have been conducted to analyse the environmental impact of current diets using different indicators in at least the following five areas: climate change, biosphere integrity, water

consumption, novel entities (new or modified substances or life forms that could have unwanted effects on the environment) and impacts of natural resources (Ran et al., 2024).

For example, Scarborough et al. (2023) analysed the environmental impacts of different diets by comparing the dietary habits of vegans, vegetarians, fish-eaters and meat-eaters with the associated GHG emissions, LU, water use, eutrophication risk and potential biodiversity loss associated from a review of 570 LCAs covering more than 38.000 farms in 119 countries. The study found that the environmental impact of a diet is strongly linked to the amount of animal-based food consumed. Vegans had significantly lower environmental impacts compared to those who consumed large amounts of meat, with reductions ranging from 25% to 46% across several environmental indicators.

Alves et al. (2024) created a database of GHG emissions and LU data for about 900 foods to assess the environmental impact of individual diets across Europe. They found that average dietary GHG emissions and LU per capita ranged from 4 $kgCO_2 \cdot day^{-1}$ and 5 $m^2 \cdot year \cdot day^{-1}$ in Spain to 6.5 $kgCO_2 \cdot day^{-1}$ and 82 $m^2 \cdot year \cdot day^{-1}$ in France. Lower environmental impacts were observed among women, older adults (66-79) and vegetarians, while people with a secondary education had a higher footprint. The study highlighted differences between countries and demographic groups, and underlined the need for tailored, sustainable food policies.

Based on health recommendations from European Food Safety Authority (EFSA), World Health Organisation (WHO) and other country-specific guidance, large-scale dietary changes have begun to be developed to achieve a shift towards more plant-based diets that reduce the environmental impact of food systems and promote public health (Bunge et al., 2024; James-Martin et al., 2022).

### 1.1.2 Safeguarding quality, ensuring safety, and nurturing health in diets

While industrial agriculture has increased productivity, resulting in sufficient food availability and improved access for a population of over 8 billion, it does not guarantee sufficient and adequate nutrition for all (Dury et al., 2019). Conversely, a balanced diet has the potential to prevent many NCDs (Dolui et al., 2023) and is associated with better mental health and cognitive function (Zhang et al., 2024).

Nowadays one-third of the world's population suffers from at least one form of malnutrition (undernutrition, vitamin or mineral deficiencies, overweight, obesity and diet-related NCDs). Alarmingly, without immediate intervention, these statistics could worsen, with projections suggesting that half of the world's population could be affected by malnutrition by 2025 (Global Panel on Agriculture and Food Systems for Nutrition, 2016). This underscores the urgent need for decisive action to address this growing global health challenge.

Global hunger in 2022, as measured by the prevalence of persistent undernourishment, is significantly higher than pre-pandemic levels. In 2022, 9.2% of the world's population experienced persistent hunger, an increase from the 7.9% recorded in 2019. This increase is mainly due to the impact of unprecedented crises (the COVID-19 pandemic, the Russian invasion of Ukraine and population displacement), extreme weather conditions and the unaffordability of healthy food. Based on the latest available data, the number of individuals unable to afford a healthy diet has increased by 112 million globally to nearly 3.1 billion, reflecting the impact of escalating consumer food prices during the overlapping crises. This number could be even higher as the ongoing conflict in Ukraine disrupts supply chains and drives up the price of grains, fertilizer and energy (FAO et al., 2023).

In 2022, there were also 149 million children worldwide under the age of five whose stunted growth (too short for their age) threatens the achievement of their full physical, intellectual and health potential, and 45 million whose lives were threatened by wasting,

characterised by being too thin for their height (WHO, 2023a). Furthermore, more than 2 billion people worldwide suffer from micronutrient deficiencies of essential vitamins and minerals.

At the same time, about 1.9 billion adults are overweight or obese, and 462 million are underweight (WHO, 2023a). The global obesity epidemic continues unabated, with serious health consequences (Koliaki et al., 2023). Overweight begins early in life, affecting 37 million children under five. This category of malnutrition is a major contributor to the rise in NCDs such as type 2 diabetes (T2D), hypertension, heart disease, stroke and some cancers (WHO, 2023a), which account for 70% of deaths and 70-80% of healthcare costs in the European Union (European Commission, 2020a).

### 1.1.3 Socioeconomic and sociocultural disparity in nutrition

Socio-economic and socio-cultural factors have a significant impact on how food is accessed and consumed. People from lower socio-economic backgrounds often face barriers to accessing quality food due to financial constraints and limited physical access, which can limit their ability to make preferred dietary choices. These challenges are compounded by factors such as low-income levels, limited education, time constraints in single-parent households and the widespread availability of fast-food options (Plazcek, 2021).

Some high-income countries have reached a plateau in meat consumption. A shift to more plant-based diets in these regions could have positive effects on both human health and the environment. However, many low- and middle-income countries have not yet reached a plateau in meat consumption and may not do so for several decades. Meanwhile, the traditional plant-based diets common in these regions remain deficient in essential micronutrients, including iron, zinc, calcium, vitamin A and vitamin D, which are typically abundant in animal-based foods. Meeting the growing demand for animal protein in these countries may be an effective strategy for addressing multiple nutrient deficiencies (Drewnowski, 2024).

Two opposing trends in protein consumption are therefore emerging. In low- and middle-income countries, animal proteins are increasingly preferred to plant-based options such as wheat, rice and beans. This shift is actively encouraged by international agencies and local governments to improve diet quality and public health. Conversely, high-income countries are promoting the replacement of meat, eggs and dairy products with plant-based alternatives, including products from soy, pulses, cereals, nuts and unconventional sources such as fungi (Biesbroek et al., 2023).

On the other hand, sensory and physiological factors play a key role in shaping food preferences. Taste, texture and the eating experience are all important factors. Preferences for sensory attributes of food are acquired through cultural socialization, in addition to the innate human tendency towards sweetness, fat, umami and salt. However, these innate preferences can be altered by cultural norms, marketing strategies and exposure to different food environments (Biesbroek et al., 2023). For example, a recent study showed that people exposed to natural environments choose healthier foods than those exposed to urban environments (Langlois and Chandon, 2024).

Another study explores and characterises the web-based discourse of popular diets and examines the interactions between community networks and mental health issues. The study found that the vegan and ketogenic diets had the largest online communities, while the zone diet had the smallest. Many influential voices in these communities claimed to be health or science professionals, but few were nutritionists. While most diet networks interacted, there was significant fragmentation and hub-and-spoke messaging. Discussions about mental health were more common in the zone diet network than in others (Eaton et al., 2023). Understanding the complex relationship between these factors is crucial to comprehending food choices.

## 1.2 Enabling transition towards more sustainable food systems: partnership for people, planet and climate.

The food we eat has a significant and influential impact on optimising human health and promoting environmental sustainability on the planet. Paradoxically, the current state of our food systems poses a double threat to both people and the planet (Food Systems Countdown Initiative, 2023) Without action, the world risks missing the targets set out in the UN Sustainable Development Goals (SDGs) and the Paris Agreement. Rising populations, incomes and urbanization are all driving demand for more resource-intensive animal products and processed foods (Willet et al., 2019a).

This has the potential to cause further damage to climate stability and ecosystem resilience and may exacerbate health problems such as obesity and chronic diseases. Policymakers, non-governmental organisations and the business community agree that addressing our environmental challenges, responding to climate change and creating a food system that provides security, improves nutrition and promotes health will require a transformation of current food systems. A better understanding of food systems is therefore essential to ensure that these systems evolve in ways that minimise negative impacts and maximise positive contributions.

The complexity of food systems requires a comprehensive and coordinated approach (FAO, 2018). In increasingly globalized food systems, many challenges related to food security, nutrition and the environment are complex problems with contested solutions that cut across disciplinary, departmental, and institutional boundaries. They require coordinated efforts by stakeholders at local, national, regional, and global levels, involving both public and private entities, and spanning multiple sectors – not only agriculture, but also trade, politics, health, environment, gender perspective education, transport, infrastructure and more (UNDP, 2024).

Food systems encompass not only the set of processes that facilitate the flow of food (production, aggregation, processing, distribution, consumption and waste disposal), but also the social norms and cultures (e.g. dietary preferences) in which these activities are embedded, as well as the natural environment on which they depend for their functioning (land, water, soils, air, climate, ecosystems) (UNEP, 2019). In addition, food systems involve individuals who depend on food for their livelihoods, as well as other actors who indirectly and directly influence the food sector (e.g. producers, retailers, governments, health officials, teachers, etc.). A wide range of institutions, regulations, subsidies and laws also have a profound impact on food systems and their outcomes on a daily basis. **Fig. 1.3** shows the elements, key drivers, activities and outcomes of the food system (UNEP et al., 2023).

Outcomes can have a positive or negative impact on socioeconomic conditions, the environment and food security and nutrition. For example, in terms of socio-economic conditions, the consequences of a situation may affect the socio-economic scenario of smallholder farmers, poverty levels, employment generation and income. Similarly, the effects of a situation can affect the environment in terms of forest conservation or pollution levels. Finally, the results of a situation can affect food security and nutrition, concerning elements such as the availability of healthy food and diets, access to food and food prices. The food system functions as a feedback loop mechanism, with activities and outcomes leading to processes that feedback to environmental and socio-economic drivers (UNEP, 2019).

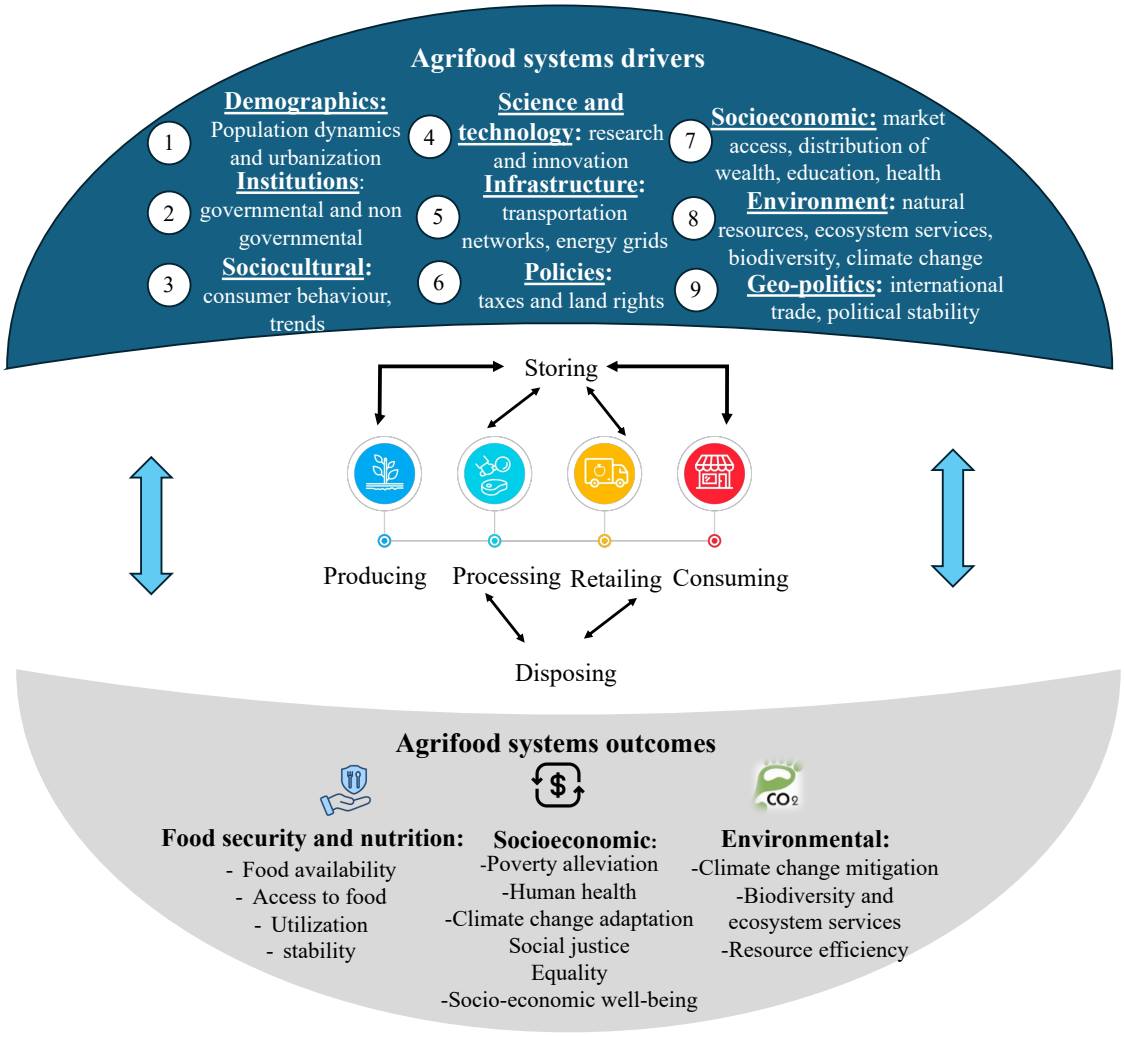


**Fig. 1.3. Food system elements, key drivers, activities and outcomes. Adapted from FAO (2018) and UNEP (2019)**

According to Food and Agricultural Organisation (FAO) "A sustainable food system is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" (FAO, 2018). It includes three dimensions of sustainability as shown in **Fig. 1.4**: economic resilience, social well-being, and environmental integrity (Antonio and Vasileios, 2023).

The economic aspect of the system assesses the financial viability of the activities undertaken by each participant in the system, taking into account both the benefits (wages for workers, taxes for governments, profits for businesses and improvements in the food supply for consumers) and costs to society as a whole. This includes, for example, evaluating the reduction in medical costs resulting from a healthy population with a nutritious diet, or the increased productivity that contributes to economic development (Béné et al., 2019).

The social aspect of sustainability emphasizes the equitable distribution of economic gains and seeks to ensure societal benefits, with particular attention to vulnerable groups identified by factors such as gender, age, ethnicity, income/wealth and socio-economic status. Achieving social sustainability requires the development of food systems in ways that contribute to the promotion of important socio-cultural outcomes, including nutrition and health, traditions, working conditions and animal welfare (Ly and Cope, 2023).

The environmental dimension of sustainable food systems is concerned with reducing pollution, implementing effective waste management and ensuring that the impact of food system activities on the surrounding natural environment is either neutral or beneficial. This requires consideration of a range of factors, including biodiversity, water and soil quality, animal and plant health, carbon footprint (CF) and water footprint (WF), and food loss and waste (FAO et al., 2021).

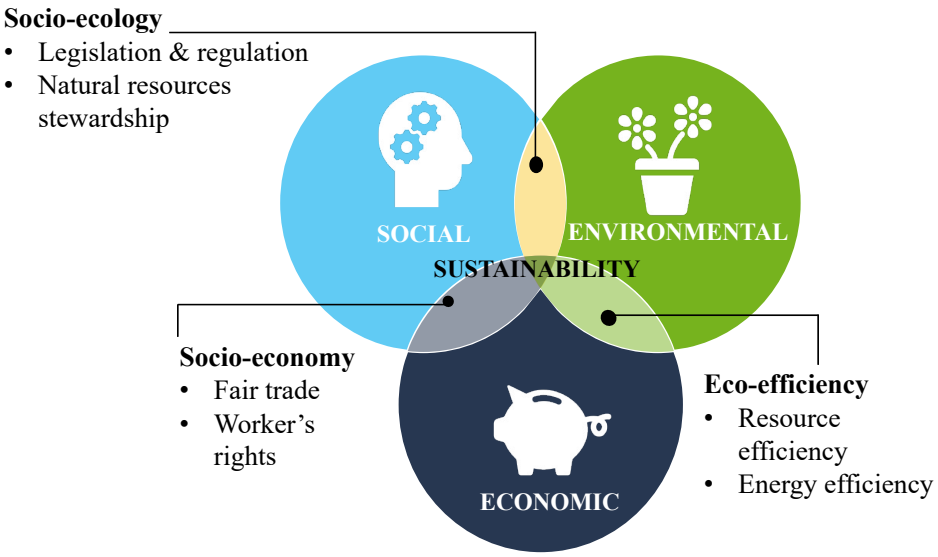


**Fig. 1.4. Dimensions of sustainable food systems. Adapted from FAO (2018)**

A large body of scientific evidence and pertinent policy recommendations outlines recommendations to achieve a sustainable food system (UNDP, 2023a). While there are different approaches to the precise actions needed, there is a broad consensus that a synergistic combination of policies and actions is essential (European Commission, 2020b; Kusch-Brandt, 2023). The European Commission (2023a) identifies several actions that must be considered to ensure the sustainability and resilience of the food system.

Policy integration and governance are key to creating a sustainable food system. Governments should ensure that sustainability and climate neutrality are at the heart of all relevant policies and legislation. Additionally, involving smallholder farmers, artisanal fishers and other workers in the food supply chain in decision-making processes can promote inclusiveness and improve food system governance.

Climate change and biodiversity are interlinked with food systems. Countries should formulate more ambitious national climate change plans, implement climate change mitigation policies, programmes and investments, and support the most vulnerable. Protecting ecosystems, such as forests and wetlands, is essential for conserving biodiversity and ensuring the long-term sustainability of agriculture, ocean management and aquaculture. Integrating food systems into national biodiversity strategies and action plans can help achieve these goals.

Sustainable consumption and production are fundamental to reducing the environmental impact of the food system. Promoting healthy and sustainable diets can reduce demand for resource-intensive foods and improve consumer health. Investing in sustainable production methods, such as agroecology, can help reduce the use of harmful chemicals and promote biodiversity. Strengthening social protection institutions and mechanisms and implementing inclusive growth programmes can help those most vulnerable to food insecurity. This should include supporting small-scale food producers by implementing policies that link food aid

initiatives to sustainable local food production or improving access to health and diverse diets through channels such as school meals. Addressing gender inequalities in food systems by ensuring that women have equal rights and control over land, capital and social benefits is essential to promote equity.

Energy efficiency and energy transition are critical to reducing dependence on fossil fuels and mitigating climate change. Transitioning to renewable energy sources, using agricultural and food waste for energy, and reducing LU trade-offs between food and energy production can help to reduce GHG emissions. Optimising resource use through efficient food production, distribution and consumption can help maximise resource use and minimise food loss and waste.

A holistic approach to food systems is needed to address the complex challenges facing the food sector. Considering the entire food system, moving beyond a linear perspective that focuses only on the food supply chain, can help identify opportunities for improvement and ensure that sustainability is integrated into all aspects of the food value chain. Developing market-based solutions that promote sustainability, moving beyond considerations based solely on food safety can also play a crucial role.

### 1.2.1 The vital role of Sustainable Development Goals in building resilient food systems.

A sustainable food system lies at the core of the SDGs. SDGs were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet and ensure that by 2030 all people enjoy peace and prosperity (UNDP, 2023b). Food systems have the potential to drive significant advancements across all 17 SDGs (see **Fig. 1.5**) (United Nations, 2023b).

SDG 1 - No poverty: 165 million people fell into poverty between 2020 and 2023 (UNDP, 2023c). Today, almost 700 million people around the world live in extreme poverty and it is expected around 600 million people will still live in poverty by 2030 (United Nations, 2023a). Sustainable food systems can aid in poverty alleviation generating employment and increasing access to healthy foods (United Nations, 2021).

SDG 2 - Zero hunger: Transforming our food system to promote sustainability, productivity and resilience is essential to help the 723 million people who suffer from hunger (WFP, 2023) and successfully managing unforeseen crises such as diseases outbreaks and climate extremes.

SDG 3 – Good health and well-being: Access to nutritious and safe food is essential for extending life expectancy (Macrotrends, 2024), and for promoting good health across all age groups.

SDG 4 – Quality education: Sustainable food systems play a critical role in improving the livelihoods of children completing primary and secondary education (United Nations, 2021).

SDG 5 – Gender equality: Empowering women and promoting their equal access to land and economic resources will help increase agricultural productivity and promote sustainable economic prosperity in rural communities in the long term (FAO, 2023). Globally, only 12.8% of individuals who own agricultural land are women farmers (UNWOMEN, 2018).

SDG 6 – Clean water and sanitation: Good quality water is fundamental to most food production, processing, transformation and preparation (Jackson et al., 2015). However, the depletion of freshwater resources is accelerating at an alarming rate and the issue of water scarcity is becoming increasingly critical due to overpopulation, high living standards, dietary changes and the impacts of climate change (FAO, 2021a). Sustainable agri-food systems have the potential to address the challenge of water scarcity, which affects approximately two billion

people worldwide who lack access to safely managed drinking water (WHO and UNICEF, 2021).

SDG 7 – Affordable and clean energy - Investing in sustainable food systems that maximise the use of clean energy sources such as solar, wind and thermal will reduce the environmental footprint of the food sector while increasing people's access to affordable energy.

SDG 8 – Decent work and economic growth – Agri-food systems support the incomes of 1.06 billion people (Davis et al., 2023). A food system that prioritises sustainability has the potential to create quality employment opportunities and contribute to the livelihoods of billions of people worldwide.

SDG 9 – Industry, innovation and infrastructure - Recent advances in climate-smart agriculture and texture-modified foods have the potential to improve access to food nutrition, with positive environmental, social and economic benefits (Chen et al., 2023).

SDG 10 – Reduced inequalities: There are about 510 million farms of less than two hectares; they account for 84% of all farms, but only use about 12% of all agricultural land (World Economic Forum, 2024). Transforming small-scale family farming, securing tenure rights for farmland and advocating for sustainable food systems are critical elements for long-term global food and nutrition security, addressing rural poverty and combating hunger (Woodhill et al., 2020).

SDG 11 – Sustainable cities and communities: Disparities in access to basic services persist among urban population, with more than 800 million people living in slums. The economically disadvantaged in urban areas are particularly vulnerable to financial crises or food price increases. Sustainable food systems can help ensure that the world's urban dwellers have the financial means and adequate nutrition (United Nations, 2021).

SDG 12 – Responsible consumption and production: The level of overexploitation of natural resources and generation of waste exceeds the threshold at which ecosystems can absorb disturbances and maintain their integrity (Cunha and Custódio, 2021). In the food sector, food losses and food waste are estimated at 30-40% of the food supply (Blakeney, 2019). Catalysing a sustainable transformation of food systems is essential to lay the foundations for successful responsible consumption and production. Some of the measures to be implemented are: i) shifting to healthier and more sustainable diets, ii) minimising food loss and waste by adopting a circular economy approach and, iii) preventing overnutrition.

SDG 13 – Climate action: a quarter of global GHG emissions come from agriculture and land-use change (Laborde et al., 2021). Sustainable food systems have the potential to mitigate these impacts by reducing the release of key climate-warming gases, such as methane and carbon dioxide.

SDG 14 -Life below water: The livelihoods of more than 3 billion people depend on marine and coastal diversity. It is estimated that up to 12 million tons of plastic enter the oceans every year (Greenpeace, 2023). Implementing sustainable food systems can ensure the long-term viability of global fisheries, while maintaining the health of the ecosystems that support them.

SDG 15 – Life on land: In 2022, global deforestation reached 6.6 million hectares, with primary tropical forest loss reaching 4.1 million hectares (Baldwin Cantello, 2023). Reducing deforestation, halting land degradation and supporting healthy terrestrial ecosystems can be achieved by developing more sustainable agriculture and food systems.

SDG 16 – Peace, justice and strong institutions: By the end of 2022, 108.4 million people worldwide were forcibly displaced as a result of persecution, conflict, violence or human rights violations (UNHCR, 2023). Adopting sustainable food systems has the potential to alleviate significant challenges faced by families, communities and nations around the world, laying the foundation for the development of peace and strong institutions.

SDG 17 – Partnerships for the goals: Since the beginning of the 21st century, global development assistance has grown steadily. At the same time, there has been a surge in the formation of coalitions and multi-stakeholder partnerships. A renewed emphasis on sustainable food systems has the potential to further this positive trajectory and deliver tangible benefits to people and communities around the world.

**Fig. 1.5. Interconnectedness of Sustainable Development Goals in Resilient Food Systems. Adapted from UNDP (2023b)**

### 1.2.2 Food sustainability education

A fundamental prerequisite for food system transformation is a change in individual dietary behaviour. This requires education that empowers people to make informed choices and act responsibly in relation to food for environmental integrity, economic viability and a just society for present and future generations. Given the central role of dietary habits and the food system in achieving the SDGs, Education for Sustainable Development provides an ideal framework for addressing these issues (Dornhoff et al., 2020). Education and awareness-raising campaigns have been identified as effective tools to address global challenges, including food security and sustainability.

The WHO and the FAO collaborate extensively on food safety, nutrition and health issues. They use their combined expertise to address challenges such as malnutrition, foodborne diseases, and the impact of climate change on food security (FAO and OMS, 2023). Their joint efforts encompass research, policy development, capacity building, and technical assistance, as

exemplified by initiatives such as the Codex Alimentarius (FAO and OMS, 2023) and the One Health initiative 2022-2026 (FAO et al., 2022). Together, they lead campaigns such as World Food Safety Day, which promotes better food safety practices and awareness (FAO et al., 2024). They are also co-convenors of the UN Decade of Action for Nutrition, which aims to eliminate all forms of malnutrition by 2025 (WHO and FAO, 2017).

FAO and WHO are involved in a number of awareness-raising initiatives, including the celebration of World Food Day (FAO, 2024). Furthermore, they implement initiatives such as the "Save your Food" campaign, which aims to reduce food waste and promote sustainable practices (FAO, 2019a). Recognizing the key role of school-based interventions in promoting healthy diets among children and adolescents, FAO works with governments to implement comprehensive school programs that include healthy meals and nutrition education. Such programs not only improve students' diets, but also support local agriculture, diversify food systems and alleviate poverty by sourcing food from local smallholder farmers (FAO, 2019b).

The European Commission also offers promotional campaigns for European agricultural products to open up market opportunities for farmers and the wider food industry. This is done with the aim of increasing the sustainable production and consumption of agricultural products and supporting the sustainable recovery of the European agri-food sector in the context of the economic downturn (European Commission, 2024a). The European Commission is also involved in projects to raise awareness of a holistic approach to school food, with the aim of encouraging healthier, more informed choices among young people and contributing to the sustainability of schools.

One such initiative is the SchoolFood4Change project. The SchoolFood4Change project is a European initiative that aims to promote sustainable and accessible food systems, especially in schools, in 12 European countries. The Whole School Food Approach engages over 3000 schools and 600,000 pupils. The initiative integrates educational programs, workshops and sustainable meal plans involving farmers, catering services and local governments. The aim of the project is to instil healthy eating habits in young people by emphasizing nutritious, plant-based, and locally sourced foods. This approach aims to empower them to make informed choices that benefit both their personal health and environmental sustainability (European Commission, 2023b).

In Spain, a wide range of initiatives have been implemented with the aim of promoting a healthy and sustainable diet. For instance, in 2022, the Spanish Agency for Food Safety and Nutrition (AESAN) initiated the "Move and Take Care of Your Planet" campaign. The campaign provides guidance on making healthy food choices and encourages the public to be physically active. The aim is to empower consumers to make informed choices that benefit both their personal health and the environment. By reducing the incidence of disease and the associated economic costs, these initiatives contribute to a better overall quality of life (AESAN, 2022).

A number of initiatives are also being implemented at regional level. For example, the Government of Galicia has implemented several educational programs as part of the Proxecta+ Plan for Educational Innovation, with the aim of promoting health, well-being and sustainability. One of these initiatives is Nutriescolas, which is linked to SDGs 3, 12 and 14. The course uses sensory experiences to facilitate and explore the food landscape, traditional culinary practices, and an assessment of the impact of advertising and the food industry. This enables students to develop an understanding of the importance of responsible consumption (Xunta de Galicia, 2022a).

### 1.2.3 Ecolabels and food certification systems

Food labelling plays a pivotal role in creating a healthy food environment. It provides consumers with the information they need to make informed decisions about the food they purchase, whether in terms of nutritional or environmental labelling, thereby fostering the development of safe and more accessible alternatives (Tiboni-Oschilewski et al., 2024). Moreover, food labelling is consistent with the recommendations of the World Food Security Committee's Voluntary Guidelines on Food Systems and Nutrition. It also safeguards consumer rights, particularly the right to information (CFS, 2021). In addition to its role in empowering consumers, food labelling has a practical function. Studies have demonstrated that the availability of such information can influence consumer behaviour when making purchasing decisions (Cecchini and Warin, 2016). Furthermore, labelling policies often aim to ensure and stimulate competition between market participants (Golan et al., 2001).

According to the International Organisation for Standardization (ISO), environmental labels can be classified into three principal categories: type I, type II and type III (Iraldo et al., 2020). Type I environmental labels are voluntary and are based on a comprehensive multi-criteria system that analysed the entire product life cycle. Such labels are required to undergo a rigorous external certification process, conducted by an independent body and in accordance with the standards set forth in ISO 14024. Type II environmental declarations are those made by manufacturers, importers or product distributors without the involvement of an independent certification board. These self-declarations often include claims such as "Recyclable" or "Compostable" and are governed by the guidelines specified in ISO 14021. Type III eco-labels, also referred to as Eco-profiles, comprise declarations based on pre-established parameters. These labels provide a quantitative assessment of the environmental impacts associated with the life cycle of the product through a LCA. Such labels are subject to independent verification and are presented in a clear and comparable format. An example of this type of label is the international Environmental Product Declaration (EPD) system, which is based on the standards outlined in ISO 14025.

Ownership and management of these labels may fall under the responsibility of government entities, non-profit organisations, or private sector entities. To facilitate more informed and sustainable food choices, the European Commission has articulated its commitment to developing a legislative framework for sustainable food systems. A central component of this framework would be the implementation of sustainability labelling, which would cover the nutritional, environmental and social aspects of food (European Commission, 2023c).

To date, the majority of research on eco-labelling has focused on the agricultural and food sectors (Yokessa and Marette, 2019). Furthermore, the prevalence of ecolabelling and associated research is significantly higher in developed countries compared to very low-income countries. (Manta et al., 2022). The use of sustainability claims and labels on product launches in Europe has increased markedly, with a growth rate of 2.83% annually from 2005 to 2021. However, this trend varies across countries, product categories and types of sustainability labels. Products with a focus on environmental sustainability contributed the most to this trend, accounting for 68.2% of the increase (Nes et al., 2024).

Eco-labels can be divided into two principal categories: single-attribute and multi-attribute. Single-attribute labels focus on a specific stage of the product's life cycle or a particular environmental impact, whereas multi-attribute labels consider the entire life cycle or multiple environmental impacts associated with the product or service (US EPA, 2014). Notably, multi-attribute labels are the least commonly used format (Torma and Thøgersen, 2021).

In the context of food products, eco-labels can encompass a range of product attributes, including production methods (e.g. organic labelling), environmental impacts as measured

through LCAs (e.g. CF labels) or packaging (e.g. recyclability). However, it is important to note that eco-labels do not always refer to the entire product. The effectiveness of eco-labels in influencing consumer choice is difficult to evaluate due to the wide diversity of types and requirements. Despite this, the number of eco-labels has steadily increased, reaching a total of 456 labels in 199 countries and 25 industry sectors (Ecolabel Index, 2024).

Examples of commonly recognized food-related eco-labels include (**Fig. 1.6)**:

- USDA organic: This type I label attests that the product has been produced without synthetic pesticides, fertilizers, or genetically modified organisms (GMOs), and meets the standards set by the United States Department of Agriculture (USDA).
- European ecolabel: Certified by the European Commission, this type I label ensures that products meet rigorous ecological and sustainable, including sustainable production, responsible ingredient sourcing and environmentally friendly packaging.
- EU Organic Logo: This type I label from the European Union certifies that the product adheres to stringent organic standards. It ensures the product is produced, processed, transported and stores in accordance with organic regulations. Moreover, the product must contain at least 95% organic ingredients and meet additional criteria for the remaining 5%.
- Fair Trade Certified: Issued by Fairtrade International, this label serves as a guarantee that the products in question meet rigorous social, environmental and economic standards. These standards guarantee producers safe working conditions, environmental protection and sustainable livelihoods. In addition, this label facilitates improved livelihoods, environmental conservation and transparency in supply chains, while providing financial support for community development projects.
- MSC Certified Sustainable seafood: The Marine Stewardship Council (MSC) label is applied to wild fish and seafood from fisheries certified to the MSC ecolabel standard, that includes criteria for sustainable fishing practices.
- Rainforest Alliance Certified: This label indicates that the product was produced on farms that meet strict standards for environmental protection, wildlife conservation and fair labour practices. These labels are often found on products such as coffee, cocoa and bananas.
- Non-GMO Project verified: This certification means that the food has undergone an independent verification process to ensure that it is free from GMOs. This gives consumers confidence in the genetic integrity of the product. Certification is overseen by the Non-GMO Project.
- Animal welfare labels: Although not strictly environmental, animal welfare labels can be found on food products to indicate that animals have been raised in humane standards, including access to fresh air, clean water and adequate space. Examples of such labels include the American Humane Certified label and the Certified Humane label.

Examples of type II ecolabels in the food industry include claims such as “100% recyclable packaging”, “biodegradable packaging” and “no artificial preservatives”, which emphasize environmentally responsible packaging and ingredient choices. Claims such as “locally sourced ingredients” and “GMO free” highlight efforts to reduce transportation impacts and promote natural, unmodified ingredients. Other common self-declared claims include “reduce carbon footprint”, which reflects a company’s effort to minimise GHG emissions, and “water efficiency production”, which aims to conserve water resources. In addition, claims such as “sustainably harvested” and “all-natural” appeal to consumers seeking environmentally friendly and clean production methods. Products labelled as “hormone-free” or “antibiotic-free”

demonstrate a focus on animal welfare and natural husbandry practices, while "energy efficient production" emphasizes reduced energy use in production.

Furthermore, a considerable number of published EPDs, also known as type III environmental declarations of the food and beverage category, can be accessed via the International EPD System website. It has been found EPDs for a range of food products, including bakery items, dairy and egg products, fruits, vegetables and juice, pasta, bottled water, wine and beer, olive oil, grain mill products and other products such as sauces, meat and sugar (Del Borghi et al., 2020; Barros et al., 2022).

The diverse and often inconsistent nature of eco-labelling across industries and nations has led to its application within the food sector becoming a focal point of debate. The current eco-labelling implementation guidelines, which are frequently proprietary or industry-specific, present obstacles for regulatory oversight. While guidance on obtaining specific certifications is readily accessible, a comprehensive framework for regulation and implementation remains elusive (European Commission, 2024b).

**Fig. 1.6. Examples of food eco-labelling**

## 1.3 Sustainable diets within sustainable food systems

While there is an urgent need for a significant overhaul of the global food system, our focus has been on a single endpoint: final consumption, particularly in terms of adopting healthy and sustainable diets. This factor is a major determinant of both human and environmental sustainability, with a disproportionate impact on the environment.

According to the FAO and WHO "Sustainable Healthy Diets are dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure

and impact; are accessible, affordable, safe and equitable; and are culturally acceptable" (FAO and WHO, 2019). The objectives of sustainable diets include (FAO and WHO, 2019):

i) Promote the optimal growth and development for each individual.

ii) Foster physical, mental, and social well-being at all stages of life, taking into account the needs of present and future generations.

iii) Prevent various forms of malnutrition (i.e. undernutrition, micronutrient deficiencies, overweight and obesity).

iv) Minimise the risk of diet-related NCDs.

v) Contribute to the conservation of biodiversity and the health of the planet.

Sustainable healthy diets must address all dimensions of sustainability: the environmental impact of food production, promoting social equity in terms of access to nutritious food and supporting economic systems that are resilient and equitable.

Building on the FAO definition of sustainable diets, the 2016 Chicago Consensus on Sustainable Food Systems Science proposes that sustainable diets consist of four dimensions: health, economic, environmental and social (see **Fig. 1.7).** According to these parameters, sustainable diets should not only maximise nutritional quality and minimise environmental impacts and costs but should also be adaptable to diverse dietary patterns and ensure the inclusion of social and cultural characteristics of food choices (Hooker et al., 2024).

These principles highlight the complexity of achieving sustainable diets, which must balance both local and global biophysical factors – such as health and environmental concerns – with social dimensions, including culture and economics (Biesbroek et al., 2023). Although progress has been made in multidimensional research in this area, advancement remains slow due to the research community's siloed approach. This approach often focuses on specific pairings, such as diet and climate, or adopts a discipline-specific lens, rather than examining the totality of sustainable diets.

Leydon et al. (2023) conducted a comprehensive review of 24 studies published between 2017 and 2023 to assess adherence to predefined dietary patterns. These studies examined a range of factors, including diet quality, metabolic risk factors for NCDs, environmental impact and affordability. The review found a variety of dietary quality assessments, with national dietary guidelines being the most common. For environmental impact, GHG emissions were the most reported indicator, followed by LU. All studies assessed body mass index (BMI), and seven assessed the cost of adherence. The results consistently showed a positive correlation between healthier diets and reduced environmental impacts. This is consistent with previous research by Clark et al. (2019), which found an association between the environmental impacts of food groups and mortality risk, specifically highlighting red and processed meat as high-impact, high-risk categories. In the same line, Aidoo et al. (2023) used the Food5Healthylife calculation to assess 24 model diet scenarios based on their environmental and nutritional performance. While a non-linear relationship was observed between these two factors, a trade-off analysis showed that a diet consisting of 10% pulses, 0.11% red meat and minimal processed meat could significantly reduce the global warming potential by 54.72% while maintaining a score of 74.13 on the Food compass system for diet quality.

Furthermore, indices have been developed for the evaluation of dietary sustainability. In a comprehensive review of studies published between 2019 and 2022, Neta et al. (2023) attempted to provide an overview of the available evidence on sustainable diet indices based on the EAT-Lancet Commission. Seven primary measures were identified: the EAT-Lancet diet score, the New EAT-Lancet diet score, the Planetary Health Diet Index, the Sustainable Diet Index, the Sustainable-Healthy Diet, the novel nutrient-based EAT index, and the World index for Sustainability and Health. Most studies were conducted in developed countries, where

greater adherence to these sustainable diets was observed. The most frequently reported indicator of sustainability was estimated GHG emissions, followed by diet quality and the associated health benefits. In a more recent contribution, Bôto et al. (2024) proposed the Dietary Pattern Sustainability Index (DIPASI) as a novel method for assessing the sustainability of dietary patterns. DIPASI is a single score that incorporates environmental, nutritional and economic dimensions. Environmental indicators include CF, WF and LU, while nutritional quality is evaluated using the Nutritional Rich Diet Score and the economic aspects are considered using diet cost. DIPASI measures the deviation of an individual's diet from a reference diet, expressed as a percentage.

Optimisation studies have been conducted with the objective of improving existing or culturally relevant diets. Rocabois et al. (2022) developed an innovative multi-level approach, designated as Individual Diet Including Global Objectives Optimisation (INDIGOO), for the purpose of designing diets that satisfy nutritional requirements, minimise shifts in individual dietary habits, and achieve environmental impact reduction targets at the population level. In a review of 12 studies, Wilson et al. (2019) examined the use of mathematical optimisation in identifying dietary patterns that improve nutritional outcomes while reducing environmental impacts. The studies were conducted in China, India, Tunisia and seven high-income countries. The principal findings of these studies consistently indicated that diets optimised for sustainability and nutrition were predominantly plant-based, with significant reductions in meat, particularly ruminant meats. Dairy products also tended to decrease in most studies. Other foods that were reduced included sweet foods, savoury snacks, white bread, and beverages. These findings align with the consensus of recent review articles on the sustainability of diets.

On the other hand, to address the cultural acceptability and affordability of sustainable diets, research has focused on the role of traditional diets. These diets, which are grounded in local eating habits, climate and agricultural traditions, have the potential to contribute to the development of a sustainable diet in the future. This thesis focuses on traditional European diets, with a particular emphasis on the Spanish, Mediterranean and Atlantic diets (see **Section 1.3.1**) These diets exemplify a model of healthy and sustainable eating, offering scientifically proven benefits for both health and the environment.

The growing focus on sustainability in food systems has led to the incorporation of environmental and sociocultural factors into food-based dietary guidelines (FBDGs). As observed by Martini et al. (2021) recent FBDGs have exhibited a heightened emphasis on health-related factors, whereas environmental impact and socio-cultural considerations remain comparatively underrepresented, particularly in older guidelines. In a comprehensive analysis of contemporary approaches to FBDGs in northern Europe and American countries, van Dooren (2023) identifies a range of strategies encompass the provision of supplementary advice and consumer guidance (MFAF, 2021; PHE, 2016), the demonstration of synergies between health and sustainability (HealthCanada, 2019; Rubens et al., 2021), the utilization of dietary modelling to assess the environmental implications of dietary choices (ANSES, 2016; Brink et al., 2019; Schäfer et al., 2021), and the advocacy of SDGs as a guiding framework for dietary recommendations (FAO, 2019c). A more in-dept analysis of sustainability of FBDGs is presented in **Section 1.3.2**.

Finally, future-proof diets, based on planetary boundaries, have been developed by various organisations such as the EAT-Lancet Commission and the WHO (**Section 1.3.3**). These diets emphasize the need for planet-based approaches to address sustainability challenges and promote healthy and resilient food systems.

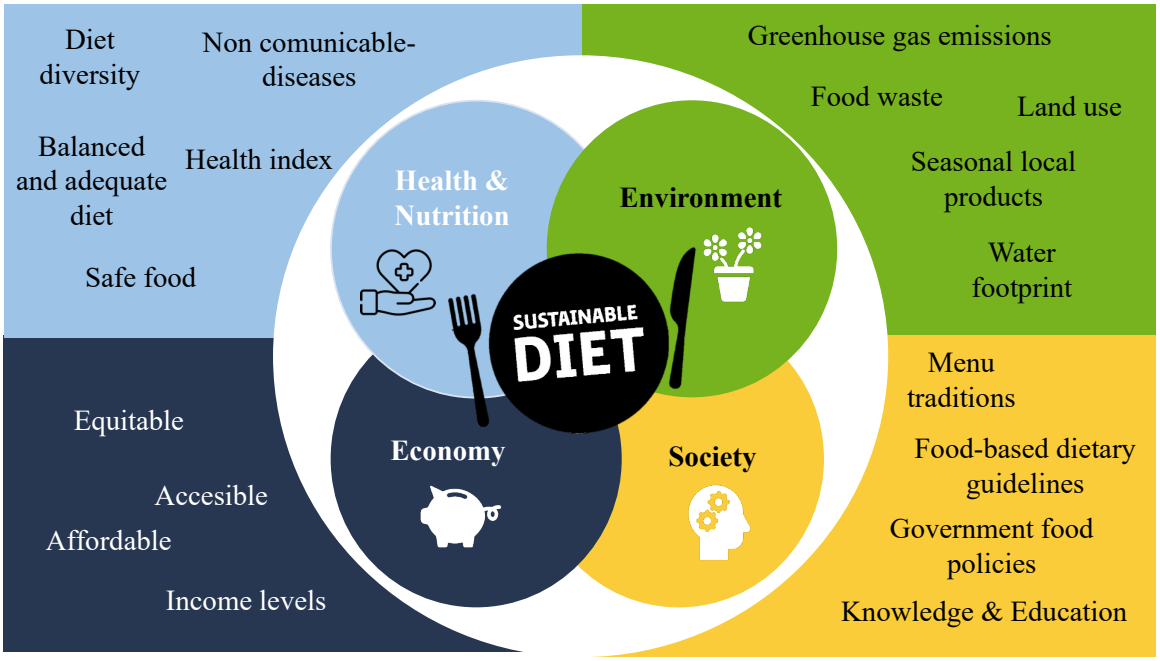


**Fig. 1.7. The four dimensions of sustainable diets.**

### 1.3.1 Traditional diets

A return to traditional regional diets (i.e. traditional diets from different regions of the world) would not only improve population health but also contribute to environmental sustainability, while respecting the identity and diversity of food systems and cultures in each region. Traditional diets have been shown to be good for health, culturally appropriate, appealing to consumers and environmentally friendly. The Mediterranean diet (MD), the traditional diet of Spain, France, Italy and Greece (CIHEAM and FAO, 2015), and the Atlantic diet, the dietary pattern of reference in Northwestern Spain and Portugal, are two examples of traditional diets which are healthy, culturally relevant, balanced and environmentally sound. Both traditional diets provide healthy food choices for Spanish citizens, and both have been studied in this thesis as tools to harmonize the health of communities and the planet.

The MD has been recognized by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) as an intangible cultural heritage. Scientific studies have shown that it has health-promoting properties that have made it a model to be pursued in the agricultural, political, cultural, economic and public health spheres in the Mediterranean region (Castaldi et al., 2022). Furthermore, it is recommended as a plant-based dietary pattern (CIHEAM and FAO, 2015). Given its health benefits, such as reduced risk of mortality and incidence of cardiovascular disease (CVD) (Trichopoulou et al., 2014), the MD could play a key role in the Europe's climate change objectives. This dietary pattern was also proposed as sustainable dietary model due to its environmental (Tilman and Clark, 2014) and sociocultural dimensions (Bach-Faig et al., 2011; Serra-Majem et al., 2012).

The MD, lauded for its beneficial effects, is characterised by a diverse dietary pattern. The diet is based on the consumption of abundant plant-based foods, including fruits, vegetables, legumes, mushrooms, nuts, breads and whole grains. Extra virgin olive oil, a source of monounsaturated fats, is the main source of fat in the diet and has been shown to have a cardioprotective effect (Fundación Dieta Mediterránea, 2023).

It emphasizes plant-based foods, but also allows daily consumption of dairy products, with a preference for yogurt and cheese. Moderate consumption of red meat and eggs is permitted,

but processed meats are limited. The diet also includes a significant amount of fish and other seafood, which is an excellent source of other omega fatty acids and another major reason for its cardioprotective properties (Widmer et al., 2015).

Hydration is essential, with water being the primary beverage. Some studies have suggested that moderate red wine consumption may have certain metabolic benefits (Fragopoulou et al., 2018), although there is ongoing debate on this topic (Martínez-González, 2024). Finally, regular physical activity complements this healthy lifestyle (Fundación Dieta Mediterránea, 2023).

The Atlantic diet, on the other hand, is based on home-cooked, local, fresh and minimally processed seasonal produce. It shares several characteristics with the MD, including a high intake of vegetables, fruit, whole grains, beans and olive oil as the main source of fat. This diet is also characterised by a high intake of fish and seafood, starch-based products (mainly potatoes and bread), dried fruits, especially chestnuts, milk and cheese, and moderate consumption of meat and wine (Calvo-Malvar et al., 2016). Since 2000, many countries have recommended adherence to the Atlantic Diet, in part because of its association with improved cardiometabolic health and lower coronary mortality (Guallar-Castillón et al., 2013; Oliveira et al., 2010). Conversely, the Atlantic diet scenario has been subjected to bibliographic analysis, which has revealed its multiple environmental benefits (Esteve-Llorens et al., 2019a).

### 1.3.2 Food-based dietary guidelines

The development of FBDGs is a key aspect of nutrition policy, providing a science-based basis for promoting healthy eating habits. Such guidelines are typically tailored to the specific needs and characteristics of the population or country formulating them. National FBDGs are government-endorsed policy documents that aim to educate consumers in their respective countries about healthy diets and lifestyles (Trichopoulou and Vasilopoulou, 2016). Designed primarily to raise consumer awareness, they must be culturally acceptable and feasible to implement in the respective country or region. They should also be consistent, easy to understand and memorable (European Commission, 2023b).

It is evident that less than 50% of countries worldwide have implemented the FBDGs, which represents a significant gap, particularly in low- and lower-middle-income countries, where the adoption rates are 13% and 26% respectively. The African region is particularly deficient in the implementation of the FBDGs, indicating a lack of these guidelines in this geographical area (UNICEF, 2020). All countries within the European Union, including Iceland, Norway, Switzerland, and the United Kingdom, have developed their own set of FBDGs (European Commission, 2023b). **Table 1.1** presents the prevalence of FBDGs across the UNICEF regions.

**Table 1.1. Avaliability of food-based dietary guidelines by UNICEF region. Adapted from UNICEF (2020).**

| Region | Number of countries |
|---|---|
| West and Central Africa | 3 |
| Eastern and Southern Africa | 4 |
| Middle East and North Africa | 5 |
| Eastern Europe and Central Asia | 8 |
| Western Europe | 24 |
| South Asia | 5 |
| East Asia and Pacific | 13 |
| Latin America and Caribbean | 28 |
| North America | 2 |

While some countries provide specific guidelines for all the above groups - infants, children, adolescents and pregnant or breastfeeding women - others provide separate recommendations only for infants and young children under 2 years of age. Consequently, a significant number of countries lack comprehensive guidelines tailored to the specific dietary needs of infants, children, adolescents, pregnant or breastfeeding women (UNICEF, 2020).

To date, only a few countries have included environmental sustainability considerations in their FBDGs. According to a survey of 83 of them, only 37 explicitly addressed environmental sustainability. As a result, only about 17% of the world population is currently covered by FBDGs that take account of environmental sustainability (James-Martin et al., 2022).

Therefore, FDBDGs should be clear and provide guidance on the appropriate intake of different animal-based foods such as dairy, meat/poultry, fish, and eggs for each age and physiological category. This should take into account the different nutrient needs and available nutrient sources for each group, while carefully balancing sustainability considerations (Springmann et al., 2020).

### 1.3.3 Planetary healthy diets

Scientific goals for healthy diets and sustainable food systems can be integrated into a common framework that is universal across food cultures and production systems in the world, with a high potential for local adaptation and scalability (Willett et al., 2019b). Achieving this goal will require the implementation of many changes and unprecedented global cooperation and commitment: a Great Food Transformation that is consistent with global challenges and policy targets, including the Paris Agreement on climate change and the Action Agenda on NCDs, as well as the SDGs and food-related planetary boundaries (Springmann et al., 2020).

Applying this framework to future projections will help food systems provide universal win-win diets for an estimated global population of around 10 billion by 2050 and beyond. These reference diets can create meals that are consistent with the diverse food cultures and cuisines found in all regions of the world. These global dietary recommendations include those of the WHO and the FAO of the United States (FAO and WHO, 2019), and the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems (Willett et al., 2019b).

The EAT-Lancet Commission uses the planetary boundaries framework as a guiding principle to set scientific targets that define recommended ranges of intakes for food groups (**Table 1.2**). The aim is to safeguard both human health and the planetary boundaries associated with food production, thereby ensuring a stable Earth system. This approach enables the

guidelines to be adapted to various cultural contexts, allowing for flexible implementation around the world. These defined boundaries include global cropland use, biodiversity loss, water use, GHG emissions, and nitrogen and phosphorus levels (Willett et al., 2019b).

**Table 1.2. EAT-Lancet reference diet, with possible ranges, designed for a caloric intake of 2500 kcal. Adapted from Willett et al. (2019b).**

| | Macronutrient intake (possible range), g/day | Caloric intake kcal/day |
|---|---|---|
| **Whole grains** | | |
| Rice, wheat, corn, and other | 232 (total gains 0-60% of energy) | 811 |
| **Tubers or starchy vegetables** | | |
| Potatoes and cassava | 50 (0-100) | 39 |
| **Vegetables** | | |
| All vegetables | 300 (200-600) | - |
| Dark green vegetables | 100 | 23 |
| Red and orange vegetables | 100 | 30 |
| Other vegetables | 100 | 25 |
| **Fruits** | | |
| All fruit | 200 (100-300) | 126 |
| **Dairy foods** | | |
| Whole milk or derivative equivalents (e.g., cheese) | 250 (0-500) | 153 |
| **Protein sources** | | |
| Beef and lamb | 7 (0-14) | 15 |
| Pork | 7 (0-14) | 15 |
| Chicken and other poultry | 29 (0-58) | 62 |
| Eggs | 13 (0-25) | 19 |
| Fish | 28 (0-100) | 40 |
| Legumes | | |
| Dry beans, lentils, and peas | 50 (0-100) | 172 |
| Soy foods | 25 (0-50) | 112 |
| Peanuts | 25 (0-75) | 142 |
| Tree nuts | 25 | 149 |
| **Added fats** | | |
| Palm oil | 6.8 (0-6.8) | 60 |
| Unsaturated oils | 40 (20-80) | 354 |
| Dairy fats (included in milk) | 0 | 0 |
| Lard or tallow | 5 (0-5) | 36 |
| **Added sugars** | | |
| All sweeteners | 31 (0-31) | 120 |

According with WHO sustainable healthy diets are based on several core principles (FAO and WHO, 2019). Sustainable healthy diets promote balance and diversity across food groups, favouring lower fat, lower sugar and lower sodium/salt options, whether prepared at home or industrially produced. Specifically, sustainable diets promote the inclusion of whole grains, nuts, and a variety of fruits and vegetables. They may also include moderate amounts of eggs, dairy products, poultry and fish, but red meat consumption should be limited. Safe and clean drinking water is strongly recommended.

By following these guidelines early in life, individuals can reduce the risk of diet-related NCDs, promote general health and foster lifelong healthy eating habits. It is recommended that 30-35 % of total energy comes from fats, emphasizing a shift from saturated to unsaturated fats and the elimination of industrial trans fats. The intake of free sugars should be limited to less than 10% (potentially less than 5%) of total energy and limiting daily salt consumption to no more than 5 grams, preferable iodized (WHO, 2018a).

Sustainable healthy diets prioritise environmental sustainability. They aim to reduce GHG emissions and minimise water and LU and advocate for limiting the application of nitrogen and phosphorus fertilizers. These guidelines also call for a reduction in the use of antibiotics in food production, minimising food loss and waste, and reducing chemical pollution. Additionally, they contribute to the preservation of biodiversity by supporting a diverse range of crops, livestock, forest-derived foods and aquatic genetic resources. Practices such as overfishing and over-hunting are discouraged to protect genetic diversity.

These guidelines should build on and respect local culture, skills, knowledge, and consumption patterns, reflecting local values related to food sourcing, production and consumption. To ensure widespread adoption, these diets should be cost-effective and appealing. They also strive to avoid negative gender impacts, particularly in terms of time allocation, such as buying and preparing food, and fetching water and firewood.

To sum up, planetary healthy diets, along with FBDGs and traditional diets, serve as important evidence-based frameworks for designing food and nutrition policies and interventions. These guidelines provide valuable insights into the food supply and dietary behaviour, and inform decisions on food labelling, nutrient standards and public health initiatives. By adopting these frameworks, policy makers can more effectively address the interrelated challenges of environmental sustainability, nutrition and public health.

# 2. OBJECTIVE AND ROADMAP OF THE THESIS

# INDEX

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**2.2 THESIS ROADMAP ..... 29**

## 2.1 OBJECTIVE OF THE THESIS

Dietary patterns are changing globally, driven by population growth and social and technological advances, in ways that are negatively impacting human and planetary health. If current dietary trends continue in the coming years, diet-related NCDs such as diabetes, obesity and CVD will become the leading cause of mortality. On the other hand, the components of the food system involved in the production and delivery of food (crop management, animal husbandry, cooking practices, etc.) can also have a significant negative impact on the environment. Within this framework, diets and the food systems that provide them present a complex and multifaceted set of challenges related to the SDGs and the Paris Agreement. The main objective of this dissertation is to assess the sustainability of different dietary patterns through a trade-off between three criteria: environmental, health and socio-economic. Through this research, we aim to advance food sustainability education by equipping the general public with the knowledge and tools necessary to make informed choices that positively impact the planet.

## 2.2 THESIS ROADMAP

This thesis is composed of six sections (see **Fig 2.1**) according to the main topic addressed:

**Section I. Contextualization.** An overview of the motivation for this thesis has been presented in **Chapter 1**. It presents the framework of the current situation of food systems, which calls for urgent coordinated action and policy solutions to transform agriculture and food systems in order to end hunger, achieve food security, improve nutrition in all its forms, and increase access to affordable planetary healthy diets. **Chapter 2** presents the objectives of this thesis, while **Chapter 3** presents the methods used to assess the sustainability of dietary patterns, considering step-by-step LCAs with modelling of environmental, health, nutritional, and economic indicators. It also explains the methodology of cluster analysis to study the sustainability of recipes and the basics of randomised controlled trials and cohort studies.

**Section II. Sustainable and healthy food-based dietary guidelines around the world.** This section focuses on the multicriteria analysis of FBDGs established by different national and international bodies reinforcing the commitment to a green and healthy future for all. Therefore, in **Chapter 4** dietary guidelines from Europe (Dutch dietary guidelines (DDG), New Nordic Diet (NND), the Strategy for Nutrition, Physical Activity and the prevention of obesity (NAOS), MD, Italian Dietary Guidelines (IDG)) and America were modelled and compared from an environmental and nutritional point of view. **Chapter 5** presents the environmental and nutritional assessment of the EAT-Lancet Diet, a sustainable reference diet developed by the EAT-Lancet Commission to reduce the incidence of NCDs and global mortality while improving the sustainability of the food system. **Chapter 6** presents a sustainability assessment integrating environmental, health, nutritional and economic indicators of a southern version of the NND (SNND).

**Section III. The Atlantic diet: A planetary healthy diet.** The Atlantic Diet is one of the best known traditional Spanish diets, along with the MD. Adherence to the Atlantic diet has been reported to have numerous health and environmental benefits. **Chapter 7** presents the first research that, from a dual perspective (health and environment), tested whether a 6-month community-based randomised controlled trial (RCT) based on a traditional Atlantic diet intervention could reduce the incidence of metabolic syndrome (MetS) and the environmental metric of CF. **Chapter 8** explores the sustainability of 60 Galician recipes, using hierarchical

cluster analysis to examine CF, energy return on investment (EROI) and cost. Based on this study, the foodservice industry could promote ecolabelling to identify and promote sustainable menus.

**Section IV. Impact of socio-cultural, health, political and economic factors on food consumption patterns.** Dietary habits and food choices are influenced by a combination of factors, including personal preferences, cultural and educational influences, and socio-economic considerations. In times of crisis, such as the COVID-19 pandemic and lockdown, these factors may be reconfigured, leading to changes in food choice motives and consequently affecting overall dietary choices. **Chapter 9** focuses on examining the changes in Spanish food consumption patterns during the COVID-19 pandemic by evaluating CF and WF indicators. Through this research, it aims to provide valuable insights into the environmental implications of changes in dietary habits during times of significant societal disruption. **Chapter 10** provides a holistic understanding of the interplay between the socio-economic status of households in Chile and the nutritional quality of their diets, the environmental pressures resulting from their consumption (particularly in terms of climate change and water scarcity), and the economic costs associated with their dietary patterns. **Chapter 11** focuses on a comprehensive analysis of the Paleo diet, including environmental sustainability, nutritional quality, economic considerations and potential associations with NCDs (CVDs, T2D, colorectal cancer (CRCA), stroke and all-cause mortality) through cohort studies.

**Section V. Fostering food sustainability in formal education through memogames and learning strategies.** How can children learn about food in a fun way? Through interactive games that allow them to explore the world of food. These games not only teach healthy eating, but also raise awareness about the importance of sustainability in our food choices. **Chapter 12** introduces the concept of food sustainability in formal education. “Eat healthy... Eat sustainably” is an educational resource designed to teach primary school students about the WF and CF of the 62 most consumed foods in Spain in 2023, while providing a comprehensive overview of the main food groups that make up a balanced diet. **Chapter 13** introduces “Ecorush”, a board game for secondary school students that combines environmental sustainability with healthy eating. Players compete to buy food while minimising their CF and maintaining a balanced diet.

**Section VI. Conclusions.** This section summarizes the main findings of each chapter and provides an overview of the main conclusions and recommendations. An outlook on areas of interest and future research is also discussed.

**CONTEXTUALIZATION**

**CHAPTER 1.** Rethinking the food system for human and planetary health.
**CHAPTER 2.** Objective and roadmap of the thesis.
**CHAPTER 3.** Sustainability assessment methodologies.

**SUSTAINABLE AND HEALTHY FOOD-BASED DIETARY GUIDELINES AROUND THE WORLD**

**CHAPTER 4.** Nourishing people, caring for the planet: evaluating the sustainability of American and European dietary guidelines.
**CHAPTER 5.** Unveiling the environmental benefits of EAT-Lancet diet in the framework of the Spanish dietary pattern.
**CHAPTER 6.** Exploring health and sustainability in southern Europe through the New Nordic Diet.

**THE ATLANTIC DIET: A PLANETARY HEALTHY DIET**

**CHAPTER 7.** A diet is more healing than ten prescriptions: clinical trial addressing the trinomial Atlantic diet-health-environment (the GALIAT study).
**CHAPTER 8.** Cluster analysis of Galician recipes: carbon footprint, energy efficiency and cost.

**IMPACT OF SOCIO-CULTURAL, HEALTH, POLITICAL AND ECONOMIC FACTORS ON FOOD CONSUMPTION PATTERNS**

**CHAPTER 9.** Examining the synchrony between Sustainable Development Goals and the COVID-19 pandemic.
**CHAPTER 10.** Socio-economic strata and dietary choices: an in-depth analysis of nutritional and environmental sustainability in Chile.
**CHAPTER 11.** Beyond the Stone Age: A holistic analysis of the Paleo Diet impact on health, economy and the planet.

**FOSTERING FOOD SUSTAINABILITY IN FORMAL EDUCATION THROUGH MEMOGAMES AND LEARNING STRATEGIES**

**CHAPTER 12.** Eat healthy… Eat sustainably.
**CHAPTER 13.** Ecorush: The race for the green shopping cart.

**CONCLUSIONS**

General findings and conclusions

**Fig 2.1. Thesis roadmap**

# 3. SUSTAINABILITY ASSESSMENT METHODOLOGIES

With growing concern that progress on most Sustainable Development Goals is either stagnating or declining, the urgency of the situation is further compounded by the fact that the deadline for achieving these goals is rapidly approaching. Ongoing conflicts, extreme weather events, environmental degradation and economic shocks, coupled with the high cost of nutritious food and growing inequalities, continue to threaten food security and nutrition. To address these pressing issues, innovative solutions are urgently needed to promote sustainable consumption and production models. In response to these demands, this chapter provides an overview of the many metrics and methodologies that have been developed to integrate health, environmental, and socioeconomic assessments of food and diet to address pressing global challenges.

Particular attention is given to life cycle assessment (LCA) as an internationally standardized methodology for assessing the environmental impact of dietary choices. The Nutrient Rich Diet Index and the Health Gain Score were chosen to assess diet quality because of their proven track record in assessing dietary patterns. Randomised controlled trials and cohort studies provide valuable insights into the relationship between dietary interventions or exposures (such as foods or dietary patterns) and health outcomes (including non-communicable diseases and metabolic syndrome). Cluster analysis is also presented as a very useful tool for linking the environmental, health and socio-economic dimensions of sustainable dietary choices.

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## 3.1 A MULTIDIMENSIONAL APPROACH TO DIETARY SUSTAINABILITY

The agri-food sector plays a central role in the global economy, but current practices are increasingly unsustainable. Transformative change is urgently needed to address the pressing challenges of hunger, climate change and inequality. A sustainable food system is one that is resilient, productive, prosperous, equitable, inclusive, empowering and regenerative. It provides healthy and nutritionally balanced diets while simultaneously reducing negative environmental impacts. However, the current state of our food systems fails to meet these ideals. To achieve a more sustainable future, measuring sustainability is of utmost importance. A comprehensive approach requires a combination of environmental, nutritional, health, and socio-economic indicators, to provide a holistic assessment of the performance of agri-food systems. By understanding the trade-offs and synergies involved, policy makers and stakeholders can make informed decisions to promote sustainable food systems (Webb et al., 2023).

LCA provides a robust framework for assessing the environmental performance of diets, as described in **Section 3.2**. By accounting for the inputs and outputs of food production and consumption throughout its entire life cycle, LCA quantifies the environmental impacts associated with different dietary choices. Key indicators include CF, EROI and WF. The CF, a measure of GHG emissions, reflects the LU, energy consumption and animal husbandry involved in food production (Shabir et al., 2023). EROI, calculated using the cumulative energy demand (CED) approach, assesses the energy efficiency of a dietary choice by comparing the amount of usable energy contained in a meal with the cumulative energy consumed throughout the entire lifecycle of the meal, from production to consumption (Simon et al., 2023). The WF measures the total amount of water used throughout the production and consumption of a product. The cultivation of food and feed crops, as well as food processing and preparation, use significant amounts of water. Understanding the WF of different dietary choices can help improve water resource management and address water scarcity issues (Harris et al., 2020). By combining these indicators, LCA provides a detailed understanding of the environmental impacts of different diets, informing policy decisions, guiding sustainable food choices, and identifying areas for improvement in agricultural practices and food systems (Ran et al., 2024).

Sustainability assessments should not be limited to environmental indicators. For a comprehensive analysis, nutrition and health factors must also be integrated. By combining these perspectives, we can gain a more nuanced understanding of the overall impact of food systems. Metrics for assessing nutrition include the Nutrient Rich Diet (NRD9.3) (Van Kernebeek et al., 2014) and the Health Gain Score (van Dooren et al., 2014). These nutrient-derived metrics differ in terms of the nutrients considered, reference values and weighting schemes (see **Section 3.3**), and can be used in a complementary way. On the other hand, different research methodologies were used to investigate the effects of diets on health as discussed in **Section 3.4**. RCTs are considered the gold standard in clinical research. In these studies, participants are randomly assigned to different intervention groups (e.g. intervention diet vs control diet) and health outcomes are compared between the groups (Temple, 2016). An alternative approach is cohort studies, which provide valuable insights into the relationship between diet (and other lifestyle factors) and disease risk. These studies follow a group of people over time to assess the relationship between dietary factors and the development of disease (Schwingshackl et al., 2021).

In addition to environmental and health considerations, socio-economic outcomes are critical to the overall sustainability of food systems. While specific methodologies for assessing these factors may vary, in this thesis economic factors are primarily assessed by calculating the total cost of diets based on relative food prices. Social factors are analysed by examining

culturally relevant diets and the relationship between measures of socio-economic position and sustainable dietary patterns (Webb et al., 2023).

Statistical models, such as cluster analysis, could be effectively used to comprehensively assess the sustainability of food choices. By categorising foods according to environmental impact, nutritional value and cost, cluster analysis helps to develop nutritionally adequate, health-promoting and climate-friendly menus. Consequently, this dissertation has adopted this analytical approach, which is described in **Section 3.5**.

## 3.2 ENVIRONMENTAL ASSESSMENT OF DIETS: LIFE CYCLE ASSESSMENT METHODOLOGIES

LCA is a widely used methodology for assessing the environmental impacts of a process, system or product throughout its life cycle (ISO, 2006a, 2006b). A LCA study allows the comparison of different products, services, systems and scenarios. It facilitates the understanding of environmental impacts and the identification of critical stages or hotspots in their life cycle. It also allows the exploration of potential trade-offs and opportunities for implementing improvements (Bjørn et al., 2018c). In addition to its analytical value, the results of an LCA study can inform decision-making in various contexts, including industry, government and non-governmental organisations. This can be seen in areas such as strategic planning, priority setting, product or process design and redesign, and marketing strategies (see **Fig. 3.1**). The results of an LCA study can also be used to develop compelling environmental claims, facilitate participation in eco-labelling schemes and enable the production of EPDs - sustainability initiatives (ISO, 2006b).

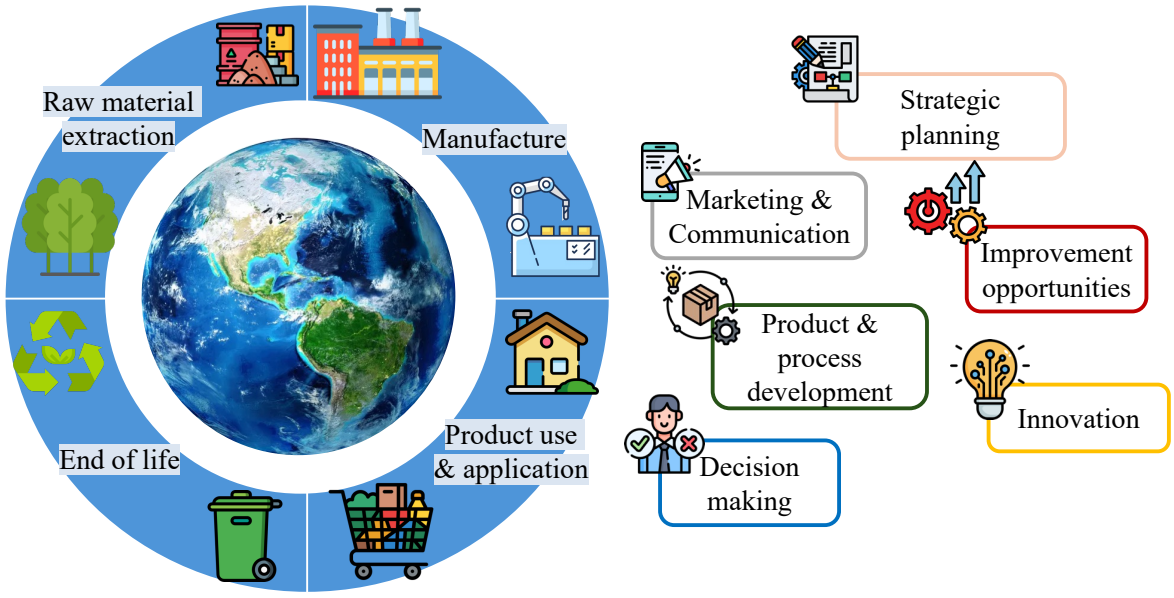


**Fig. 3.1. Life cycle concept, opportunities and potential applications of life cycle assessment. Adapted from ISO 14040:2006**

### 3.2.1 An historical overview of life cycle assessment

The development of life cycle-oriented methods, which can be considered as the forerunners of current LCA, can be traced back to collaborative efforts between universities and industry in the 1960s. The methods were initially called Resource and Environmental Profile Analysis or Ecobalances, but the term LCA was adopted in the 1990s. These early methods originated mainly in the United States and Northern Europe and were primarily

concerned with material and energy accounting, inspired by material flow accounting. The focus was on cataloguing energy and resource use, emissions and waste generation in each industrial process within product life cycles. As inventories became more complex, the focus shifted from simply accounting for physical flows to translating inventory results into potential environmental impacts (climate change, eutrophication and resource scarcity) (Bjørn et al., 2018b).

In the early history of LCA, the environmental concerns addressed by LCA methods were inconsistent and varied according to prevailing public interests. Issues such as waste generation and energy use, influenced by concerns about landfill and oil prices, were more important at different times. The perceived importance of emissions also varied over time. In the early stages of impact assessment, methods were used to quantify the impacts in question in terms of dilution volumes to achieve safe levels (Guinée et al., 2011).

Nevertheless, despite changing public concerns, the 1990s saw a notable evolution towards quantifying all relevant environmental impacts. CML92, published in 1992, was the first methodology to include a comprehensive set of intermediate impact categories (Heijungs et al., 1992). The Swedish EPS method concentrated on the damage to ecosystems and human health (Steen, 1999), whereas the Dutch Eco-indicator 99 adopted a science-based approach (Goedkoop and Spriensma, 2000). The 1990s also saw the establishment of various life cycle inventory (LCI) databases, which continued to exhibit data inconsistencies until the first ecoinvent database (v1.01) was released in 2003. This database emphasized the importance of consistent standards and quality across industry sectors (Ecoinvent, 2023). The discussion of LCI data revealed a fundamental difference in the perception and application of LCA.

- Attributional LCA: The main objective is to quantify the environmental impacts associated with a product or service under a status quo scenario. This means that the system under consideration cannot change the existing production capacity of the market. To achieve this, representative average data is used (Dastjerdi et al., 2022)
- Consequential LCA: describe how environmental flows will change in response to possible decisions for which marginal data should be utilized (Dastjerdi et al., 2022).

The increasing complexity of product systems and the abundance of LCI data led to the development of dedicated LCA software, with SimaPro and GaBi appearing in 1990 (Herrmann and Moltesen, 2015). In the 21st century, impact assessment methodologies have undergone a transformation, initially focusing on identifying differences in environmental hazards. The EDIP2003 methodology introduced spatially differentiated impact assessments, covering non-global impacts such as eutrophication and acidification (Hauschild and Potting, 2005).

The globalization of production and the increased emphasis on bio-based products in LCA has led to a significant increase in the development of methods to assess extraction-related impacts such as water use and LU, particularly in the 2000s and 2010s. Hybrid LCA is a methodology that effectively integrates the benefits of both process-based and input/output-based LCAs. Given the multifaceted nature of sustainability, there have been increasing efforts to develop methods for social LCA, which aims to quantify the social and socio-economic impacts of products throughout their life cycle (Mármol et al., 2023). A formal framework for Life cycle sustainability assessment has also been established. Life cycle sustainability assessment is the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes with the aim of promoting more sustainable products throughout their life cycle (Elegbede et al., 2023). The evolution of the LCA approach is presented in **Fig. 3.2**.

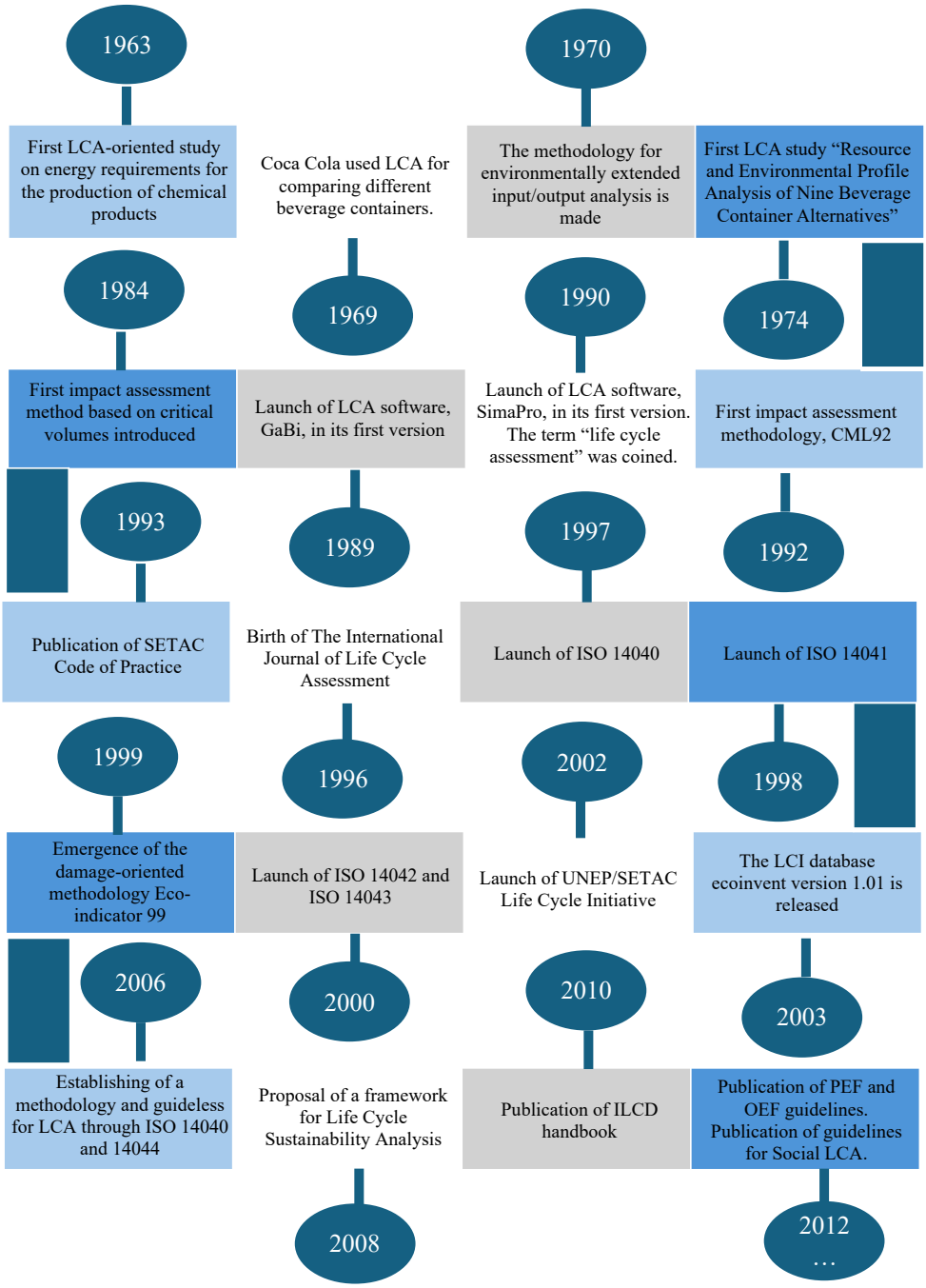


**Fig. 3.2. Historical development of life cycle assessment**

### 3.2.2 Main phases of a life cycle assessment

The ISO provides standards for LCA in ISO 14040 and 14044. A LCA study comprises four phases as can be seen in **Fig. 3.3**: i) goal and scope definition, ii) LCI, iii) life cycle impact assessment (LCIA), and iv) interpretation of results.

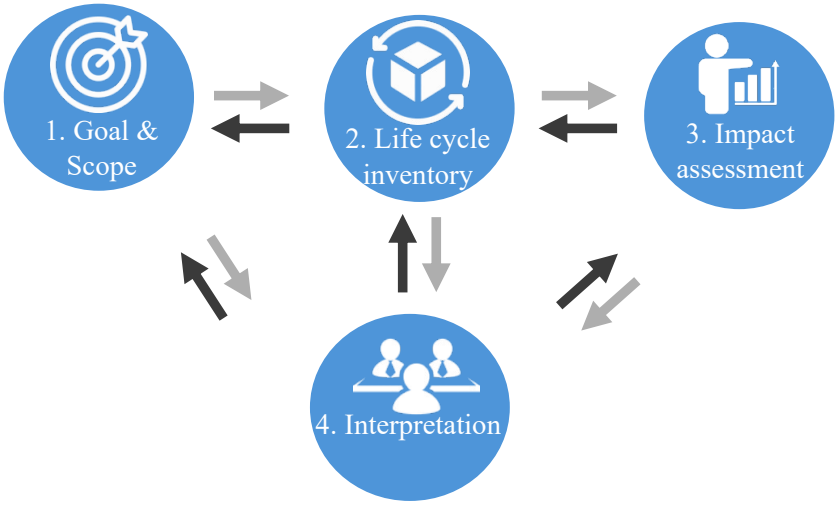


**Fig. 3.3. Life cycle methodology phases. Adapted from ISO 14040:2006**

3.2.2.1 Goal and scope definition

The aim of the study is to identify the initial phase of an LCA and to describe in detail the rationale for the study. This includes: i) the intended applications of the results, ii) the limitations imposed by the methodological choices, iii) the decision context and rationale behind the decision to conduct the study, iv) the intended audience, v) the comparative studies to be published, and vi) the commissioner of the study (European Parliament, Council of the European Union, 2013).

The goal definition serves to contextualize the LCA study and constitutes the foundation for the subsequent phase, namely the scope definition. This second phase is characterised by the framing and delimitation of the assessment, which is mainly carried out in terms of:

- Define the functional unit, which quantifies the function of the system under consideration and provides a reference to which the input and output data are related. It is essential to ensure the comparability of LCA results, which is critical when assessing different systems (ISO, 2006b).
- The scope of the system under study and its boundaries were defined in several dimensions. These included the geographical area and time horizon considered, the boundaries between production and the production of capital goods, the boundaries between the life cycle of the product under consideration and related life cycles of other products, and the boundaries between the technological system and nature (Tillman et al., 1994). To illustrate, a cradle-to-gate approach encompasses only those activities from the acquisition of raw materials, including the origin and growth of feed for animal-sourced products, up to processing and packaging of the finished product. Conversely, in a cradle-to-grave approach, the system boundary encompasses the entire life cycle of the product, from the extraction of raw materials to the disposal of components (see **Fig. 3.4**) (Golsteijn, 2022).
- Selection of the assessment parameters, i.e. the environmental impact categories to be assessed in the study (Hauschild, 2018).
- Analysing data quality requirements: time-related, geographical, technology coverage; precision, completeness and representativeness of the data; consistency and reproducibility (ISO, 2006b).
- Selecting allocation methods of processes with multiple products, which means partitioning inputs and outputs to the product under study (Bjørn et al., 2018a).

- Decide on the most appropriate perspective to use, consequential or attributional LCA. A consequential LCA assesses the expected impacts of choosing one alternative over another, whereas an attributional LCA assesses the impacts associated with the activity being studied (Weidema et al., 2018, 2020).

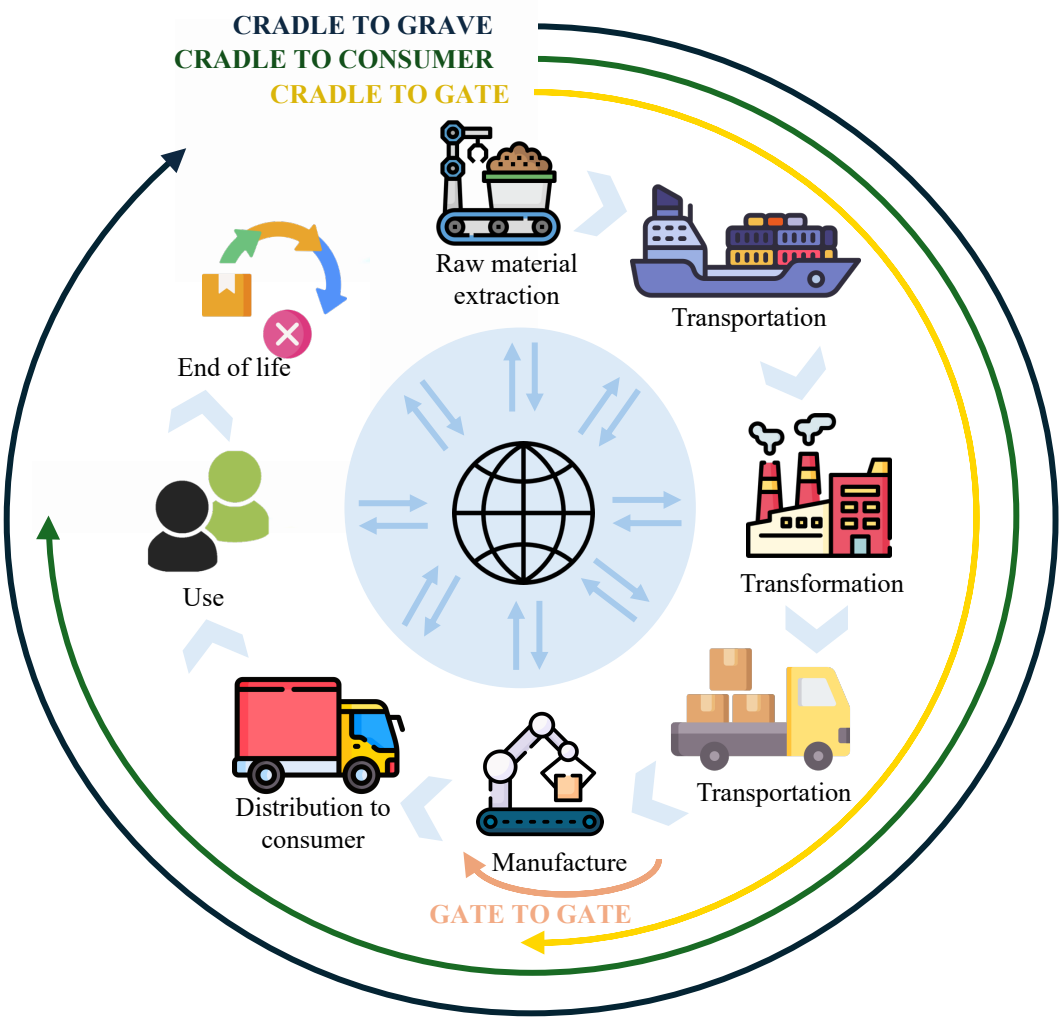


**Fig. 3.4. Different scopes in life cycle assessment**

3.2.2.2 Life cycle inventory analysis

The third phase of an LCA, the LCI, is often the most time-consuming part of an LCA. This phase involves collecting all the environmental inputs (resources, materials, semi-finished products and products) and outputs (emissions to air, water and land, and valuable products) associated with a product or service (see **Fig. 3.5**) (Golsteijn, 2022). Qualitative and quantitative data shall be collected for each unit process included within the system boundaries. The data collected should be primary data, i.e. collected directly from the site. Where primary data cannot be used, the data should be extracted or estimated from databases and/or scientific publications (secondary data).

The following measures should be considered in the modelling of the system (ISO, 2006a):

- Develop non-specific process flow diagrams that describe all the unit processes to be modelled, including their interrelationships.

- Describe each unit process in detail, with particular emphasis on the factors influencing inputs and outputs.
- Compile a list of relevant flows and data for the operating conditions associated with each unit process. A list of the units used should be compiled.
- Describe the data collection and calculation techniques to be used for all data.
- Provide instructions for documenting any special cases, irregularities or other issues that may arise in relation to the data provided.

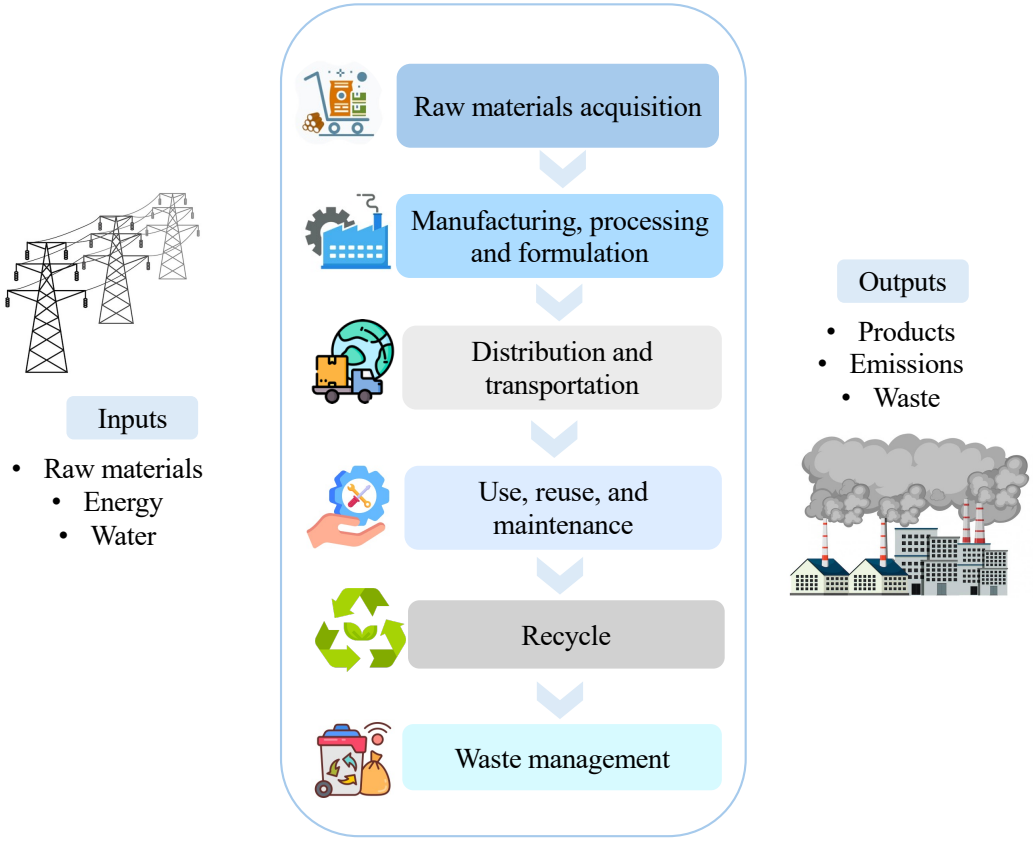


**Fig. 3.5. Steps in a life cycle inventory analysis. Adapted from ISO 14040:2006**

3.2.2.3 Life Cycle Impact Assessment

The results of the LCI or indicators of environmental interventions are translated into environmental impacts using knowledge and models from environmental science. The LCIA consists of a number of mandatory elements (ISO, 2006b):

- Selection of impact categories, category indicators and characterisation models. The assessment of impacts may be conducted at either the midpoint or endpoint level. Midpoint indicators were designed to assess single environmental problems, such as climate change or acidification. Endpoint indicators demonstrate the environmental impact at three higher aggregation levels: 1) effect on human health, 2) biodiversity and 3) resource scarcity (Landrigan et al., 2024).
- Classification: assignment of inventory data within impact categories.
- Characterisation: modelling of inventory data within impact categories (e.g. all contributions to global warming are converted into kg of equivalent $CO_2$).

A total environmental impact score in a category $IS_c$ expressed in a specific unit, can be calculated for all elementary flows within the same impact category using the general equation (**Eq. 3.1**) (Rosenbaum et al., 2018):

$$IS_c = \sum_I (LCIA_i x m_i) \quad (3.1)$$

Where, $m_i$ represents the elementary flow classified within a specific impact category and $LCIA_i$ denotes the life cycle impact characterisation factor. A characterisation factor represents the contribution per quantity of an elemental flux to a particular environmental impact category. The calculation is based on scientifically valid and quantitative models of the environmental mechanism, which aim to represent the cause-effect chain of events leading to environmental impacts in a realistic way. This includes all elementary flows contributing to the specified impact. The unit of a $LCIA_i$ remains consistent for all elementary flows within an impact category.

Subsequently, optional elements may be incorporated, such as:

- Normalization: expressing potential impacts relative to a reference.
- Grouping: the sorting or ranking of impact indicators.
- Weighting: the relative weighting of impact categories
- Evaluation and reporting.

In the field of LCA practice, the implementation of methods in LCA software is a common practice. These methods are often referred to by specific names, such as ReCiPE 2016, CML, TRACI, EDIP, LIME or IMPACT 2002 + (Hauschild, 2018). Recipe is the method of choice in Europe, having been officially endorsed by the Dutch government and recognized as the most up-to-date method (Huijbregts et al., 2017). This method encompasses 18 midpoint and three endpoint indicators, respectively (see **Fig. 3.6**).

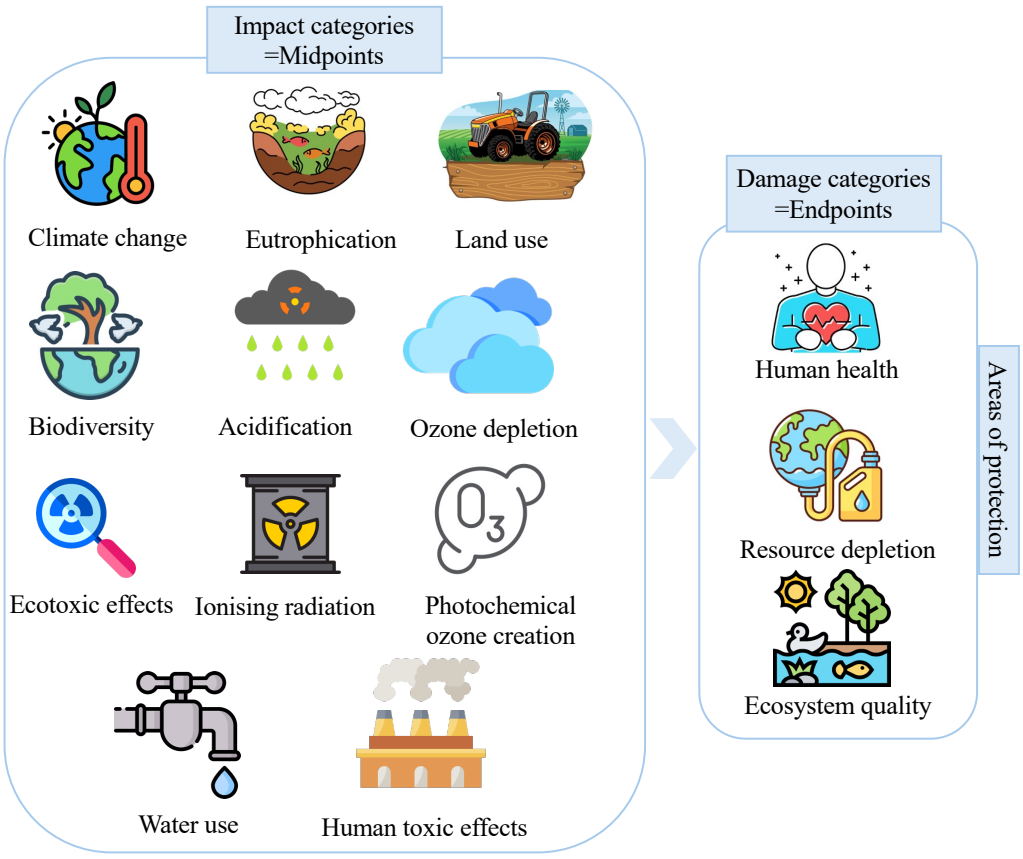


**Fig. 3.6. UNEP/SETAC integrated environmental life cycle impact assessment framework: Linking life cycle inventory results through midpoint categories to endpoint categories. Adapted from Ciroth et al. (2011)**

3.2.2.4 Interpretation of the results

The interpretation of the results represents the final phase of an LCA (Hauschild et al., 2018). The findings of the study are analysed in order to address the questions posed as part of the goal definition. The interpretation considers both the results of the inventory analysis and the impact assessment elements characterisation, as well as possible normalization and weighting. The interpretation must be carried out in accordance with the objective and scope definition and must respect the constraints imposed by the scoping choices on a meaningful interpretation of the results. For example, this may be due to geographical, temporal or technological assumptions (Figueiredo and Haddad, 2023).

The interpretation of LCA results involves three sequential steps, as depicted in **Fig. 3.7** (Hernandez et al., 2019).

- Identification of significant issues based on the results of the LCI and LCIA phases of an LCA: It is recommended that the outcomes of the LCI or LCIA phases be organized in order to facilitate the identification of significant issues, alignment with the defined goal and scope, and in conjunction with the evaluation process.
- Evaluate the study, considering completeness, sensitivity and consistency checks: Establish and reinforce confidence in the results of the LCA or LCI study, which should include the significant issues highlighted in the initial identification phase. A clear and understandable presentation of assessment results is essential to ensure that clients and stakeholders fully understand the findings of the study.
- Conclusions, limitations and recommendations: Draw final conclusions, identify any limitations and provide recommendations tailored to the intended audience of the LCA.

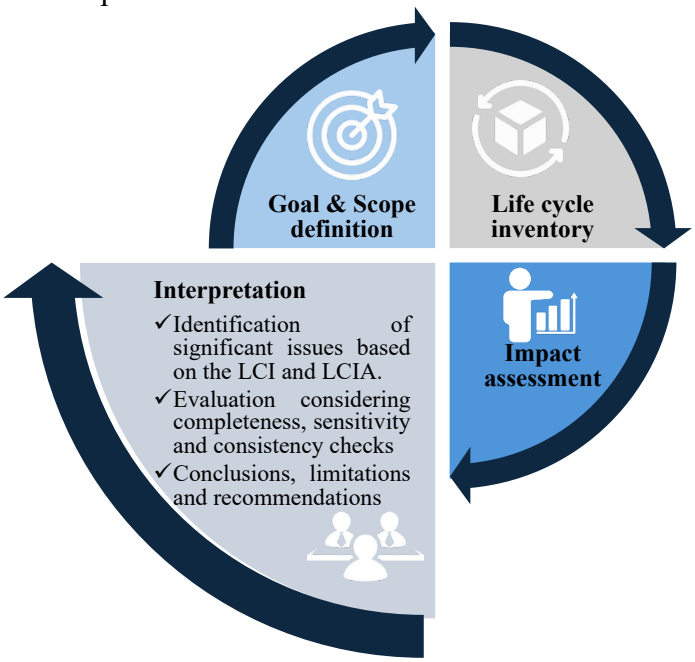


**Fig. 3.7. Life cycle assessment interpretation steps according to ISO 14040:2006**

### 3.2.3 Life cycle assessment of food systems

LCA is a valuable methodology for evaluating the environmental sustainability of food systems and dietary patterns. The life cycle of a food product or an entire diet encompasses six stages (**Fig. 3.8**): the production and transportation of inputs to the farm, cultivation, processing, distribution, consumption, and waste management. Many LCA studies focus on the initial two phases, which are referred to as the "cradle-to-farm gate LCA" (Amirahmadi et al., 2022;

Mukosha et al., 2023). These stages are primarily responsible for the majority of environmental impacts, which are mainly due to activities such as animal husbandry, manure management, fertilizer production and use, and fuel consumption associated with the operation of farm machinery. The distribution stage includes the transport of food both before and after processing. At the consumption stage, environmental impacts arise from activities such as storage, preparation and the generation of food waste. In the waste management phase, a variety of technologies can be used, including landfilling, incineration, composting, or digestion (Dijkman et al., 2018). A large number of LCA studies have been carried out to assess the environmental impacts of food (Clune et al., 2017), dietary patterns (Tucci et al., 2022) and production processes (Peano et al., 2022), focusing on the differences between conventional and organic farming (Boschiero et al., 2023), and the perceived benefits of local food.

There is currently a broad consensus among scientists that efforts to address the environmental sustainability challenges posed by food systems and diets should focus primarily on issues related to climate and water use (Grosso et al., 2020). Consequently, the joint consideration of WF and CF in the context of global dietary patterns has attracted considerable attention worldwide (Scarborough et al., 2023).

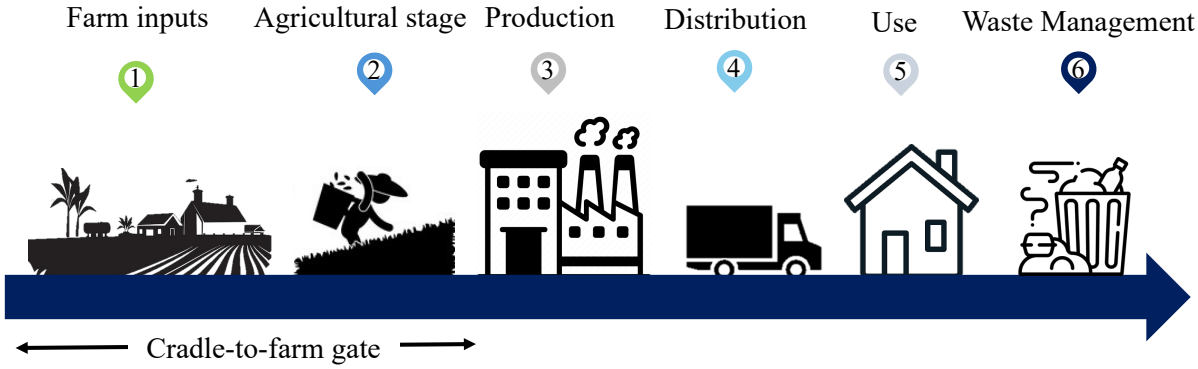


**Fig. 3.8. Stages in life cycle assessment of agricultural products**

### 3.2.4 Carbon footprint of dietary patterns

The CF is the most widely recognized indicator of climate change and is a key focus of many sustainable food policies in the food sector. The CF is a quantitative measure of the direct and indirect GHG emissions associated with a given activity or entity, expressed in kg of carbon dioxide equivalent (i.e., kg $CO_2$ eq) (ISO, 2013). Understanding the sources of these emissions is essential if we are to take effective action to reduce them. This is particularly important in light of the climate emergency currently facing humanity and the significant potential for dietary changes to mitigate GHG emissions (Willett et al., 2019b).

### 3.2.5 Water footprint of dietary patterns

The WF plays a pivotal role in the monitoring of human pressure on freshwater resources. The term WF is defined as the total volume of freshwater used to produce the goods and services consumed by an individual or community (Pfister et al., 2017). The calculation of the WF is based on the methodology proposed by the Water Footprint Network (WFN) (see **Fig. 3.9**). Water Footprint Assessment (WFA) is a four-phase process that quantifies WFs of food items and dietary patterns. The phases are as follows: i) goal and scope, ii) accounting, iii) sustainability assessment and iv) response formulation.

The objective of the WF assessment outlines the steps to be taken. The scope of the assessment defines the spatial and temporal dimensions of the study. For example, it determines whether the focus will be global or within a specific catchment area, the duration (one or more years), the extent of the value chain to be included, and whether the assessment will cover a single product, a single facility, or the entire company. The WF accounting phase involves collecting data and developing accounts, with the scope and level of detail depending on the decisions made in the previous phase. This is followed by the sustainability assessment phase, which evaluates the WF from an environmental, social and economic perspective. The final stage is the formulation of response options, strategies or policies. There is no obligation to include all steps in a single study. In the initial phase - goal and scope - it is possible to focus solely on accounting or, alternatively, to complete the study after the sustainability assessment phase, thus postponing the discussion of responses. In practice, this four-phase model serves as a flexible guideline rather than a rigid methodology (WFN, 2020)

The WF can be divided into three components: green, blue and grey. The green WF represents rainwater, the blue WF represents groundwater and surface water, and the grey WF is a measure of the volume of freshwater required to assimilate the load of pollutants generated along the production chain of a product (Harris et al., 2020; Hoeskstra et al., 2011). Therefore, the WF for a dietary pattern can be calculated according to **Eq. 3.2.** The Green WFj, Blue WFj and Grey WFj for each food item (j) were considered, as well as the total amount of a food item supplied per person and day (Mj).

$$WF_{menu} = \sum_{j=1}^{n} \left(Green\ WF_j + BlueWF_j + GreyWF_j\right) \cdot Mj \qquad (3.2)$$

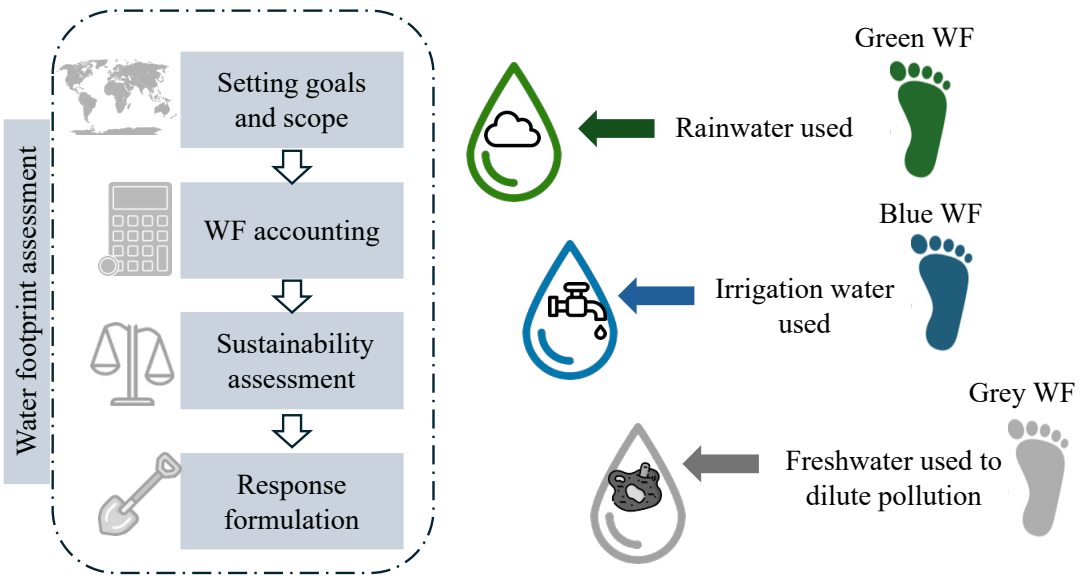


**Fig. 3.9. Water footprint assessment four-phase process for quantifying and mapping green, blue and grey water footprints.**

### 3.2.6 Energetic footprint of dietary patterns

The concept of EROI is subsumed within the domain of net energy analysis (NEA). Established in the early 1970s in response to growing concern about energy-related problems following the oil crisis, the theoretical framework of NEA was developed (Hall, 2016). The NEA posits that the primary driver of economic development in societies is net energy, defined

as the energy remaining after the costs of its acquisition have been accounted for. These costs typically include extraction, refining and delivery. The NEA advocates the elevation of net energy as the primary criterion for policy making (Carbajales-Dale et al., 2014). The energy required to supply energy can be calculated using net energy indicators, of which there are many. Developed in 1972, EROI is the ratio between the usable energy obtained from an energy source and the amount of energy required to obtain that energy (**Eq. 3.3**) (Delannoy et al., 2021).

$$EROI = \frac{Energy\ delivered}{Energy\ required\ to\ deliver\ energy} \quad (3.3)$$

Although this concept was originally used to develop an energy-focused approach to the economy, it has since been adapted to calculate ratios between the energy output of food and the energy input into food production (Laso et al., 2018).

LCA of energy is a field of research that aims to quantify the resource use and/or environmental impacts associated with the supply or use of energy. The CED approach has been widely used in LCA to calculate EROI. The ecoinvent database, the most widely used LCA database, includes a method for calculating CED for eight energy resource categories: fossil, nuclear, wind, hydro, solar, geothermal and two variants of biomass. CED serves as an indicator of the use of natural resources and is based on the premise that the intrinsic value of an energy source is determined by the amount of energy extracted from nature. CED considers the full range of primary energy derived from natural sources, tracing all energy use back to the original natural resource, while accounting for losses along the supply chain (Arvesen and Hertwich, 2015).

## 3.3 DIET QUALITY ASSESSMENT

Diet quality is an essential component of food security (Kent et al., 2024). A diversified, adequate, health-promoting and balanced diet is defined as one that provides the necessary energy and all essential nutrients to maintain the body in a healthy and active state (Alkerwi, 2014). Poor diet quality is the leading cause of health problems worldwide, including maternal and child health and NCDs (Miller et al., 2020). The United Nations SDGs set out a global commitment to achieve several nutrition targets by 2030 and to tackle undernutrition and hunger (WHO et al., 2023). To drive global progress towards these goals, it is necessary to assess the overall quality of diets (Miller et al., 2020) .

Dietary assessment includes examination of nutrient intakes, the caloric profile of the diet and the lipid profile (ALCE, 2020). In addition, valid indicators have been developed to assess diet quality and the extent to which diets are healthy in a comparable way across settings and populations (WHO et al., 2023). In this thesis, two nutrient-derived metrics, have been employed in a complementary manner: the NRD9.3 (Van Kernebeek et al., 2014) and the Health Gain Score (van Dooren et al., 2014). The metrics are based on different nutrients whose intake should be encouraged (e.g., protein or fibre) and limited (e.g., saturated fatty acids (SFA) or free sugars). In addition, the Health Gain Score takes into account food and energy intake (van Dooren et al., 2014).

### 3.3.1 NRD9.3.

The NRD9.3 is based on the principles of the Nutrient Rich Food 9.3 (NRF9.3). To assess the overall nutritional quality of a food, the principles of the NRF9.3 score have been applied. This score measures the overall nutritional quality of a food per 100 kcal.

To assess the overall nutritional quality of a diet, we adapted the NRF9.3 into the NRD9.3 score. Unlike the NRF9.3 score, which is calculated per 100 kcal of a specific food, the NRD9.3 score is not standardized to energy intake.

The NRD9.3 consists of a total of nine qualifying nutrients (protein, calcium, fibre, magnesium, potassium, iron, vitamin A, vitamin C, vitamin E) and three disqualifying nutrients (sodium, SFA and added sugar) (Van Kernebeek et al., 2014). The NRD9.3 score of a diet was calculated using **Eq. 3.4**.

$$NRD9.3 = \left(\sum_{i=1}^{i=9} \frac{nutrient_{i,capped}}{RDV_i} - \sum_{k=1}^{k=3} \frac{nutrient_k}{RDV_k}\right) \cdot 100 \quad (3.4)$$

Where $nutrient_i$ is the daily intake of the qualifying nutrient i in the diet, $nutrient_k$ the daily intake of the disqualifying nutrient k in the diet, and $RDV_i$, $RDV_k$ the recommended daily values of nutrients i and k, respectively. It is worth mentioning that an average value was considered when the RDV fall between two values.

The RDV of the nutrients were established according to the average requirements, population reference intakes, reference intake ranges and tolerable upper intake levels established by EFSA (2021). The dietary reference intakes issued by the Food and Nutrition Board of the Institute of Medicine (NIH, 2021) and the USDA were also used for cases where EFSA did not give quantitative recommendations (see **Table 3.1**).

**Table 3.1. Recommended daily values of nutrients used for the calculation of the Nutrient Rich Diet Score (NRD9.3) based on a diet of 2228 kcal**

| Nutrient | Value | Source |
|---|---|---|
| Nutrient Rich Diet Score (NRD9.3) | | |
| Fiber | 25 g | (EFSA, 2021) |
| Protein | 51 g | (EFSA, 2021) |
| Vitamin A | 750-3000 µg | (EFSA, 2021) |
| Vitamin C | 102-2000 mg | (EFSA, 2021; NIH, 2021) |
| Vitamin E | 12-300 mg | (EFSA, 2021) |
| Calcium | 950-2500 mg | (EFSA, 2021) |
| Iron | 11-45 mg | (EFSA, 2021; NIH, 2021) |
| Potassium | 3500 mg | (EFSA, 2021) |
| Magnesium | 300 mg | (EFSA, 2021) |
| Sodium | 2 g | (EFSA, 2021) |
| Added sugars | 55.7 g (10% of total energy intake) | (EFSA, 2021; WHO, 2003) |
| Saturated fatty acids | 24.8 g (10% of total energy intake) | (EFSA, 2021; WHO, 2003) |
| Health Gain Score | | |
| Fruits and vegetables | 400 g | (WHO, 2003) |
| Fish | 37 g | (van Dooren et al., 2014) |
| Sodium Chloride | 6 g | (Turck et al., 2019) |
| Total fatty acids | 31.5% of total energy consumed | (EFSA, 2021; WHO, 2003) |
| Total carbohydrates | 52% of total energy consumed | (EFSA, 2021) |
| Free sugar | 10% of total energy consumed | (EFSA, 2021; WHO, 2003) |

Note: values refer to an average citizen

### 3.3.2 Health Gain Score

The Health Gain Score has also been proposed as a means of assessing overall diet quality and taking into account the potential health benefits of a balanced diet (Van Dooren et al., 2014). The score was calculated on the basis of ten nutritional indicators (fruits, vegetables, total fat, saturated fat, sodium, fibre, fish, carbohydrates, free sugar and total energy intake) related to diet-related diseases and established according to the recommendations of different health organisations.: WHO, World Cancer Research Fund (WCRF) and Dutch Health Council (DHC, 2020; WCRF, 2020; WHO, 2020a). A higher consumption of beneficial components such as fruits, vegetables, dietary fibre and fish, and a reduced consumption of presumed harmful components (SFA, sodium and free sugar), were associated with a lower risk of obesity, CVD and heart disease. The recommended nutrient intake targets for the ten indicators reported by the WHO, WCRF and EFSA (EFSA, 2017; WCRF, 2020; WHO, 2020a) were considered, as can be seen in **Eq. 3.5**.

$$Health\ index = \left(\frac{g\ veg}{200} + \frac{g\ fruit}{200} + \frac{g\ fish}{37} + \frac{g\ fiber}{30} + \frac{6}{g\ sodium} + \frac{31.5}{E\%\ total\ fat} + \frac{10}{E\%\ free\ sugar} + \frac{9}{E\%\ sat.fat} + \frac{52}{E\%\ carbohydrates} + \frac{2228}{kcal\ energy}\right) \cdot \frac{100}{10} \quad (3.5)$$

The reference energy was set at 2228 kcal, in accordance with the health recommendations established for an average Spanish adult (EFSA, 2017). With regard to the amount of fruit and vegetables, the WHO (2003b) recommends daily intake of more than 400 g. Therefore, 200 g of each has been used in the index. It should be noted that the category of tubers (e.g. potatoes) was not included in fruits and vegetables. For fish, the recommended intake is about 37 g per day (Van Dooren et al., 2014).

On the other hand, 25 g of fibre was considered adequate for normal laxation in adults (EFSA, 2010), while 6 g of sodium was proposed, which is in line with dietary guidelines for the general population (Turck et al., 2019). The WHO and EFSA recommend that no more than 31.5% of total energy intake should come from total fatty acids and that intake of free sugars (or added sugars) should be limited to 10% of total energy intake. In addition, EFSA recommends 260 g of carbohydrates per day, equivalent to 52% of total energy needs (for a 2000 kcal diet), and a reference intake of 20 g of SFA, equivalent to 9% of total energy needs. The Spanish Food Composition Database (BEDCA, 2017) was consulted to complete the nutritional composition of the raw foods that make up the diet.

## 3.4 INVESTIGATING THE ASSOCIATION BETWEEN DIET AND HEALTH OUTCOMES USING OBSERVATIONAL AND INTERVENTIONAL STUDIES

### 3.4.1 Cohort studies

NCDs, including CVD, cancer, chronic respiratory diseases, diabetes, obesity and cognitive impairment, are a major cause of global mortality and disability. These diseases affect populations in both developed and developing countries and represent a major global health challenge (WHO, 2023b). While genetics and environmental factors are recognized as contributing to the risk of NCDs, the influence of modifiable lifestyle factors at the individual level is substantial (Cena and Calder, 2020).

Dietary choices, such as the consumption of certain foods, contribute to the susceptibility of developing conditions such as hypertension, hypercholesterolemia, overweight/obesity and inflammation. These in turn increase the risk of diseases associated with significant morbidity and mortality, including CVD, diabetes and cancer (Koene et al., 2016). The remarkable increase in chronic NCDs is causally linked to the adoption of global dietary patterns that are

increasingly westernized (Cordain et al., 2005), characterised by high intakes of fatty and processed meats, saturated fats, refined grains, salt and sugar, and low intakes of fresh fruits and vegetables. It is therefore of paramount importance to investigate the relationship between dietary patterns and food choices and the major diseases associated with malnutrition in advanced societies.

Prospective cohort studies were found to be a useful method for conducting a health assessment. Cohort studies are observational epidemiological studies that follow a population over time to examine how certain diseases depend on changes in risk factors, such as food consumption or dietary patterns (Clark et al., 2019). The statistical models used in these studies are flexible enough to control for or eliminate the effects of possible confounding variables such as gender, age or smoking habits (Pourhoseingholi et al., 2012).

Two objectives were addressed in this thesis. The first was to estimate the percentage reduction in disease associated with a dietary pattern. On the other hand, the relationship between the foods present in the dietary patterns and the risk of disease using dose-response meta-analysis, as a dose-response meta-analysis of prospective cohort studies is a useful tool to investigate the possible dose-response relationship between a particular food category and a health outcome (Springmann et al., 2018b).

The association between a food category and a NCD in cohort studies is quantified by the relative risk (RR) of disease due to the consumption of one additional plate of food per day compared to the average intake in an observational study (Clark et al., 2019). If the RR is greater than 1, the health outcome is more likely to occur if an additional serving is consumed. If the RR is less than 1, the health outcome is less likely to occur if an additional serving is consumed. An RR of 1 means that there is no difference in the health outcome if an additional serving of a food is consumed or not (Tenny and Hoffman, 2023).

### 3.4.2 Randomised Controlled Trials of nutritional interventions

Randomised Controlled Trials (RCTs) are widely regarded as the gold standard for evaluating the effects of an intervention. In human nutrition, RCTs are considered the most reliable method for establishing a cause-effect relationship between the intake of nutrients, foods or dietary patterns and specific outcomes such as body composition, biomarkers or incidence rates (Lichtenstein et al., 2021). In a RCT, the study population is randomly divided into two groups: the intervention group and the control group. Participants in the intervention group receive the specified intervention, such as educational sessions, cooking classes, and foods characteristic of a regional diet, while those in the control group receive a control condition, such as continuing with their usual lifestyle (Twisk, 2021). There are guidelines for reporting RCTs, such as the CONSORT 2010 guidelines. Important methodological aspects should be considered in the design and conduct of RCTs, as shown in **Fig. 3.10**.

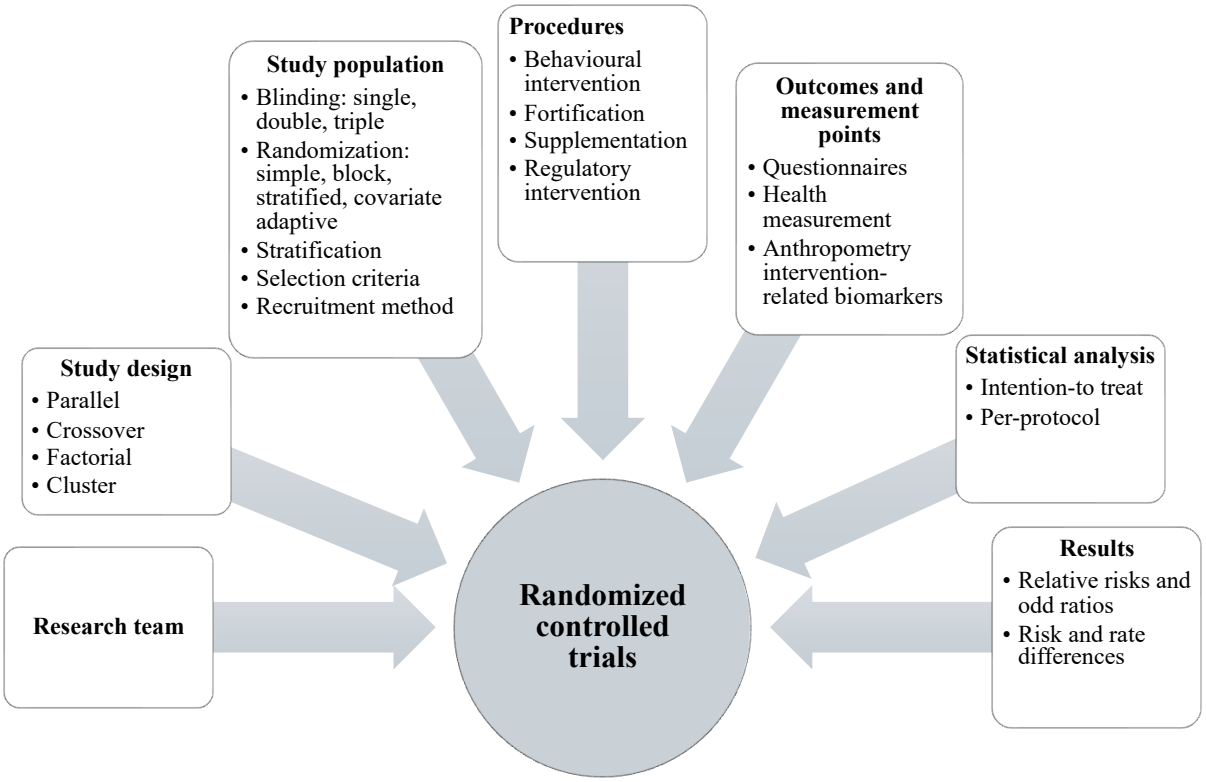


**Fig. 3.10. Major methodological aspects in a randomised controlled trials based on nutritional interventions.**

3.4.2.1 Gathering the research team.

RCTs typically require the involvement of a multidisciplinary team of clinical experts, experienced researchers, statisticians and investigators to address potential barriers to participation. For multicenter trials, it may be advisable it may be advisable to appoint a project coordinator to ensure consistent application of the standardized protocol (Houle, 2015).

3.4.2.2 Study design

The choice of study design for human nutrition RCTs is influenced by the aims and characteristics of the intervention. Common designs include parallel, crossover, factorial and cluster, each with its own strengths and weaknesses. In a parallel design, participants are randomly assigned to receive one intervention or the other. In a crossover design, participants receive treatments in a random or fixed order. In factorial designs, combinations of two or more interventions are randomly assigned to participants, allowing the evaluation of main effects and interactions. In cluster designs, interventions are randomly assigned to whole groups rather than individuals (Lichtenstein et al., 2021).

For a research question to be answered by an RCT, a hypothesis needs to be formulated. The hypothesis must be precise and should adhere to the PICOT framework. This implies that the components of a research question should include P (population of interest), I (Intervention to be assessed), C (comparator intervention), O (outcomes to be evaluated) and t (time duration for intervention/outcome ascertainment time).

Once the research question has been defined, the next step is to detail the target population, inclusion and exclusion criteria, randomisation process, allocation, blinding procedures, outcome assessment methods, sample size determination, ethical considerations, consent

process and data management. These elements are then consolidated into a well-defined protocol, which must be reviewed and approved by an independent ethics committee before the trial can begin (Bhide et al., 2018).

A RCT may be conducted at a single or at multiple sites. When a RCT is conducted according to a single protocol but involves multiple sites, it is known as a multicenter trial.

#### 3.4.2.3 Participants (or patients)

Investigators are required to provide a comprehensive description of the study population in their protocols, ensuring that it is consistent with the research objectives. Inclusion criteria describe the characteristics that individuals must have in order to be eligible to participate in the study. On the other hand, exclusion criteria identify the disqualifying factors that preclude a subject from participating. These criteria cover several different aspects, including age, gender, race, disease type and stage, treatment history, and the presence of medical or psychosocial conditions. Establishing these criteria serves to increase the reliability of results, reduce the risk of harm and protect vulnerable individuals from exploitation (Yale University, 2024).

Recruitment is a fundamental aspect of research and investigators must choose methods that are both feasible and appropriate to reach the target population. The most common methods include direct advertising, letters, telephone calls and face-to-face interviews (Yale University, 2024).

It is also necessary to specify the methodology used to collect sex/gender data, including whether self-report, genetic testing or other methods were used. It is also important to state whether participants provide written or verbal informed consent.

The strength of randomised trials lies in their design, which can reduce bias. The process of randomisation ensures that all participants receive the same treatment allocation, creating groups that are comparable except for the intervention they receive. To achieve this, randomisation plans are generated using random numbers assigned to individuals. While simple trials may use random number tables, larger trials often use computer programs, such as SAS, to perform randomisation to ensure fairness (Saxena et al., 2012). There are different types of randomisation such as simple randomisation, block randomisation, stratified randomisation and covariate adaptive randomisation. Simple randomisation, similar to flipping a coin, is appropriate for large samples but can lead to imbalance in smaller studies. Block randomisation maintains equal group sizes and is ideal for slower recruitment and small samples. Stratified randomisation takes into account factors that influence intervention response and ensures balanced groups. Covariate adaptive randomisation minimises differences between groups by taking into account subject characteristics (Martínez-López et al., 2022).

Pre-randomisation stratification aims to prevent imbalances in factors that may affect treatment outcomes, such as age, gender, and race. Blinding refers to the practice of maintaining the confidentiality of the assigned intervention to study participants, investigators (typically healthcare providers), and assessors (those responsible for collecting outcome data) to prevent undue influence. Blinding can be divided into three distinct categories (Houle, 2015):

- Single-blind trial: In single-blind trials, one category of individuals (participant, investigator or assessor) is unaware of the intervention assignments.
- Double-blind trials: In double-blind trials, both participants and investigators are kept unaware of intervention assignments.
- Triple-blind trial: These are typically an extension of double-blind studies that also maintain blinded data analysis.

A robust RCT must use allocation concealment, which involves separating the act of randomisation from the person responsible for recruiting participants. Effective methods include a sealed opaque envelope system, remote randomisation via a centralized telephone system, or remote randomisation via the Internet (Clark et al., 2016).

#### 3.4.2.4 Procedures

The following section outlines the procedures in question, providing details of the intervention (type, method of delivery, duration, follow-up intervals, and assessments made at each visit). In this case, we focus on nutritional interventions. A nutrition intervention is defined as a set of interventions designed to change a nutritional aspect of an individual or a population. Nutrition interventions cover a wide range of activities, from the administration of nutrients to the implementation of a nutrition education program. WHO classifies these interventions into four different types (Martínez-López et al., 2022):

- Behavioural interventions: These modify eating habits.
- Fortification: this involves the addition of nutrients to basic foods.
- Supplementation: this entails the administration of specific nutrients to targeted populations.
- Regulatory interventions: these regulate activities to improve nutrition and health.

#### 3.4.2.5 Outcomes and measurement time points

In nutrition RCTs, the primary outcome is the main measure used to assess the effectiveness of the intervention, while the secondary outcomes provide complementary information. For example, in the nutrition intervention developed in **Chapter 7**, the primary outcomes were the CF as an environmental metric calculated using LCA and the incidence of MetS.

MetS was defined according to criteria from the National Cholesterol Education Program Adult Treatment Panel III (ATP III) guidelines (see **Fig. 3.11)**. The prevalence of diseases associated with MetS has a significant impact on mortality and morbidity, well-being and per capita public health expenditure worldwide (Jamali et al., 2024). At a global level, the epidemic proportion of MetS has been estimated to be between 20 and 25%, with a range of 12 to 26% observed in the European population (Manaf et al., 2021). Lifestyle modification, particularly dietary habits, is the primary therapeutic strategy for the treatment and management of MetS (Castro-Barquero et al., 2020).

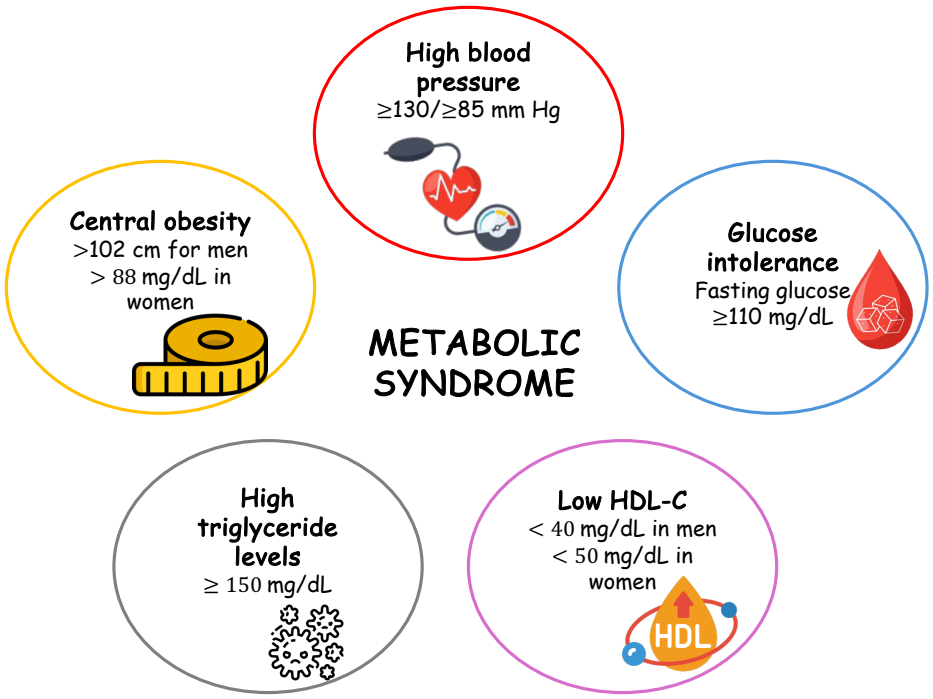


**Fig. 3.11. Definition of metabolic syndrome according to the National Cholesterol Education Program Adult Treatment Panel III**

Human nutrition RCTs often use questionnaires, health measurements, anthropometry, and intervention-related biomarkers as determined by the study-specific objectives. Questionnaires are an essential component of human nutrition RCTs, serving as a conduit for data collection through self-administered paper or electronic instruments or interviewer-administered protocols. Baseline questionnaires are used to record the characteristics of participants, including their demographic details, health history, medication use, and lifestyle habits. This includes data on tobacco and alcohol use, dietary patterns, and physical activity levels, which are critical for estimating energy needs. During the intervention period, questionnaires are used to monitor adherence, tolerability, and other factors that may affect study results, such as illness, travel, or medication changes (Lichtenstein et al., 2021).

It is of utmost importance to identify appropriate anthropometric characteristics, biomarkers and outcomes at baseline, during and at the end of a human nutrition RCT. These may include, but are not limited to, height, body weight, BMI, serum cholesterol, glucose, insulin concentrations, or blood pressure. Standardized procedures should provide guidance on the equipment, collection, aliquoting, and storage conditions for these measures (Lichtenstein et al., 2021; Schulz, et al. 2010).

3.4.2.6 Statistical analysis

It is important to conduct a trial with a large enough sample size and sufficient power to draw robust conclusions that can be applied to the larger population. Sample size is particularly important in superiority trials, where the aim is to detect clinically significant differences between the intervention and placebo groups. It is influenced by a number of factors, including effect size. It is of the utmost importance to carefully consider the baseline outcome rates and the expected benefit of the intervention to avoid under- or overestimation. It is also important to define the acceptable levels of type 1 and type 2 error (Bhide et al., 2018).

In RCTs significant differences in primary outcomes between groups are indicative of intervention effectiveness. This is typically determined by a p-value < 0.05, which indicates a low likelihood of chance. The type 1 error, which is conventionally fixed at 0.05, refers to the erroneous conclusion of a difference when none exists. The conventional power setting is 0.8 to 0.95, which reflects the likelihood of detecting a true difference (type 2 error, typically set at 0.2 to 0.05). These values serve as a guide for sample size calculation. For proportion-based effects, these values are sufficient; however, for continuous variables, additional information is required, including the mean, standard deviation, and error values (Bhide et al., 2018).

The standard method for estimating treatment effects in an RCT is an intention-to-treat analysis. In this approach, all participants assigned to the intervention group are considered to have received the intervention, regardless of whether they completed all, part, or none of the intervention. The analysis ignores protocol deviations, noncompliance, dropouts, and any subsequent events that occur after randomisation (Andrade, 2022). Missing data handling in the primary analysis typically includes complete case analysis, available case methods, model-based methods, and imputation methods (fixed value imputation and multiple imputation) (Jakobsen et al., 2017). In a per-protocol analysis, participants are included only if they received and completed the intended treatment according to the protocol. This type of analysis often overestimates the impact of the outcome of interest (Andrade, 2022)

Selecting an appropriate statistical method to test differences between groups in RCTs is crucial, primarily determined by the type of dependent variable and context. Commonly employed tests include t-test, analysis of variance (ANOVA), non-parametric tests, chi-square, and post-hoc analyses (Lee, 2022).

- T-test: Independent samples t-test is a statistical procedure used to determine whether the means of two independent groups are significantly different. This test assumes that the data are normally distributed and that the variances of the two groups are equal (homogeneity of variance). The paired samples t-test is used when comparing means from the same group at different times (e.g., before and after treatment) or between matched groups.
- ANOVA: One-way ANOVA is a statistical technique used to determine whether the means of three or more independent groups differ on the basis of a single factor. The assumptions underlying one-way ANOVA include normality of the data, homogeneity of variance, and independence of observations. Two-way ANOVA extends one-way ANOVA to include two independent variables, allowing the examination of interaction effects between the factors.
- Non-parametric tests: The Mann-Whitney U test is an alternative to the independent-samples t-test for comparing two independent groups when the data do not meet the parametric assumptions. The Wilcoxon Signed Rank Test is an alternative to the paired samples t-test for comparing two related groups. The Kruskal-Wallis H test is an alternative to one-way ANOVA for comparing three or more independent groups.
- Chi-square test: The test is used to assess the association between categorical variables. The test evaluates whether the observed frequencies in each category are significantly different from the expected frequencies.
- Post-hoc analyses: Conducted after an ANOVA when significant differences are found, to determine which specific groups differ from each other. Common post-hoc tests include Tukey's HSD, Bonferroni correction, and Scheffé's method.

In the context of clustered RCTs, it is important to consider specific design, analysis, and reporting considerations. Due to the tendency for individuals within a cluster to be more similar to each other, clustered RCTs are statistically less efficient than non-clustered RCTs. The

intraclass correlation (ICC) is a statistical measure that quantifies the proportion of total variance that is due to clustering. The ICC ranges from 0 to 1, with values closer to 0 indicating less similarity among individuals within clusters and values closer to 1 indicating greater similarity. In RCTs with clustering, the ICC typically falls between 0.001 and 0.05. Although these values may seem modest, they can have a profound effect on statistical power and Type I error rates. Failure to account for ICCs in sample size calculations can lead to underpowered designs, while failure to account for ICCs in the analysis phase can lead to inflated Type I error rates, also known as anticonservative testing or increased false-positive results (Brown et al., 2015).

To account for the influence of ICCs, two types of statistical models are commonly used to analyse individual-level data in cluster RCTs. These are: 1) conditional or subject-specific models, also called mixed-effects models, and 2) marginal or population-averaged models. These models differ in their approach to handling within-cluster correlations and in the interpretation of treatment effect estimates. Marginal models estimate the average treatment effect across the population, whereas conditional models provide cluster-specific estimates. For large numbers of clusters, both models yield similar results. Cluster-level and individual-level covariates, such as baseline measures, can be included in either model. It is advisable to adjust for baseline covariates that are expected to correlate significantly with the outcome, which should be decided a priori. A sufficiently large number of clusters or parametric assumptions must be met to obtain valid confounding. It is important to note that special considerations are needed with a small number of clusters (less than 10), as not all methods perform well under such conditions (Brown et al., 2015).

#### 3.4.2.7 Effect Measures and Precision in RCTs

The most informative way to report the results of RCTs is to provide an estimate of the effect measure, accompanied by a quantified description of its precision. Effect measures include absolute effect measures (such as rate or risk difference), relative or proportional effect measures (such as rate ratio, risk ratio), and odds ratios. The number needed to treat is the inverse of the absolute risk. On the other hand, common measures of precision include the confidence interval and the standard error (Stang and Rothman, 2023).

Relative risks (RR) and odds ratios (OR) are simply the risks or odds, respectively, of an outcome in one group divided by the risk or odds of the outcome in another group (**Eq. 3.6**).

$$Relative\ risk = (Risk\ of\ disease\ in\ exposure\ or\ intervention\ group) \\ /(Risk\ of\ disease\ in\ the\ nonexposed\ or\ control\ group) \tag{3.6}$$

The interpretation of the RR and OR is similar. A RR or OR of 1 indicates that there is no difference in risk or odds between the two groups. A RR or OR greater than 1 suggests that the exposed or intervention group is at an increased risk or odds compared to the non-exposed or control group. Conversely, a RR or OR less than 1 indicates that the exposed or intervention group is at a decreased risk, or odds compared to the non-exposed or control group.

Although the RR incorporates the risk ratio and rate ratio, there are notable distinctions between the two. The risk ratio is calculated as the cumulative incidence of the outcome in the exposed group divided by the cumulative incidence of the outcome in the non-exposed group. Similarly, a rate ratio compares the incidence rate of the outcome between groups, rather than the cumulative incidence (Monaghan et al., 2021).

The term “risk difference” is indicative of the difference in probability of an outcome between different study groups (**Eq. 3.7**)

$$Risk\ difference = (Risk\ of\ disease\ in\ exposure\ group) - (Risk\ of\ disease\ in\ the\ nonexposed\ group) \quad (3.7)$$

In contrast, rate difference is analogous to risk difference but is expressed in terms of time and focuses on incidence rates rather than cumulative incidence. Essentially, rate difference is calculated by determining the number of exposed individuals who develop the condition per unit of time, and then subtracting the number of unexposed individuals who develop the condition per unit of time (Monaghan et al., 2021).

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## 3.5 THE POTENTIAL OF CLUSTER ANALYSIS TO SHAPE SUSTAINABLE DIETARY CHOICES

Cluster analysis is a set of statistical classification techniques that divide cases into groups (clusters) according to some measure of similarity. The aim is to ensure that cases within a group are similar (or related) to each other and different (or unrelated) to cases in other groups (Ezugwu et al., 2022)

Cluster analysis has a wide range of applications in fields as diverse as market research, astronomy, psychiatry, weather classification, archaeology and bioinformatics. In market research, cluster analysis enables segmentation of customers based on their preferences and financial characteristics, facilitating targeted marketing. In astronomy, cluster analysis is used to classify astronomical objects, leading to discoveries such as high-redshift quasars. In psychiatry, it is used to refine diagnostic categories, identifying subtypes of depression and classifying people who attempt suicide. Weather classification benefits from cluster analysis when exploring large data sets for insights into climatological trends. Archaeology uses the method to classify artefacts, revealing information about historical uses and populations. In bioinformatics and genetics, cluster analysis plays a key role in elucidating gene expression patterns in high-dimensional data, contributing to advances in disease research and gene identification (Tan et al., 2018).

Cluster analysis has also proven to be a valuable tool for organizing complex datasets within the food sector. It is also an important tool in promoting food sustainability by addressing key aspects of the food supply chain. In the context of supply chain optimisation, it facilitates the categorisation of food suppliers based on sustainability criteria, enabling the selection of partners in line with ethical and environmental objectives. Cluster analysis in logistics is a valuable tool for optimising routes, reducing food miles and environmental impact (Mavi et al., 2023). Assessing environmental impacts, particularly through LCA, enables targeted efforts to reduce the overall environmental footprint of specific food products (Braun et al., 2022). In addition, clustering of consumer segments based on preferences and waste patterns enables companies to tailor marketing strategies and interventions for sustainable consumption (Durga et al., 2023). Certification compliance assessment and benchmarking practices also help improve industry standards, while policy impact and risk assessments support informed decision-making for a more holistic and resilient food system that balances environmental, social and economic indicators.

Researchers use a variety of clustering models, as illustrated in **Fig. 3.12**: i) connectivity models, ii) centroid models, iii) distribution models, iv) density models. The following sections provides a detailed description of each of the aforementioned models.

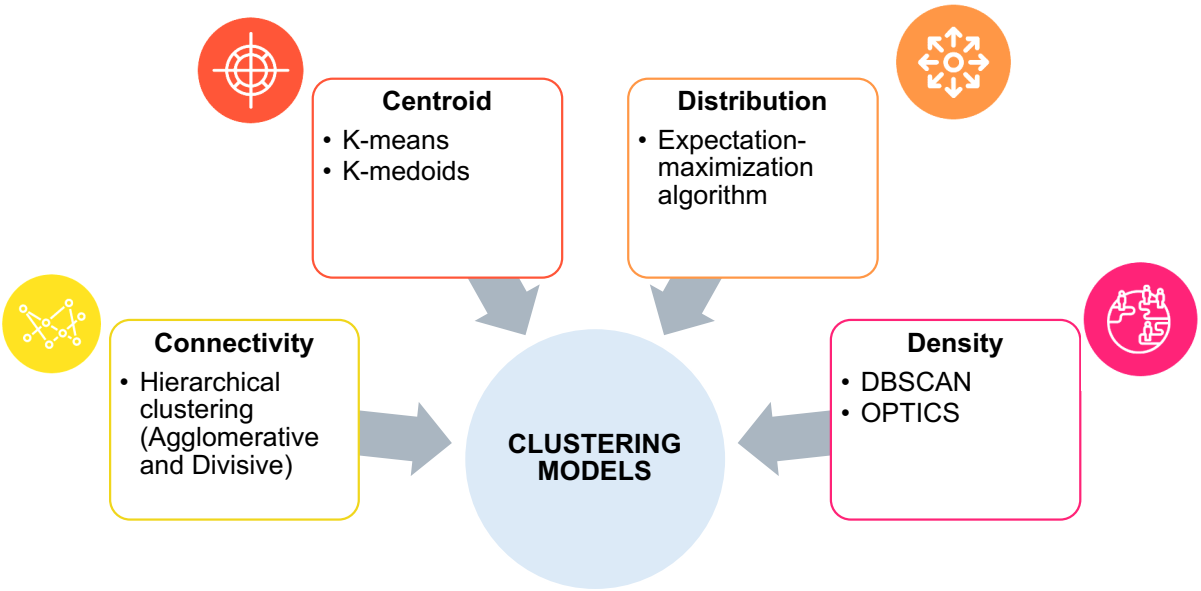


**Fig. 3.12. Clustering models**

### 3.5.1 Connectivity model

The connectivity model is used in hierarchical clustering, resulting in the generation of a cluster tree, which is often a binary tree. In this configuration, each higher-level cluster includes the clusters positioned at lower levels within the branches of the tree. This clustering methodology can be implemented in two different ways: an agglomerative approach, which starts with individual data points as discrete clusters that are subsequently merged into larger entities, and a divisive approach, which starts with all data points consolidated into a single cluster that is subsequently partitioned into smaller, distinct clusters (Aggarwal and Reddy, 2014).

The resulting tree is presented as a dendrogram. In the final phase, the tree is effectively segmented or "cut" at a designated level, a determination made either by the user or by an additional analysis of distances between clusters. This segmentation creates subtrees, each representing distinct clusters within the hierarchical structure (Novoselsky and Kagan, 2021).

During clustering the distances between the clusters are calculated using different methods such as complete linkage (uses the maximum distance between two elements within clusters), single linkage (relies on the distance between the closest pair of elements from the clusters) or average linkage (the distance between two clusters is calculated as the average distance between all pairs of subjects in the two clusters) (Jarman, 2020)

Hierarchical clustering has several advantages. One of the main advantages is that this method does not require the exact number of clusters to be specified in advance. In addition, comparing solutions with different numbers of clusters does not require the clustering procedure to be repeated. However, hierarchical clustering also has drawbacks. It is sensitive to outliers. This sensitivity can lead to the generation of additional clusters and the merging of disparate groups of entities into a single cluster. In addition, the phenomenon of chaining can occur, where adjacent clusters are linked together. This phenomenon is particularly prevalent in single linkage (Kashyap and Mishra, 2022).

### 3.5.2 Centroid model

Centroid-based clustering is a method of partitioning data that starts by identifying certain objects, called centroids, and then assigns each remaining object to its nearest centroid. The centroids can be either fictitious objects, as in the k-means method (MacQueen J.B., 1967), or real ones, as in the K-medoids method (Kaufman and Rouseeuw, 2009).

In the k-means method, the user specifies the desired number of clusters, denoted as k. The initial cluster positions are then assigned either randomly or through an algorithmic approach. In the next stage, the k-means algorithm proceeds through two iterations. In the first iteration, entities are assigned to their nearest cluster and in the second iteration, the cluster centre is updated based on the assigned entities. The iterative process aims to minimise the sum of the distances from each entity to its respective cluster centre. As a result, intra-cluster distances are minimised, promoting cohesion within clusters, while the sum of inter-cluster distances is maximised, ensuring clear separation between clusters (Novoselsky and Kagan, 2021).

The k-medoids algorithm differs from the k-means algorithm in that it determines the cluster center through the minimisation of distances from entities to the median location within the assigned cluster, rather than the mean location. Using the median increases the robustness of the algorithm to outliers compared to the k-means algorithm (Mirantika and Rijanto, 2023).

### 3.5.3 Distribution model

The distribution model considers a predefined set of entities as observations drawn from a mixture of probability distributions. In this model, a cluster is defined as a group of entities drawn from the same underlying distribution. Gaussian Mixture Models assume that entities are drawn from a mixture of multivariate normal distributions. The process of clustering in Gaussian Mixture Models is performed by an iterative expectation maximisation algorithm (Novoselsky and Kagan, 2021).

### 3.5.4 Density model

Density-based clustering is an unsupervised learning technique that identifies unique groups or clusters within data (Das et al., 2024). This method is based on the assumption that a cluster in a data space can be identified as a contiguous region of high point density that is distinguished from other clusters by adjacent regions of low point density. The data points within these low-density regions are commonly considered to be noise or outliers (Sander, 2011). The most popular method of clustering using this model is DBSCAN, which first assesses the density of entities within a defined neighbourhood of each entity. Based on this assessment, the algorithm distinguishes between core, boundary and noise points. The algorithm then proceeds to group the core points into clusters and the boundary points into these clusters (Ma et al., 2023).

### 3.5.5 How to choose the appropriate clustering algorithm?

Selecting the most appropriate method is not a straightforward task. It often requires experimental consideration based on the characteristics of the data being analysed. To increase the robustness of the results, it is possible to implement some pre-processing approaches before initiating the clustering process (Novoselsky and Kagan, 2021).

- Graphical representation of data (histograms, two-dimensional and three-dimensional scatter plots).

- Normalization of data, for instance, using the standard score (z-score). This method adjusts the input data by subtracting the mean from the input values and dividing the resulting difference by the standard deviation.
- Removal of outliers, which is significant due to the sensitivity of clustering methods to outliers.
- Eliminating highly correlated variables.

In **Chapter 8**, hierarchical clustering was selected as the most appropriate method for our purposes due to its ability to create clusters at different levels of detail and its flexibility in handling different types of data. It offers several advantages such as the flexibility to generate clusters at different levels and does not require a predetermined number of clusters. However, it can be computationally expensive and may not always produce optimal results (Brown et al., 2020). Many clustering methods are available in freely distributed and commercial mathematical software packages such as MATLAB, Mathematica, Octave-Forge, R, SAS/STAT, or SPSS Statistics.

# SECTION II

## SUSTAINABLE AND HEALTHY FOOD-BASED DIETARY GUIDELINES AROUND THE WORLD

# 4. NOURISHING PEOPLE, CARING FOR THE PLANET: EVALUATING THE SUSTAINABILITY OF AMERICAN AND EUROPEAN DIETARY GUIDELINES[1]

Diet and nutrition are essential factors in promoting good health throughout life. Their role as determinants of chronic non-communicable diseases is widely recognized. In addition, food demand is associated with relevant environmental burdens that need to be taken into account in the pursuit of the Sustainable Development Goals. As an important part of nutrition policy, food-based dietary guidelines have been revised. The key question is: Are environmental considerations being incorporated into them? To address this issue, this chapter models and compares both the main environmental indicators in terms of carbon footprint and water footprint, and nutritional quality (according to the Nutrient Rich Diet 9.3 and a Health Gain Score) of dietary guidelines from Northern and Southern Europe and America. Particularly, the food-based dietary guidelines compared were the Dutch Dietary Guidelines, the New Nordic Diet, the Spanish Strategy for Nutrition, Physical Activity and Obesity Prevention, the Mediterranean Diet, the Italian Dietary Guidelines, and the American Dietary Guidelines.

The Italian Dietary Guidelines and the Mediterranean Diet offered the best profiles from a climate change perspective (2.04 and 2.21 kg $CO_2$eq·day$^{-1}$). Overall, the American Dietary Guidelines had the highest CF (2.98 kg$CO_2$eq·day$^{-1}$). WF showed greater variation, not only because of the recommended daily amounts, but also because of the different climatic conditions and production systems of the reference countries. Hence, water footprint ranged from 1760 L·person$^{-1}$·day$^{-1}$ in Italian Dietary Guidelines to 3181 L·person$^{-1}$·day$^{-1}$ in the Spanish Strategy for Nutrition, Physical Activity and Obesity Prevention. Finally, the nutritional value of Mediterranean Diet, which had the highest Nutrient Rich Diet 9.3 score (477) and Health Gain Score (178), was demonstrated when compared with Dutch Dietary Guidelines, which had the lowest Health Gain Score (97), and American Dietary Guidelines, which was the worst in terms of NRD9.3 (391).

In order to move beyond food-based dietary guidelines that advocate comprehensive sustainability, it is essential to prioritise the inclusion of environmental sustainability dimensions into nutrition guidelines.

[1] Cambeses-Franco, C., González-García, S., Feijoo, G., Moreira, M. T., 2022. Driving commitment to sustainable food policies within the framework of American and European dietary guidelines. Science of The Total Environment, 807, 150894. https://doi.org/10.1016/j.scitotenv.2021.15089

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## 4.1 INTRODUCTION

A substantial body of scientific evidence shows that adopting a balanced diet that is both healthy and environmentally sustainable is a cost-effective and prudent decision (Springmann et al., 2021). The FOOD 2030 initiative, which is aligned with the European Green Deal, the Farm to Fork Strategy and the Bioeconomy Strategy, is committed to facilitating this transition. It aims to encourage the adoption of sustainable and healthy diets, to promote circularity and resource efficiency, to foster innovation and to empower communities (Björkbom, 2023).

FOOD 2030 highlights the development of FBDGs for healthy, balanced and sustainable diets as a driver for change (European Commission, 2020c). FBDGs are an attempt to provide a framework for food and nutrition services, public health, agricultural policies and consumer education to promote healthy eating habits and control diet-related diseases (FAO, 2021b). For instance, the Linee guida per una sana alimentazione (CREA, 2019) in Italy, the DDG (Health Council, 2015) in the Netherlands or the NAOS strategy in Spain (Neira and de Onis, 2006), support consumers in making better food choices, taking into account their cultural preferences, eating habits, and food availability. In the United States, as in European countries, the Department of Health and Human Services (HHS) and the Department of Agriculture (USDA) jointly published the Dietary Guidelines for Americans (DGA), which have been updated since their first publication in 1980. In addition to the goal of promoting good health and preventing chronic disease, the latest edition, for the first time, identifies nutritional needs for all stages of life, from childhood to old age (USDA and HHS, 2020).

### 4.1.1 Dietary Guidelines for Americans 2020-2025

The National Nutrition and Related Research Surveillance Act 1190, the USDA and the HHS require the publication of the DGA at least every five years. The 2020-2025 edition builds on the 2015 edition but incorporates new aspects in parallel with evolving scientific and medical knowledge. For example, the DGA address the general public regardless of health status; emphasize the importance of a healthy diet as a whole, rather than individual foods or nutrients; and identify dietary needs from a life-cycle perspective. According to this latest version, a healthy dietary pattern is based on nutrient-dense foods and beverages from all food groups, including core elements such as vegetables of all types, fruits, grains, dairy products, protein foods and oils.

### 4.1.2 Dutch Dietary Guidelines 2015

The Dutch Health Council periodically publishes the DDG, which are the product of nutritional research on the relationship between diet and health benefits. The first version of the dietary guidelines was published in 1986 and provided advice on nutrients only. Food recommendations were included in the second version in 2006. The third comprehensive assessment was published in 2015. This latest report also reflects scientific developments on dietary patterns available to consumers (Health Council, 2015). These guidelines emphasize: eat more plant-based foods and less animal-based foods; include fruits, vegetables, whole-grain bread, nuts, a few servings of dairy products and three cups of tea in the daily diet; consume legumes and fish weekly; promote whole-grain products and liquid cooking fats and vegetable oils; limit consumption of red meat, sugary drinks, salt and alcohol.

### 4.1.3 Italian Dietary Guidelines 2018 (Linee guida per una sana alimentazione)

For more than three decades, Italian consumers have been provided with guidelines for a healthy diet (the first edition was published in 1986). The IDG summarize technical-scientific information focused on the food sector and practical recommendations for adults to make their

daily diet as balanced and varied as possible. The latest edition of the Council for Agricultural Research and Economics (CREA), under the auspices of the Ministry of Agriculture, Food and Forestry, was published in 2018 (CREA, 2019). Its principles are to be active and maintain a healthy weight; consume more fresh fruits and vegetables daily; consume bread, pasta, rice, and other grains (preferably whole grains) regularly; consume plenty of water daily; moderate the amount of fats and oils used for seasoning and cooking; and limit the consumption of sugary foods, salt, and alcoholic beverages.

#### 4.1.4 New Nordic Diet

Inspired by the MD, the NND was developed in 2004 within the Danish project OPUS (Optimal well-being, Development and Health for Danish children through a healthy NND) under the principles of health, gastronomic potential, Nordic identity and sustainability (Meltzer et al., 2019). The NND is a heuristic concept that combines the FBDGs from the five Nordic countries that collaborated on the long-term Nordic Nutrition Recommendations with typical products from the Nordic regions (Meltzer et al., 2019). Mithril et al. (2013) outline their basic guidelines: i) more calories from plant foods and fewer from meat; ii) more food from the sea and lakes; iii) more food from the wild countryside.

#### 4.1.5 Strategy for Nutrition, Physical Activity and the prevention of obesity in Spain

The NAOS strategy in line with the policies of the WHO and the European Union, is a public health strategy to reverse the trend in the prevalence of obesity. It was launched in 2005 and consolidated in 2011 by Law 17/2011 on Food Safety and Nutrition. Its motto is based on the following statement Eat healthy and move. In the latest update of the dietary recommendations for the Spanish population, the AESAN included both human health and planetary sustainability (Neira and de Onis, 2006).

#### 4.1.6 Mediterranean Diet

The MD is a traditional plant-based diet typical of the olive-growing regions of the Mediterranean basin (Trichopoulou and Vasilopoulou, 2016), including France, Greece, Italy and Spain. It has been recognized as an intangible cultural heritage by the UNESCO and as a healthy and nutritious diet by the FAO due to its proven health benefits (Zupo et al., 2023). It has been associated with the prevention of a variety of diseases, such as cardiovascular (Martínez-González et al., 2019), neurodegenerative (Gardener and Caunca, 2018), inflammatory diseases (Tsigalou et al., 2020), MetS (Dayi and Ozgoren, 2022) and cancer (Monllor-Tormos et al., 2023).

#### 4.1.7 Environmental aspects of food-based dietary guidelines

Despite the growing body of data, only 95 countries have issued dietary recommendations, which mainly focus on the health dimension (James-Martin et al., 2022). Consequently, research on the extent to which environmental issues are incorporated into national FBDGs is of great interest (Herforth et al., 2019; Springmann et al., 2020).

To date, few studies have quantified the environmental burdens of different FBDGs worldwide, with a particular focus on GHG emissions. For instance, Kovacs et al. (2021) modeled the CF of the dietary guidelines from Germany, India, the Netherlands, Oman, Thailand, Uruguay and the United States. Another study compared 37 dietary recommendations from middle- to high-income countries in terms of GHG emissions, eutrophication and LU (Behrens et al., 2017).

However, it is pertinent to identify other environmental metrics, that have not been extensively studied for national-level FBDGs, such as water consumption, following the initial path marked by other authors who included the analysis of WF related to food consumption. In this line, Blas et al. (2016) evaluated the WF of two one-week menus based on an earlier version of the American guidelines (USDA, 2016b) and on the study by Haven et al. (2014). In a subsequent study, Vanham et al. (2018) identified geographical differences between the water consumption values of the French, German and United Kingdom dietary recommendations. González-García et al. (2020b) additionally evaluated, among other metrics, the WF of the NAOS, MD and the Atlantic diets.

On the other hand, it is necessary to calculate the CF of the most updated versions of the dietary guidelines, as was done for the previous versions. van Dooren et al. (2014) examined the GHG and LU of the 2006 version of the recommended DDG (Health Council, 2006). Similarly, Pairotti et al. (2015) explored the energy consumption and GHG emission of the MD in the Italian scenario (Ministero della Salute, 2004).

Moreover, although the identification of synergies between the nutritional, health and environmental outcomes of the European and American guidelines is central to the progress of the Millennium Development Goals, the SDGs and the Decade of Action on Nutrition (Willett et al., 2019b), it has not yet been fully developed in the scientific literature. In order to incorporate nutritional and health information, it is necessary to utilize appropriate metrics such as the NRD9.3 (Van Kernebeek et al., 2014) or the Health Gain Score (van Dooren et al., 2014).

The aim of this chapter is to analyse for the first time the CF and WF and the nutritional aspects (in terms of two nutritional indices, NRD9.3 and a health index) of the FBDGs of three representative regions: Northern Europe, Southern Europe and North America. For a broader perspective, several representative dietary guidelines from these geographical areas have been selected: the DDG 2015, the IDG 2016 revision, the DGA 2020-2025, the NAOS strategy in Spain, the NND and the MD. This analysis can be considered a step forward in the development of dietary guidelines that incorporate health and sustainability aspects and meet the nutritional needs of consumers.

## 4.2 Materials and methods

### 4.2.1 Scope of the food-based dietary guidelines

The scope of this research focuses on the Western world, where the modern Western dietary pattern has recently gained much popularity, increasing the incidence of obesity, CVD, cancer, or MetS among the population, while threatening the health of the planet. America and Europe were the two geographical regions chosen as the study framework. For convenience, we divided the European dietary guidelines into two sub-regions: Northern Europe and Southern Europe. Countries classified as Western Europe according to the United Nations Geoscheme Classification, such as the Netherlands, were included in the Northern Europe region in this study.

### 4.2.2 Dietary scenarios designed and trade statistics

4.2.2.1 Dietary Guidelines for Americans 2020-2025

The nutritional goals and amounts of each food group considered in this study are based on the most recent edition of DGA (USDA and HHS, 2020), published in 2020. The United States was chosen as the reference country. For each food group, only the most consumed foodstuffs in America were considered, according to the most recent food availability data provided by the USDA ERS (2020). The design of the fish and seafood category was based on information given by the National Oceanic and Atmospheric Administration (NOAA, 2020).

Further details on the technical description of the dietary scenario can be found in **Tables 4.1-4.12.**

For information on total exports and imports by country or region, data from the Economic Research Service of the USDA were used (USDA, 2019). The leading importing countries with a representative percentage of the total import volume above 70% were considered for the weighted import calculations in the WF assessment. FAO (2019) provided free access to food and agriculture production data.

4.2.2.2 Dutch Dietary Guidelines 2015

The Dutch dietary scenario was based on the DDG 2015 (Health Council, 2015). However, the recommendations are broad and qualitative, and in many cases, they do not specify quantities ("eat legumes weekly", "limit consumption of red meat, in particular processed meat"). To provide consistent and practical advice to consumers, Brink et al. (2019) developed a key food counselling model with practical advice on daily quantities of food groups. Their optimisation model, based on expert judgment, has been considered in this chapter. A comprehensive presentation of the recommended average daily intakes per food group and food was presented in **Tables 4.1-4.11**.

On the other hand, the Dutch National Food Consumption Survey 2012-2016 (RIVM, 2020), the import and export information of the European fruit and vegetables business (GmbH, 2019) and the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA, 2018) were consulted in order to establish the specific amount of each foodstuff (in mass units) for the different food categories.

For the WF assessment, the open-access multidimensional Datacomex platform, which includes information on the volume of imports and exports per food product and country, was used as a source of information (Ministerio de Economia, 2019). The data management process was carried out with reference to the year 2019. The list of suppliers was expanded to include all those that supply more than 70% of the total volume of imports. FAO (2019) was used as the principal source of statistical data on production.

4.2.2.3 Italian Dietary Guidelines 2018 (Linee guida per una sana alimentazione)

The Italian case study was based on the 2018 revision of the IDG for Healthy Eating (Line Guida per una sana alimentazione). The 2018 IDG provided detailed information about the amount of each foodstuff in grams that constitutes each food category (CREA, 2019). Further details on the design of the Italian case study can be found in **Tables 4.1-4.11**.

Nevertheless, supplementary sources of information were required to design the dietary scenario. The export and import information of the European Statistics Handbook (GmbH, 2019), the meat production statistics (EUROSTAT), the Tree Nuts Annual Report (USDA, 2016a) and the EU Fish Market Report (EUMOFA, 2019) were considered as a basis for establishing the recommended daily intake of each raw food per food category. Finally, trade information from the Datacomex platform (Ministerio de Economia, 2019) was used, with the same considerations as for the Dutch dietary scenario. The data production was primarily sourced from the FAO (2019).

4.2.2.4 New Nordic Diet

The NND scenario was developed with reference to the fundamental principles set out by Mithril et al. (2012) and Ulaszewska et al. (2017). **Table 4.12** shows the average daily recommended intakes and the CF per food for the NND.

#### 4.2.2.5 Strategy for Nutrition, Physical Activity and the prevention of obesity in Spain

The NAOS strategy is a health strategy in line with the policies set out by international health organisations (WHO, European Union, etc.). The detailed case study considered for NAOS regarding the average daily recommended intake for each country was taken from González-García et al. (2020b).

#### 4.2.2.6 Mediterranean Diet

The detailed scenario for MD was taken from González-García et al. (2020b).

**Table 4.1. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff. Fruits.**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Fruits | ($g \cdot person^{-1} \cdot day^{-1}$) | | | ($kgCO_2eq \cdot kg^{-1}$) | |
| Oranges | 111.7 | 23.7 | 130.6 | 0.15 | (Aguilera et al., 2015a) |
| Bananas | 49.2 | 38.7 | 49.9 | 0.64 | (Aguilera et al., 2015a) |
| Apples | 59.1 | 75.3 | 79.3 | 0.12 | (Aguilera et al., 2015a) |
| Watermelon | 29.2 | - | - | 0.32 | (Clune et al., 2017) |
| Grapes | 22.3 | 12.9 | 24.1 | 0.06 | (Aguilera et al., 2015a) |
| Pineapple | 26.3 | - | 10.7 | 0.95 | (West Africa Fair Fruit, 2011) |
| Lemon | 25.5 | - | 5.4 | 0.15 | (Aguilera et al., 2015a) |
| Mandarin | - | 17.2 | 47.1 | 0.15 | (Aguilera et al., 2015a) |
| Pear | - | 19.4 | 26.5 | 0.12 | (Aguilera et al., 2015a) |
| Strawberry | - | 12.9 | - | 0.33 | (Gunady et al., 2012) |
| Nectarine | - | - | 39.3 | 0.43 | (Audsley et al., 2009) |
| Peach | - | - | 33.1 | 0.12 | (Aguilera et al., 2015a) |
| Kiwifruit | - | - | 4.1 | 0.83 | (Zeus, 2012) |
| Total | 323.3 | 200.0 | 450.0 | | |

**Table 4.2. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Vegetables**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Vegetables | (g·person$^{-1}$·day$^{-1}$) | | | (kg$CO_2$eq·kg$^{-1}$) | |
| Lettuce | 24.6 | 23.1 | 43.1 | 0.23 | (Aguilera et al., 2015b) |
| Broccoli | 7.7 | - | - | 1.94 | (Audsley et al., 2009) |
| Tomato | 120.5 | 47.9 | 116.7 | 0.22 | (Aguilera et al., 2015b) |
| Carrot | 16.1 | 22.9 | 46.3 | 0.20 | (Nemecek et al., 2012) |
| Sweet potato | 7.9 | - | - | 0.30 | (Heller et al., 2018) |
| Pumpkin | 5.1 | - | - | 0.20 | (Aguilera et al., 2015b) |
| Onion | 32.9 | 8.4 | 39.1 | 0.24 | (Aguilera et al., 2015b) |
| Cucumber | 12.5 | 29.7 | - | 1.30 | (Audsley et al., 2009) |
| Celery | 4.9 | 3.5 | - | 0.24 | (Aguilera et al., 2015b) |
| Cabbage | 5.8 | 41.6 | - | 0.24 | (Aguilera et al., 2015b) |
| Pepper | 24.7 | 20.2 | 38.6 | 0.22 | (Aguilera et al., 2015b) |
| Squash | 6.2 | - | - | 0.20 | (Aguilera et al., 2015b) |
| Asparagus | 2.3 | 5.6 | - | 2.22 | (Audsley et al., 2009) |
| Cauliflower | 3.7 | - | 30.7 | 0.24 | (Aguilera et al., 2015b) |
| Garlic | 2.4 | 8.4 | - | 0.39 | (Khoshnevisan and Rafiee, 2013) |
| Mushroom | 3.4 | 6.2 | - | 1.82 | (Leiva et al., 2015) |
| Spinach | - | 18.1 | - | 0.54 | (Clune et al., 2017) |
| Aubergine | - | 6.0 | 35.5 | 1.30 | (Audsley et al., 2009) |
| Leek | - | 8.4 | - | 0.39 | (Clune et al., 2017) |
| Courgette | - | - | 58.5 | 0.20 | (Frankowska et al., 2019a) |
| Artichoke | - | - | 41.2 | 0.48 | (Audsley et al., 2009) |
| Fennel | - | - | 50.3 | 0.48 | (Stoessel et al., 2012) |
| Total | 280.7 | 250.0 | 500.0 | | |

**Table 4.3. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Pulses**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Pulses | (g·person$^{-1}$·day$^{-1}$) | | | (kg$CO_2$eq·kg$^{-1}$) | |
| Beans | 53.1 | 8.6 | 21.7 | 0.51 | (Clune et al., 2017) |
| Peas | - | 8.6 | 13.7 | 0.60 | (Aguilera et al., 2015b) |
| Lentils | - | - | 6.1 | 1.03 | (Clune et al., 2017) |
| Chickpeas | - | - | 5.7 | 0.67 | (Clune et al., 2017) |
| Total | 53.1 | 17.1 | 47.1 | | |

**Table 4.4. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff. Starch-based products**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Starch-based products | ($g \cdot person^{-1} \cdot day^{-1}$) | | | ($kgCO_2eq \cdot kg^{-1}$) | |
| Potatoes | 109.7 | 157.5 | 57.1 | 0.24 | (Aguilera et al., 2015b) |
| Sweet corn | 18.2 | - | - | 0.45 | (Audsley et al., 2009) |
| Rice | 28.2 | - | - | 2.31 | (Hess et al., 2016) |
| Bread | 181.2 | 188.1 | 175.0 | 1.15 | (Espinoza-Orias et al., 2011; Kulak et al., 2015; Notarnicola et al., 2017) |
| Breakfast cereal | - | - | 8.6 | 2.64 | (Jeswani et al., 2015) |
| Cereal products | | 112.5 | - | 1.13 | (Audsley et al., 2009; Hess et al., 2016) |
| Pasta | - | - | 120.0 | 1.28 | (Hess et al., 2016) |
| Bread substitutes | - | - | 15.7 | 1.03 | (Konstantas et al., 2019) |
| Total | 337.3 | 458.1 | 376.4 | | |

**Table 4.5. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff. Nuts and olives**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Nuts | ($g \cdot person^{-1} \cdot day^{-1}$) | | | ($kgCO_2eq \cdot kg^{-1}$) | |
| Pistachio | - | 5.6 | - | 0.53 | (Volpe et al., 2015) |
| Almond | 14.7 | 5.6 | 4.5 | 1.74 | (Clune et al., 2017) |
| Walnut | 3.4 | 5.6 | 4.1 | 1.62 | (Clune et al., 2017) |
| Pecan | 3.4 | - | - | 1.62 | (Clune et al., 2017) |
| Peanut | - | 5.6 | - | 0.62 | (Volpe et al., 2015) |
| Total | 21.5 | 22.5 | 8.6 | | |

**Table 4.6. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff. Dairy Products**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Dairy | ($g \cdot person^{-1} \cdot day^{-1}$) | | | ($kgCO_2eq \cdot kg^{-1}$) | |
| Cheese | 63.4 | 40.0 | 42.9 | 10.44 | (González-García et al., 2013c) |
| Milk | 611.5 | 340.2 | 258.0 | 0.77 | (Iribarren et al., 2011a) |
| Yogurt | 37.0 | 91.1 | 125.0 | 1.50 | (González-García et al., 2013a) |
| Total | 711.9 | 471.3 | 425.9 | | |

**Table 4.7. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff. Eggs**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Eggs | ($g \cdot person^{-1} \cdot day^{-1}$) | | | ($kgCO_2eq \cdot kg^{-1}$) | |
| Eggs | 21.7 | 17.9 | 21.4 | 1.80 | (Nielsen et al., 2013) |
| Total | 21.7 | 17.9 | 21.4 | | |

**Table 4.8. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Meat**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Meat | (g·person$^{-1}$·day$^{-1}$) | | | (kg$CO_2$eq·kg$^{-1}$) | |
| Beef | 31.8 | 20.7 | 5.0 | 24.69 | (van Oort and Andrew, 2016) |
| Chicken | 38.5 | 22.1 | 9.3 | 2.50 | (González-García et al., 2014) |
| Pork | 28.0 | 28.6 | 28.6 | 4.96 | (Noya et al., 2017) |
| Total | 98.3 | 71.4 | 42.9 | | |

**Table 4.9. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Fish and seafood**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Fish and seafood | (g·person$^{-1}$·day$^{-1}$) | | | (kg$CO_2$eq·kg$^{-1}$) | |
| Shrimp | 15.8 | - | - | 6.19 | (Blonk et al., 2008) |
| Salmon | 8.8 | - | - | 2.26 | (Sherry and Koester, 2020) |
| Tuna | 7.2 | - | - | 1.64 | (Hospido and Tyedmers, 2005) |
| Pollock | 2.6 | - | - | 2.26 | (Iribarren et al., 2011b) |
| Cod | 2.1 | - | - | 1.20 | (Ziegler et al., 2013) |
| Clams | 2.1 | - | 11.6 | 1.42 | (Iribarren et al., 2010a) |
| Herring | - | 4.8 | - | 1.47 | (Werner et al., 2014) |
| Blue whiting | - | 3.8 | - | 1.54 | (Iribarren et al., 2010b) |
| Mackerel | - | 3.3 | - | 1.54 | (Vázquez-Rowe et al., 2010a) |
| European Plaice | - | 1.0 | - | 2.26 | (Iribarren et al., 2011b) |
| Mussel | - | 1.4 | 11.6 | 1.42 | (Iribarren et al., 2010a) |
| Anchovies | - | - | 16.2 | 0.76 | (Iribarren et al., 2010b) |
| Hake | - | - | 3.7 | 5.98 | (Iribarren et al., 2010b) |
| Striped Venus | - | - | 3.7 | 1.59 | (Iribarren et al., 2010a) |
| Sardines | - | - | 3.1 | 0.43 | (González-García et al., 2015a) |
| Total | 38.6 | 14.3 | 50.0 | | |

**Table 4.10. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Sweets**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Sweets | | (g·person$^{-1}$·day$^{-1}$) | | (kg$CO_2$eq·kg$^{-1}$) | |
| Sugar | 4.0 | 5.0 | 4.5 | 0.23 | (Klenk et al., 2012) |
| Total | 4.0 | 5.0 | 4.5 | | |

**Table 4.11. Average daily-recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff. Oils and fats**

| | DGA | DDG | IDG | CF | Source |
|---|---|---|---|---|---|
| Oils and fats | (g·person$^{-1}$·day$^{-1}$) | | | (kg$CO_2$eq·kg$^{-1}$) | |
| Soybean oil | 30.6 | - | - | 0.81 | (Heller et al., 2018) |
| Soft Margarine | - | 16.7 | - | 1.36 | (Nilsson et al., 2010) |
| Olive oil | - | 16.7 | 23.0 | 3.73 | (Monini, 2014) |
| Sesame oil | - | 16.7 | - | 2.33 | (Heller et al., 2018) |
| Butter | - | - | 5.0 | 7.20 | (Vergé et al., 2013) |
| Total | 30.6 | 50.0 | 28.0 | | |

**Table 4.12. Average daily-recommended country intake ($g \cdot person^{-1} \cdot day^{-1}$) and carbon footprint ($kgCO_2eq \cdot kg^{-1}$) per foodstuff for New Nordic Diet. Data from Mithril et al. (2013) and Ulaszewska et al. (2017)**

| | ($g \cdot person^{-1} \cdot day^{-1}$) | ($kgCO_2eq \cdot kg^{-1}$) | Source |
|---|---|---|---|
| | | Fruits | |
| Fruit assorted | 239.4 | 0.19 | Average value |
| Berries | 71.8 | 0.80 | (Clune et al., 2017) |
| Fruit juice | 47.9 | 0.19 | Average value |
| | | Vegetables | |
| Cabbages | 28.8 | 0.24 | (Aguilera et al., 2015b) |
| Root vegetables | 143.7 | 0.22 | Average value |
| Other vegetables | 229.7 | 0.23 | Average value |
| | | Mushroom | |
| Mushroom | 4.8 | 1.82 | (Leiva et al., 2015) |
| | | Seaweed | |
| Seaweed | 5.4 | 0.18 | (Heller et al., 2018) |
| | | Pulses | |
| Pulses | 43.1 | 1.7 | (Barilla Center for Food Nutrition, 2015) |
| | | Starch-based products | |
| Potatoes | 167.5 | 0.24 | (Aguilera et al., 2015b) |
| Wholegrain cereal | 263.2 | 1.55 | (Chiriacò et al., 2017) |
| | | Nuts and seeds | |
| Nuts and seeds | 28.8 | 1.13 | Average value |
| | | Dairy products | |
| Milk | 459.5 | 0.77 | (Iribarren et al., 2011a) |
| Cream | 19.1 | 2.30 | (Vergé et al., 2013) |
| Cheese | 24.0 | 10.44 | (González-García et al., 2013c) |
| | | Eggs | |
| Eggs | 24.0 | 1.80 | (Nielsen et al., 2013) |
| | | Meat | |
| Beef | 8.2 | 24.69 | (van Oort and Andrew, 2016) |
| Veal | 0.3 | 22.86 | (Barilla Center for Food Nutrition, 2015) |
| Pork | 10.1 | 4.96 | (Noya et al., 2017) |
| Mutton/lamb | 0.5 | 15.38 | (Barilla Center for Food Nutrition, 2015) |
| Game | 3.9 | 21.57 | (Saxe, 2015) |

Notes:
CF for fruits assorted and fruit juice is an average value for apple, pear and strawberries, the most consumed fruits in Denmark, Finland and Sweden (GmbH, 2019)
CF for root vegetables is an average value for onion and carrot, the most consumed root vegetables in Denmark, Finland and Sweden (GmbH, 2019)
In other vegetables, tomato, the other most consumed vegetable in Nordic countries, was included (GmbH, 2019)
The CF for nuts is an average value of the CF for walnut, almond, pistachio and peanut

**Table 4.12. (cont.) Average daily recommended country intake (g·person$^{-1}$·day$^{-1}$) and carbon footprint (kg$CO_2$eq·kg$^{-1}$) per foodstuff for New Nordic Diet.**

| | | | |
|---|---|---|---|
| Fish and shellfish | | | |
| Fish and shellfish | 41.1 | 4.4 | (Barilla Center for Food Nutrition, 2015) |
| Sweets | | | |
| Sugar | 14.4 | 0.23 | (Klenk et al., 2012) |
| Oils and fats | | | |
| Butter | 9.7 | 7.20 | (Vergé et al., 2013) |
| Rapeseed oil | 14.3 | 3.11 | (Barilla Center for Food Nutrition, 2015) |

Notes: CF for fruits assorted and fruit juice is an average value for apple, pear and strawberries, the most consumed fruits in Denmark, Finland and Sweden (GmbH, 2019)
CF for root vegetables is an average value for onion and carrot, the most consumed root vegetables in Denmark, Finland and Sweden (GmbH, 2019)
In other vegetables tomato, the other most consumed vegetable in Nordic countries, was included (GmbH, 2019)
The CF for nuts is an average value of the CF for walnut, almond, pistachio and peanut

### 4.2.3 Assessment of environmental impacts, including quantification of water and carbon footprint

For the estimation of the CF, a life cycle approach was considered. As the main objective of the study is to compare dietary patterns, it is convenient to consider only GHG emissions associated with the production of food ingredients. Actually, the production stage is by far the largest contributor to GHG emissions in FBDGs (Zhang et al., 2023). CF scores for each foodstuff were taken from literature. Depending on the source, cradle-to-farm, cradle-to-factory gate or cradle-to-port gate were considered as system boundary.

Transport, household tasks and waste treatment were removed from the system boundaries due to fluctuations between data from different countries (Heller et al., 2013). The functional unit selected for this analysis was the average daily dietary reference intake per individual. Furthermore, despite variations across countries, the recommended average daily energy intake per day for a European citizen was about 2500 and 2000 kcal·person$^{-1}$·day$^{-1}$ for men and women, respectively (European Commission, 2018). Considering that environmental impact assessments of NAOS and MD were referred to a Spanish middle-aged woman with a recommended energy intake of 2228 kcal·person$^{-1}$·day$^{-1}$ (EFSA, 2017; González-García et al., 2020b), the energy values of diets analysed in this study were adjusted to this value of reference for comparison purposes.

The WF was calculated following the first two steps (goal and scope and accounting) of the four-phase of the WFA methodology (WFN, 2020). Mekonnen and Hoekstra (2011, 2012) explicitly estimated the three components of WF for farm animal products, crops and derived crops products by country. These two scientific papers were used as a reference database for the WF quantification of all foodstuffs included in the diets, excluding fish and seafood products. While for aquaculture products this metric was calculated according to the WF of their corresponding commercial aquafeed (Pahlow et al., 2015), for wild fishery products a WF of zero was considered (Blas et al., 2019; Harris et al., 2017). Climate, soils and production conditions make it necessary to consider the spatial variable for WF estimation (Mekonnen and Hoekstra, 2011, 2012). The methodology described by González-García et al. (2020b) was followed in detail to calculate the average percentages of domestically produced and imported food. The open-access database Datacomex (Ministerio de Economia, 2019) and data from the USDA (2019) were used to find detailed information on import and export trade statistics for Europe and America, as explained in **Section 4.2.2**. Detailed information on export volumes, import volumes, main importing countries and the percentage produced domestically and imported per foodstuff and country is collected in **Tables 4.13 - 4.15.**

**Table 4.13. Main importing countries and the percentage produced domestically and imported per food item. Dietary Guidelines for Americans 2020-2025.**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Oranges | Chile (48%), Mexico (30%), South Africa (15%), Morocco (3%), Australia (1%) | 95 | 5 |
| Bananas | Guatemala (41%), Costa Rica (17%), Ecuador (14%), Honduras (11%), Mexico (9%) | 0 | 100 |
| Apples | Chile (54%), New Zealand (22%), Canada (16%), Argentina (7%), China (1%) | 96 | 4 |
| Watermelon | Mexico (64%), Guatermala (28%), Costa Rica (3%), Honduras (4%) | 97 | 3 |
| Grapes | Chile (50%), Mexico (25%), Peru (24%), Brazil (1%) | 100 | 0 |
| Pineapples | Costa Rica (87%), Mexico (5%), Honduras (5%), Guatemala (2%) | 10 | 90 |
| Lemons | Mexico (31%), Chile (26%), Argentina (15%), Spain (5%), Uruguay (2%) | 83 | 17 |
| Lettuce | Mexico (89%), Canada (11%) | 89 | 11 |
| Broccoli | Mexico (97%), Canada (2%), Guatemala (1%) | 94 | 6 |
| Tomato | Mexico (98%), Canada (2%) | 99 | 1 |
| Carrots | Mexico (46%), Canada (44%), Israel (8%), Guatemala (2%) | 90 | 10 |
| Sweet potatoes | Dominican Republic (69%), Peru (9%), China (7%), Canada (7%), Honduras (7%) | 99 | 1 |
| Pumpkin | Canada (59%), Costa Rica (29%), Honduras (3%), Panama (4%) | 93 | 7 |
| Onion | Mexico (56%), Peru (29%), Canada (11%), Netherlands (1%), China (1%) | 26 | 74 |
| Cucumber | Mexico (80%), Canada (16%), Honduras (3%), Dominican Republic (1%) | 38 | 62 |
| Celery | Mexico (93%), Canada (7%) | 85 | 15 |
| Cabbage | Mexico (57%), Canada (42%), Costa Rica (1%) | 87 | 13 |
| Pepper | Mexico (85%), Dominican Republic (1%), Canada (1%), Netherlands (1%), Honduras (1%) | 30 | 70 |
| Squash | Mexico (59%), Costa Rica (41%) | 91 | 9 |
| Asparagus | Mexico (64%), Peru (35%), Canada (1%) | 3 | 97 |
| Cauliflower | Mexico (77%), Canada (23%) | 91 | 9 |
| Garlic | China (64%), Spain (18%), Mexico (10%), Argentina (5%) | 69 | 31 |
| Mushroom | Canada (79%), Mexico (14%), South Korea (5%), China (2%), | 71 | 29 |
| Beans | Canada (88%), Mexico (8%), Nicaragua (2%), Brazil (2%) | 98 | 2 |
| Potatoes | Canada (44%), Netherlands (24%), Germany (22%), Mexico (2%), Spain (1%) | 100 | 0 |
| Sweet corn | Mexico (93%), Canada (7%) | 98 | 2 |
| Wheat flour-bread | Canada (68%), Australia (11%), Germany (5%), France (3%) | 87 | 13 |

**Table 4.13. (cont.) Main importing countries and the percentage produced domestically and imported per food item. Dietary Guidelines for Americans 2020-2025.**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Rice | Thailand (58%), India (26%), Pakistan (4%), Vietnam (2%) | 88 | 12 |
| Almond | Spain (73%), Australia (11%), Italy (14%) | 99 | 1 |
| Walnut | Chile (59%), Moldova (15%), Romania (3%) | 99 | 1 |
| Pecans | Mexico (100%) | 26 | 74 |
| Eggs | Canada (60%), Taiwan (15%), Thailand (14%), China (5%), Netherlands (2%) | 100 | 0 |
| Cheese | Italy (26%), France (14%), Spain (8%), Netherlands (7%), Switzerland (6%), Germany (4%), United Kingdom (4%) | 97 | 3 |
| Milk | Mexico (31%), Chile (17%), Peru (14%), Netherland (9%), Brazil (7%), Canada (7%) | 99 | 1 |
| Yogurt | New Zealand (70%), Canada (21%), France (2%) | 99 | 1 |
| Beef | Canada (28%), Australia (23%), New Zealand (19%), Mexico (17%), Brasil (5%), Nicaragua (5%) | 88 | 12 |
| Chicken | Chile (65%), Canada (35%), Israel (1%) | 100 | 0 |
| Pork | Canada (61%), Poland (14%), Denmark (6%), Mexico (5%), Netherlands (1%), Italy (3%), Spain (3%), United Kingdom (2%) | 96 | 4 |
| Sugar | Mexico (36%), Brasil (9%), Philippines (6%), Guatermala (6%), Dominican Republic (6%), Australia (4%), Colombia (4%) | 100 | 0 |
| Soybean oil | India (32%), China (9%), Bangladesh (6%), Algeria (6%), Morocco (5%), Peru (5%), European Union (4%), South Korea (4%) | 80 | 20 |

**Table 4.14. Main importing countries and the percentage produced domestically and imported per food item. Dutch dietary guidelines 2015.**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Oranges | South Africa (38%), Egypt (20%), Spain (13%), Morocco (8%), Zimbabwe (4%) | 0 | 100 |
| Bananas | Ecuador (18%), Costa Rica (15%), Belgium (15%), Panama (15%), Colombia (10%), Dominican Republic (9%), Guatemala (7%) | 0 | 100 |
| Apples | Chile (21%), Belgium (18%), New Zealand (13%), France (12%), Italy (9%), Germany (8%) | 24 | 76 |
| Grapes | South Africa (27%), India (17%), Peru (13%), Chile (9%), Turkey (5%), Egypt (5%), Namibia (4%) | 45 | 55 |
| Mandarin | South Africa (28%), Morocco (22%), Spain (19%), Germany (9%), Peru (8%), France (3%) | 0 | 100 |
| Pear | Belgium (32%), South Africa (27%), Chile (15%), Argentina (13%) | 8 | 92 |
| Strawberries | Belgium (40%), Spain (38%), Germany (8%), Egypt (5%), Poland (3%) | 38 | 62 |
| Lettuce | Spain (64%), Belgium (13%), Italy (9%), Germany (8%), France (4%) | 61 | 39 |
| Tomatoes | Spain (38%), Belgium (21%), Morocco (14%), France (13%), Tunisia (4%) | 100 | 0 |
| Carrots | Germany (26%), Belgium (25%), Israel (21%), Spain (15%), United Kingdom (5%) | 60 | 40 |
| Onion | Egypt (23%), Belgium (14%), Spain (14%), New Zealand (10%), China (10%), Poland (7%), Germany (7%), France (4%) | 20 | 80 |
| Cucumber | Spain (69%), Belgium (20%), Germany (9%) | 100 | 0 |
| Celery | Spain (81%), Germany (9%), Belgium (7%), Italy (1%) | 86 | 14 |
| Cabbage | Spain (54%), Portugal (13%), Germany (10%), South Africa (6%) | 73 | 27 |
| Pepper | Spain (71%), Belgium (10%), Germany (6%), Morocco (3%) | 100 | 0 |
| Asparagus | Peru (56%), Belgium (13%), Mexico (13%), Germany (7%), Spain (5%) | 100 | 0 |
| Garlic | China (66%), Spain (10%), Argentina (6%), Germany (4%), France (4%) | 0 | 100 |
| Mushroom | Poland (41%), Belgium (28%), Germany (21%), United Kingdom (2%), China (2%) | 86 | 14 |
| Spinach | Spain (48%), Italy (30%), Germany (11%), Belgium (9%), France (1%) | 87 | 13 |
| Aubergines | Spain (74%), Germany (8%), Belgium (8%), Czech Republic (3%), Turkey (2%), Surinam (1%) | 15 | 85 |
| Leek | Belgium (39%), Spain (19%), Kenya (13%), Tanzania (9%) | 91 | 9 |
| Beans | United Kingdom (52%), Myanmar (15%), Denmark (6%), Belgium (5%), Poland (5%) | 60 | 40 |

**Table 4.14. (cont.). Main importing countries and the percentage produced domestically and imported per food item. Dutch dietary guidelines 2015.**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Peas | Belgium (33%), Guatemala (18%), Zimbabwe (10%), Kenya (9%), Peru (5%) | 38 | 62 |
| Potatoes | Germany (53%), Belgium (23%), France (14%), Israel (3%) | 71 | 29 |
| Bread | Italy (21%), Belgium (19%), United Kingdom (15%), Germany (15%) | 91 | 9 |
| Cereal products | Ukraine (35%), France (29%), Germany (11%), Belgium (5%), Romania (5%) | 0 | 100 |
| Pistachios | United States of America (72%), Spain (12%), United Kingdom (5%), Germany (4%), Australia (3%) | 0 | 100 |
| Almonds | United States of America (72%), Spain (12%), United Kingdom (5%), Germany (4%), Australia (3%) | 0 | 100 |
| Walnut | United States of America (45%), Germany (16%), Chile (12%), Moldavia (9%) | 0 | 100 |
| Peanut | Argentina (57%), United States of America (16%), China (7%), Brazil (6%), Nicaragua (4%), Germany (3%), India (3%) | 0 | 100 |
| Cheese | Germany (39%), Belgium (16%), France (13%), Ireland (9%), Denmark (7%), United Kingdom (5%) | 8 | 92 |
| Milk | Germany (42%), Belgium (24%), Ireland (9%), France (9%), United Kingdom (7%), Poland (2%) | 85 | 15 |
| Yogurt | Germany (76%), Belgium (14%), France (3%), Austria (2%), Luxembourg (1%), Croatia (1%) | 73 | 27 |
| Beef | Germany (21%), Belgium (13%), Poland (10%), United Kingdom (10%), Ireland (7%), Italy (4%), Italy (4%), Spain (4%), Brazil (4%), Argentina (4%), Austria (4%) | 100 | 0 |
| Chicken | Germany (23%), United Kingdom (19%), Belgium (16%), Poland (13%), Ukraine (10%), Brazil (4%), France (3%) | 100 | 0 |
| Pork | Germany (58%), Belgium (15%), United Kingdom (10%), France (6%), Poland (5%), Spain (3%), Italy (3%), Hungary (1%) | 46 | 54 |
| Eggs | Germany (41%), Poland (21%), Belgium (20%), United Kingdom (6%), France (4%) | 49 | 51 |
| Sugar | Belgium (28%), Germany (24%), France (21%), Cuba (6%), United Kingdom (3%), Austria (2%) | 86 | 14 |
| Olive oil | Spain (58%), Italy (20%), Belgium (5%), Greece (5%), Germany (4%), Morocco (2%) | 0 | 100 |
| Soft margarine | United States (32%), Belgium (31%), Germany (21%), France (3%), Poland (2%), Spain (2%) | 100 | 0 |
| Vegetable oil | Mexico (41%), India (17%), United States (8%), Singapore (8%), China (5%), Germany (4%) | 15 | 85 |

**Table 4.15. Main importing countries and the percentage produced domestically and imported per food item. Italian guidelines 2018**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Oranges | Spain (62%), South Africa (16%), Egypt (4%), Netherlands (3%), Greece (3%), Germany (3%) | 89 | 11 |
| Bananas | Ecuador (31%), Colombia (29%), Costa Rica (24%), Guatemala (7%), France (4%), Netherlands (1%), Mexico (1%) | 0 | 100 |
| Apples | Germany (18%), France (17%), Austria (15%), Croatia (10%), Slovakia (8%), Chile (6%), Spain (6%) | 97 | 3 |
| Grapes | Turkey (42%), Netherlands (12%), Spain (11%), Germany (8%), Egypt (7%), Chile (7%), Australia (2%) | 99 | 1 |
| Pineapple | Costa Rica (91%), Spain (3%), Netherlands (3%), Colombia (1%) | 6 | 94 |
| Lemons | Spain (53%), Argentina (17%), South Africa (11%), Netherlands (7%), Germany (3%), Uruguay (2%) | 73 | 27 |
| Mandarin | Spain (70%), France (4%), Germany (3%), Israel (2%) | 89 | 11 |
| Pear | Spain (35%), Argentina (20%), Chile (13%), Netherlands (10%), South Africa (9%), Belgium (3%) | 77 | 23 |
| Nectarine | Spain (88%), France (4%), Germany (4%), Greece (2%), Chile (1%) | 97 | 3 |
| Peach | Spain (88%), France (6%), Germany (4%), Greece (1%) | 91 | 9 |
| Kiwifruit | Greece (37%), New Zealand (21%), Chile (17%), Belgium (14%), Spain (6%) | 76 | 24 |
| Lettuce | Spain (48%), Netherlands (28%), Germany (8%), France (8%), Greece (4%) | 84 | 16 |
| Tomatoes | Netherlands (38%), Spain (28%), France (14%), Germany (8%), Belgium (4%), Albania (3%), Poland (3%) | 97 | 3 |
| Carrots | Belgium (28%), Germany (18%), Spain (12%), Netherlands (10%), Poland (10%), Israel (9%) | 98 | 2 |
| Onion | Egypt (28%), Netherlands (19%), France (17%), Germany (14%), India (8%), Spain (4%), Austria (4%), New Zealand (1%) | 84 | 16 |
| Peppers | Spain (72%), France (10%), Netherlands (6%), Germany (4%) | 71 | 29 |
| Cauliflower | Netherlands (26%), Spain (21%), France (19%), Germany (14%), Poland (8%) | 82 | 18 |
| Aubergines | Spain (86%), Germany (5%), France (5%), Netherlands (3%) | 93 | 7 |
| Courgette | Spain (56%), France (31%) | 96 | 4 |
| Artichokes | Egypt (49%), Tunisia (37%), France (8%), Spain (6%) | 96 | 4 |
| Fennel | Spain (74%), Tunisia (11%), Germany (6%), Austria (5%), China (2%) | 100 | 0 |
| Beans | Denmark (20%), France (19%), United Kingdom (14%), Germany (11%), Egypt (7%), China (5%), Canada (4%) | 86 | 14 |

**Table 4.15. (cont.) Main importing countries and the percentage produced domestically and imported per food item. Italian guidelines 2018**

| Food item | Main importing countries | % Domestically produced | % Imported |
|---|---|---|---|
| Peas | France (64%), Netherlands (9%), Germany (6%), Austria (6%) | 95 | 5 |
| Lentils | Canada (56%), Turkey (19%), United States (12%), China (4%), Spain (2%) | 5 | 95 |
| Chickpeas | Argentina (28%), United States (21%), Mexico (18%), Turkey (17%), Canada (9%) | 62 | 38 |
| Potatoes | France (40%), Germany (16%), Netherlands (11%), Spain (10%), Egypt (9%), Denmark (5%) | 64 | 36 |
| Bread | France (28%), Germany (25%), Spain (20%), Ireland (5%) | 95 | 5 |
| Breakfast cereals | Hungary (18%), Ukraine (13%), France (11%), Austria (8%), Romania (7%), Canada (7%), Slovenia (6%), United States (5%) | 49 | 51 |
| Pasta | France (31%), Greece (26%), China (10%), Belgium (5%), Germany (3%), Morocco (3%), South Korea (3%) | 93 | 7 |
| Almonds | United States (58%), Spain (30%), Germany (3%), Australia (2%), France (1%) | 52 | 48 |
| Walnut | United States (45%), Chile (19%), France (14%), Argentina (5%), Spain (4%), Germany (2%) | 13 | 87 |
| Cheese | Germany (47%), France (9%), Belgium (7%), Netherlands (6%), Lithuania (5%), Spain (5%), Czech Republic (4%), Poland (4%) | 59 | 41 |
| Milk | Germany (46%), France (22%), Austria (17%), Netherlands (4%), Poland (2%), Belgium (2%) | 83 | 17 |
| Yogurt | Germany (52%), Greece (20%), Austria (17%), France (4%), Belgium (2%), Luxembourg (2%), Czech Republic (2%) | 61 | 39 |
| Eggs | Spain (39%), Romania (29%), Poland (16%), Germany (5%), United Kingdom (3%) | 76 | 24 |
| Sugar | France (32%), Germany (29%), Netherlands (7%), Swaziland (5%), Mauritius (3%), United Kingdom (2%), Austria (2%) | 46 | 54 |
| Beef | Poland (21%), France (16%), Netherlands (14%), Germany (8%), Spain (7%), Brazil (7%), Ireland (6%), Austria (3%), Belgium (3%), Denmark (3%) | 62 | 38 |
| Chicken | Germany (37%), Netherlands (19%), Poland (17%), Greece (4%), Spain (4%), Slovakia (3%), France (2%) | 95 | 5 |
| Pork | Germany (32%), Spain (17%), Netherlands (14%), France (9%), Denmark (9%), Poland (6%), Austria (5%), Hungary (3%) | 55 | 45 |
| Olive oil | Spain (74%), Greece (11%), Tunisia (8%), Portugal (5%), Turkey (1%) | 87 | 13 |
| Butter | Netherlands (23%), Belgium (19%), France (13%), Germany (13%), Spain (11%), United Kingdom (10%), Poland (3%), Czech Republic (2%) | 53 | 47 |

### 4.2.4 Assessment of the nutritional quality of diets, including quantification of the Nutrient Rich Diet and estimation of the Health Gain Score

The analysis of dietary nutritional quality employed a dual approach, using both the NRD9.3 (Van Kernebeek et al., 2014) and the Health Gain Score (van Dooren et al., 2014) in a complementary manner. **Chapter 3 (Section I)** provides an in-depth overview of both indexes, offering detailed descriptions, equations, the involved nutrients, and additional considerations.

## 4.3 Results and discussion

### 4.3.1 Composition of the food-based dietary guidelines

The recommended daily intake for DGA, DDG and IDG was 1.92, 1.58 and 1.96 $kg \cdot person^{-1} \cdot day^{-1}$, respectively. Their corresponding dietary energy supply was 2229, 2226 and 2226 $kcal \cdot person^{-1} \cdot day^{-1}$, respectively. Adjusting the caloric value of these three diets to 2228 $kcal \cdot person^{-1} \cdot day^{-1}$, allowed the comparison with the results of González-García et al. (2020b) for NAOS and MD. Moreover, a normalisation to the daily dietary intake established by Mithril et al. (2013) and used by Ulaszewska et al. (2017) in their assessment of diet-related GHG emissions for NND was made in order to include this diet in the benchmarking with other diets of 2228 kcal.

Differences in the contents of plant-based and animal source food can be found between the Northern European, Southern European and American guidelines. The DGA are particularly rich in animal source foods (45% of the daily recommended intake) compared with the Northern European dietary recommendations (36% and 34% of daily recommended intake for DDG and NND, respectively) and with the Southern European Dietary Guidelines (31%, 19% and 28% for NAOS, MD and IDG, respectively). On the other hand, MD was the most predominantly plant-based diet (81% of the daily recommended intake). Plant based-foods (including fruits, vegetables, pulses, starch-based products, nuts and oils) were also the main focus of the other Southern European dietary guidelines, NAOS and IDG. The average contribution of each food category (in percentage) to the average recommended daily intake for the diets is shown in **Fig. 4.1.**

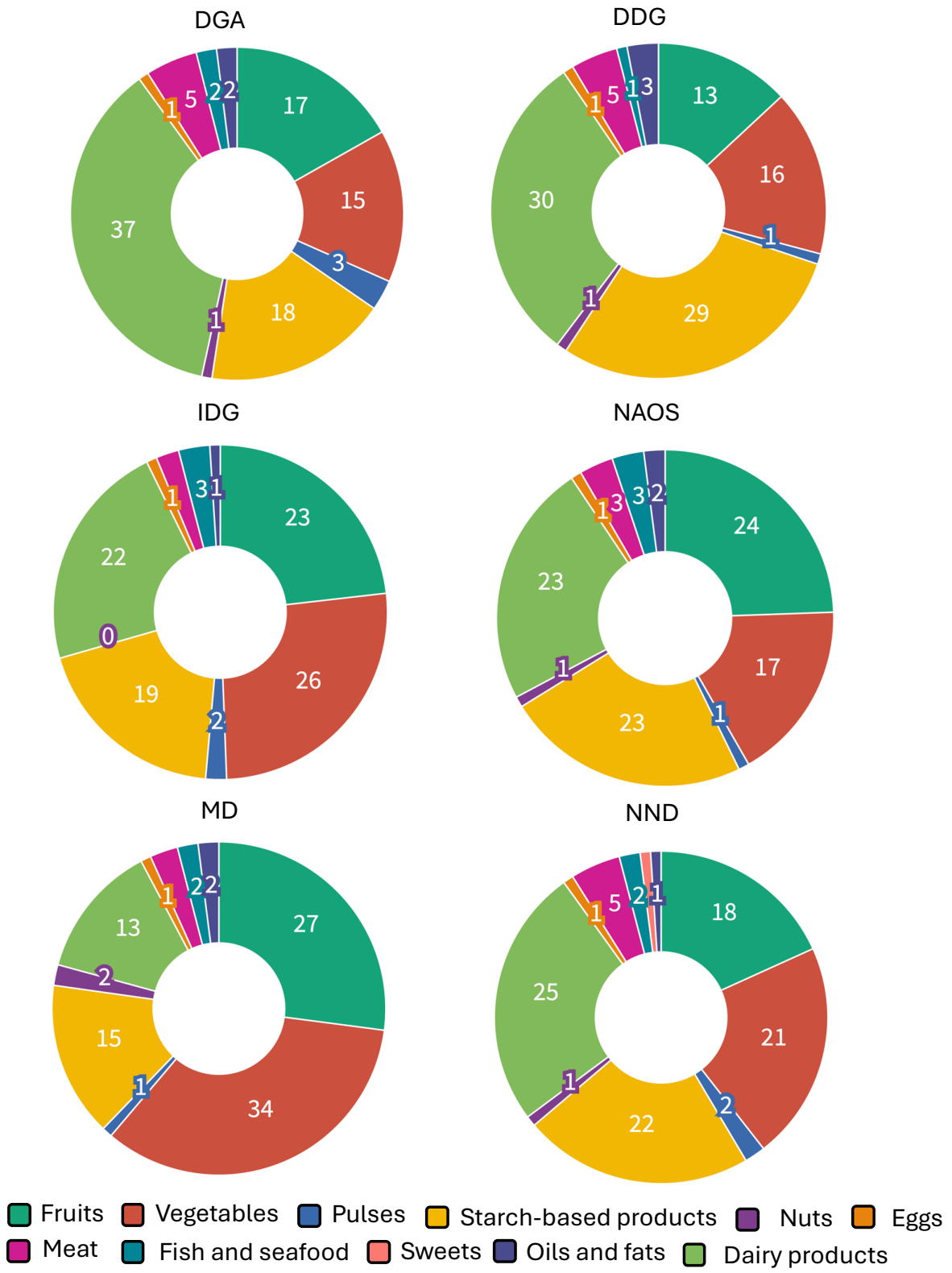


**Fig. 4.1. Contribution of each food category (%) to the average daily recommended for Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND, Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS, Italian Dietary Guidelines 2018 - IDG and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020b), Ulaszewska et al. (2017) and Mithril et al. (2013).**

### 4.3.2 Assessment of environmental impacts- quantification of carbon footprint

The GHG emissions of the DGA, DDG and IDG food guidelines were 2.98, 2.28 and 2.04 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, respectively. Our results were in line with those reported for various recommended dietary patterns in Spain (NAOS), Mediterranean countries (MD) (González-García et al., 2020b) and the Nordic Countries (NND) (Ulaszewska et al., 2017). The comparison between the dietary patterns was performed paying attention only to the production stage. Therefore, the additional stages of distribution to wholesalers and retailers, household consumption, and food losses and waste were eliminated from the results reported by González-García et al. (2020b). On the other hand, the CF for NND was adapted to a cradle-to-gate approach considering the average intake reported by Mithril et al. (2013) standardized to 2228 kcal according to the methodology detailed in Ulaszewska et al. (2017). The beverages and daily allowances detailed by Mithril et al. (2013) were excluded from the dietary composition of NND. To ensure consistency in the comparison, the same data sources were used for the estimation of the GHG emissions of each food item in all the diets analysed (see **Tables 4.1- 4.12)**. Despite the rigor of the study, and even taking into account this assumption is considered better for comparison purposes, it may mean a slight deviation of the results because the same LCA studies considered by González-García et al. (2020b) were used and most of them take Spain as the reference location instead of considering a global perspective.

As illustrated in **Fig. 4.2**, the DGA had the highest CF (2.98 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) of the six dietary patterns. The CF of the DGA was about 1.5 times higher than that of the IDG, the country with the lowest GHG emissions (2.04 kg $CO_2$eq·person$^{-1}$·day$^{-1}$), and 1.3 times higher than that of MD (2.21 kg $CO_2$eq·person$^{-1}$·day$^{-1}$), the second lowest CF. The GHG emissions profiles of the Northern European dietary patterns were very similar.

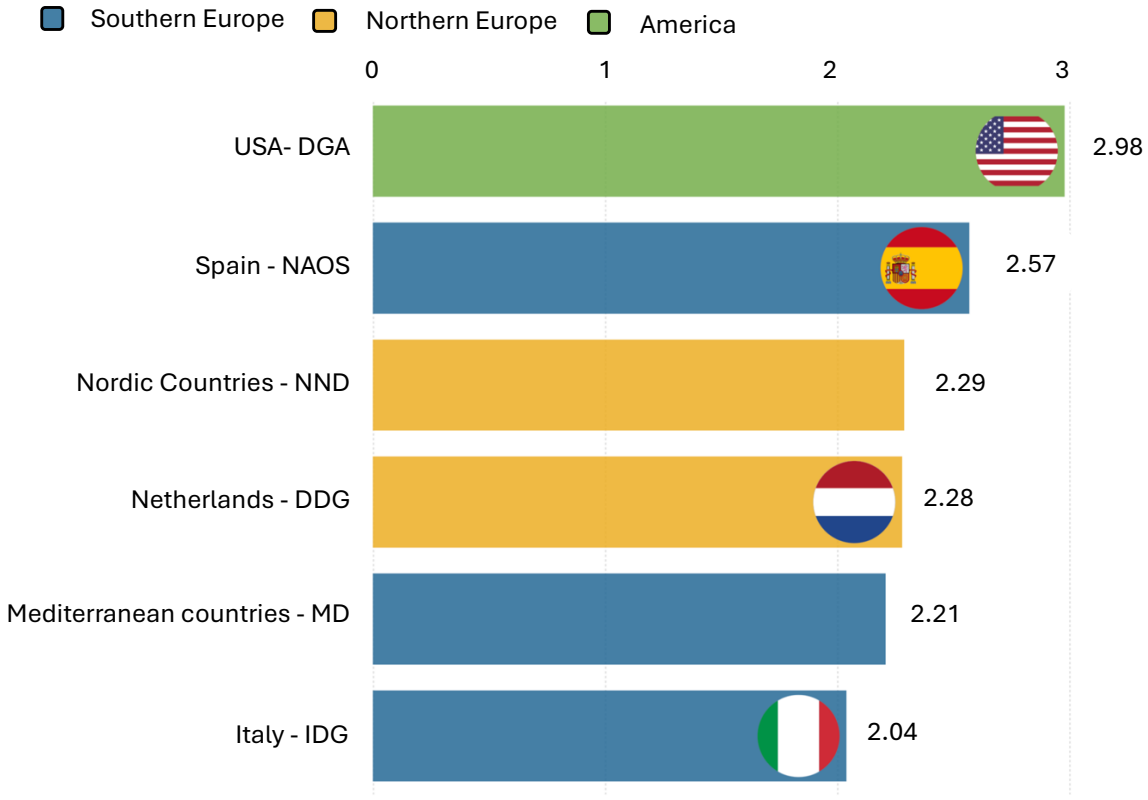


**Fig. 4.2. Carbon footprint (kg $CO_2$eq·person$^{-1}$·day$^{-1}$) for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020b), Ulaszewska et al. (2017) and Mithril et al. (2013).**

Animal food sources accounted for 80% of the CF for DGA, 69% and 61% for DDG and NND, 58% for IDG and MD, and 70% for NAOS. Dairy products were responsible for the highest emissions for the food-based dietary patterns in the three regions analysed, with the largest associated CF in DGA (1.19 kg $CO_2$eq·person$^{-1}$·day$^{-1}$), as can be seen in **Table 4.16**. In general, meat was the second food category with the largest impact on global warming (between a range of 12% of GHG emissions for IDG and 34% of GHG emissions for DGA). Starch-based products also had a significantly impact in GHG emissions for all the nationally recommended diets, particularly for NND (0.45 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) and IDG (0.41 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). For all the FBDGs the number of starch-based products consumed daily is high in comparison with other food categories. The inclusion of wholegrain cereals in the NND scenario and cereal breakfast in IDG explains the high CF results in this category for these two FBDGs. The highest fish and seafood intake in NAOS in comparison with the other FBDGs would result in a more significant CF in this food category (0.33 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). The AESAN recommends the high intake of fish in NAOS due to its great protein richness and because it provides omega-3 fatty acids and other essential nutrients (Neira and de Onis, 2006). **Fig. 4.3** shows the breakdown of CF among food categories.

**Table 4.16. Breakdown of carbon footprint (kg $CO_2$eq·person$^{-1}$·day$^{-1}$) between food categories for DDG (Dutch Dietary Guidelines 2015), MD (Mediterranean Diet), NAOS (Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity), IDG (Italian Dietary Guidelines 2018), New Nordic Diet (NND) and Dietary Guidelines for Americans 2020-2025 (DGA)**

| | NAOS | MD | IDG | NND | DDG | DGA |
|---|---|---|---|---|---|---|
| Fruits | 0.14 | 0.16 | 0.11 | 0.11 | 0.05 | 0.09 |
| Vegetables | 0.08 | 0.15 | 0.17 | 0.10 | 0.12 | 0.10 |
| Pulses | 0.02 | 0.01 | 0.03 | 0.07 | 0.01 | 0.03 |
| Starch-based products | 0.36 | 0.38 | 0.41 | 0.45 | 0.38 | 0.31 |
| Nuts | 0.03 | 0.06 | 0.01 | 0.03 | 0.03 | 0.04 |
| Dairy products | 0.76 | 0.61 | 0.83 | 0.64 | 0.82 | 1.19 |
| Eggs | 0.05 | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 |
| Meat | 0.64 | 0.43 | 0.24 | 0.53 | 0.69 | 1.02 |
| Fish and seafood | 0.33 | 0.19 | 0.07 | 0.18 | 0.02 | 0.14 |
| Sweets | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oils and fats | 0.15 | 0.17 | 0.12 | 0.11 | 0.12 | 0.02 |

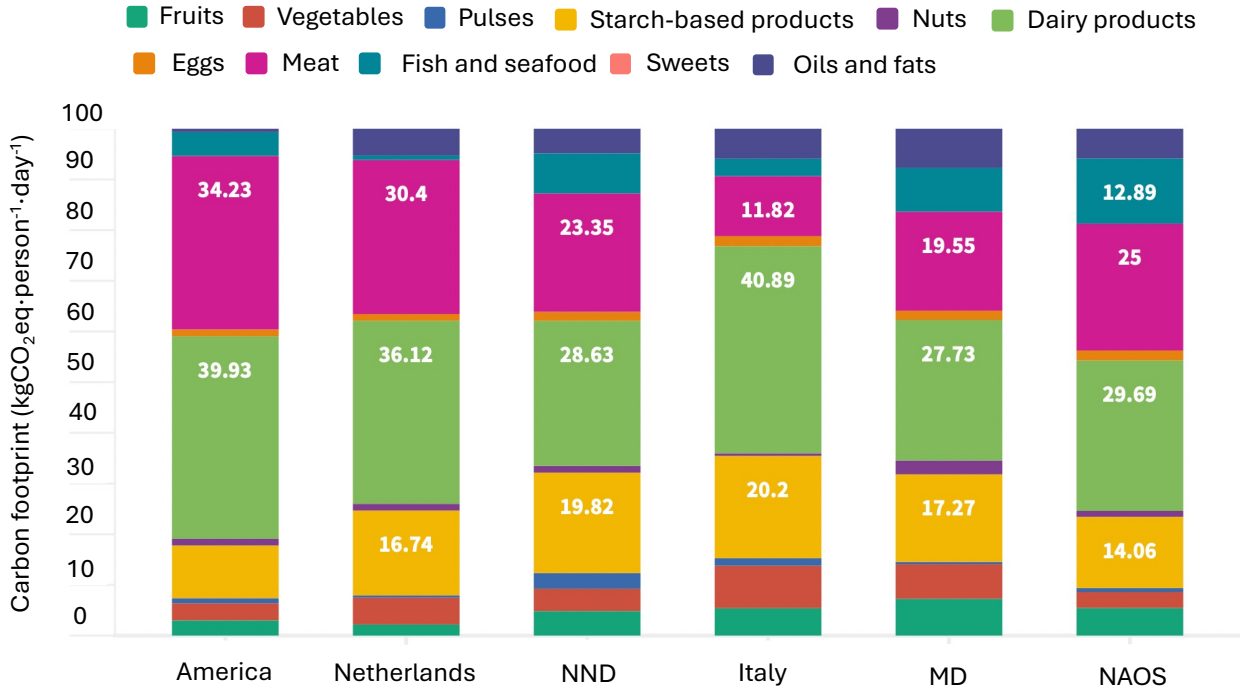


**Fig. 4.3. Breakdown of carbon footprint (kg $CO_2$eq·person$^{-1}$·day$^{-1}$) between food categories for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity - NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020b), Ulaszewska et al. (2017) and Mithril et al. (2013).**

On the other hand, the GHG emissions derived from the fruit and vegetable categories that could be attributed to the country's dietary recommendations ranged from 7% of CF in DGA (0.19 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) to 14% of CF in MD (0.32 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). The great potential to drive up the GHG emissions attributed to dairy and meat products was not justified based on their recommended amounts in the nation-specific diets. Consumption of meat ranges from 2% of the total daily-recommended intake (g·person$^{-1}$·day$^{-1}$) in IDG to 5% in DGA. Moreover, even though dairy products were consumed in large proportions in the nationally

recommended guidelines, their quantitative recommendations were still lower than those for fruits and vegetables together. These general trends can be explained with the fact that animal-based food production is more carbon intensive than plant-based food production, particularly for ruminants (Heller et al., 2018; Petrovic et al., 2015).

### 4.3.3 Assessment of environmental impacts- quantification of the water footprint

The WF varied depending on the country-specific recommended diet, although similar trends could be observed for all the countries analysed. Regarding the three nationally recommended diets analysed in this study, the dietary WF was 2583, 2309 and 1760 L·person$^{-1}$·day$^{-1}$ for DGA, DDG and IDG, respectively. For comparison with NAOS and MD the WF related to food waste and losses was removed from the value provided by González-García et al. (2020b). There were considerable differences in the WFs of FBDGs in the reference countries as can be seen in **Fig. 4.4**.

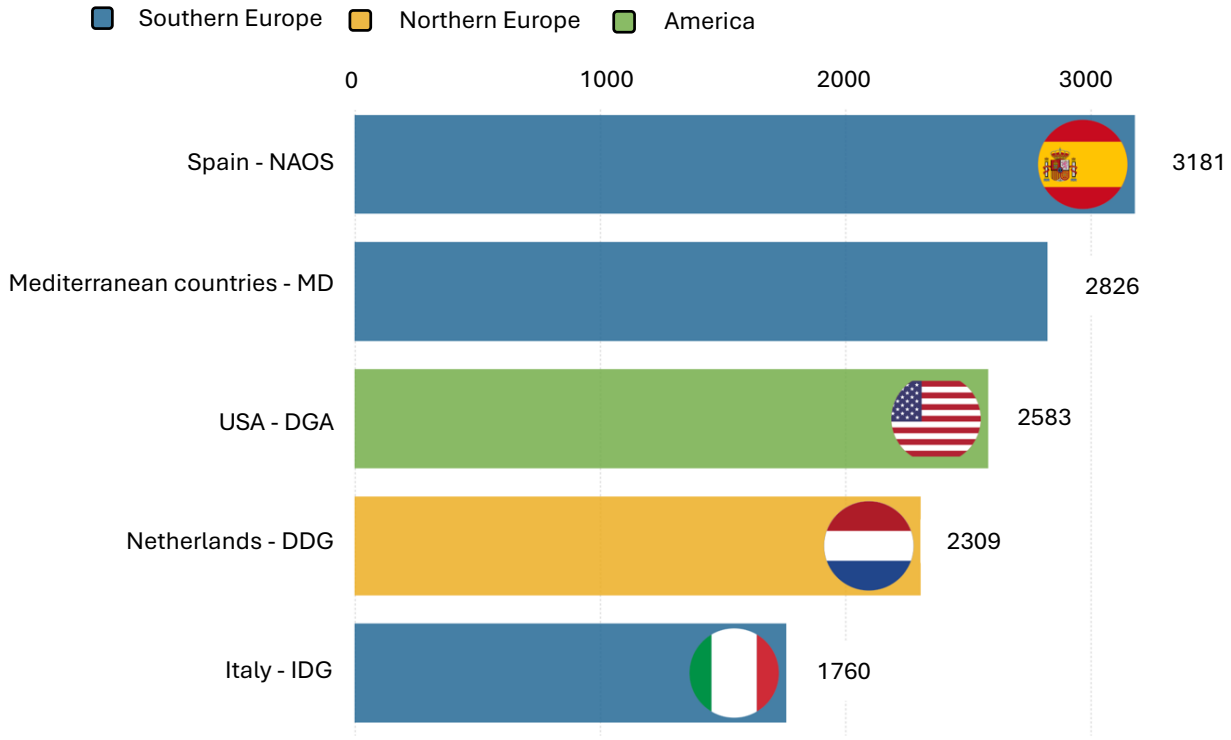


**Fig. 4.4. Water footprint (L·person$^{-1}$·day$^{-1}$) for Northern Europe (Dutch Dietary Guidelines 2015 - DDG), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD, NAOS were taken from González-García et al. (2020b).**

NAOS and MD showed higher WFs (3181 and 2826 L per capita and day, respectively) than IDG, DDG and DGA (1760, 2309 and 2583 L·person$^{-1}$·day$^{-1}$, respectively). Then, to make the comparison of the WF of these three diets between them and with NAOS and MD, it is interesting to check the breakdown of the WF between food categories shown in **Fig. 4.5.**

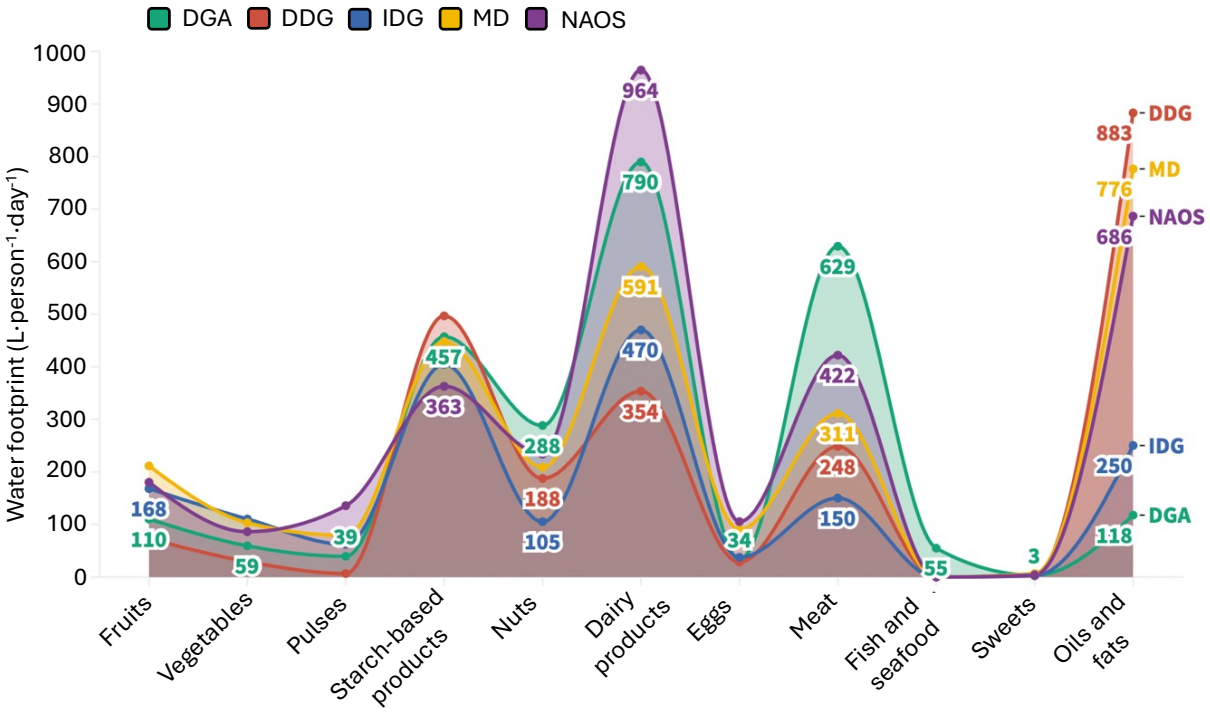


**Fig. 4.5. Breakdown of water footprint (L·person$^{-1}$·day$^{-1}$) between food categories for Northern Europe (Dutch Dietary Guidelines 2015 -DDG), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD and NAOS were taken from González-García et al. (2020b).**

For the DDG, the WFs of fruits and vegetables were lower (103 L·person$^{-1}$·day$^{-1}$) than for the rest of FBDGs mainly due to their lower contribution to the recommended average daily intake. On the other hand, although dairy products contributed in a high proportion to daily intake in DDG compared to NAOS, MD and IDG, its associated WF (354 L·person$^{-1}$·day-1) was also lower than that of them. Similarly, the comparative analysis of total meat intake could not account for the differences in meat-related WF for DDG (248 L·person$^{-1}$·day$^{-1}$), MD (311 L·person$^{-1}$·day$^{-1}$) and NAOS (422 L·person$^{-1}$·day$^{-1}$). The rationale behind these results is that marked differences were observed between the national WFs of the reference countries for milk (most representative item in the dairy food category), beef, pork and chicken. According with Mekonnen and Hoekstra (2010) local climate, soil conditions, data on irrigation and the relative occurrence of the different production systems (grazing, mixed and industrial) explains the differences regarding the corresponding WF of each reference country.

By far, in DGA the largest contribution to the total WF comes from dairy products (790 L·person$^{-1}$·day$^{-1}$). However, NAOS leads the ranking in terms of the WF associated with this food category. Although the contribution of milk to total dietary intake was much higher in the DGA than in NAOS, the Spanish WF for milk was a value 2.2 greater than that of America, according with the study of Mekonnen and Hoekstra (2010), who considered the different production systems and feed composition per animal type and country. On the other hand, DGA represented the country with the highest meat-related water impact (629 L·person$^{-1}$·day$^{-1}$). The high per capita beef consumption in the American guidelines and its associated water demand explain the high WF values. On the other hand, oils and fats WF for DGA (118 L·person$^{-1}$·day$^{-1}$) was lower than for the other dietary patterns. The large variability was due to the fact that, in

the DGA, olive oil was substituted by soybean oil, with a lower WF in USA than olive oil in Spain, The Netherlands or Italy (Mekonnen and Hoekstra, 2011).

Regarding the Italian case study, we found that the meat category had a relatively small WF (150 $L \cdot person^{-1} \cdot day^{-1}$). Based on the IDG, high levels of white meat consumption were observed with a lower WF than red meat (Mekonnen and Hoekstra, 2010). Finally, the low WFs for oils and fats in Italy (250 $L \cdot person^{-1} \cdot day^{-1}$) were indicative of lower olive oil consumption following Italian recommendations (23 $g \cdot person^{-1} \cdot day^{-1}$) compared to the FBDGs of the other olive-growing regions, MD (45 $g \cdot person^{-1} \cdot day^{-1}$) and NAOS (40 $g \cdot person^{-1} \cdot day^{-1}$). In addition, the national Italian WF for olive oil was less than that of the Netherlands and Spain (Mekonnen and Hoekstra, 2011).

Overall, meat, dairy products, oils and fats and starch-based products were the major contributing food groups to WF of the European and American dietary recommendations. Dairy products were the main components of total WFs of NAOS (964 $L \cdot person^{-1} \cdot day^{-1}$) (González-García et al., 2020b), IDG (470 $L \cdot person^{-1} \cdot day^{-1}$) and DGA (790 $L \cdot person^{-1} \cdot day^{-1}$). However, oils and fats were dominant in the dietary WFs of DDG (883 $L \cdot person^{-1} \cdot day^{-1}$) and MD (776 $L \cdot person^{-1} \cdot day^{-1}$). Starch-based products were also major foods contributing to the WF of all the dietary guidelines (ranging from 11% of total WF in NAOS to 23% of total WF in IDG).

#### 4.3.4 Assessment of nutritional quality of diets - Nutrient Rich Diet and Health Gain Score

**Table 4.17** shows the nutrient intake for each FBDGs. These values were obtained considering the amount of each foodstuff and its nutritional information (see **Tables 4.18 - 4.20**). The analysis of nutritional quality focused on the analysis of qualifying nutrients, disqualifying nutrients, and food categories included in the Health Gain Score. The results of this nutritional comparison were used for better interpretation of the NRD9.3 and the Health Gain Score of the FBDGs.

**Table 4.17. Daily average nutrient composition for DDG 2015, MD, NAOS, IDG 2018, NND and DGA 2020-2025.**

| | MD | NAOS | IDG | DDG | NND | DGA | Recommended |
|---|---|---|---|---|---|---|---|
| Boosting nutrients | | | | | | | |
| Protein (g) | 82.2 | 94.9 | 99.8 | 95.0 | 109.5 | 118.3 | 51 |
| Fibre (g) | 36.8 | 32.6 | 45.2 | 28.1 | 35.4 | 35.5 | 25 |
| Vitamin A (µg) | 1557.2 | 1008.9 | 1254.4 | 967.4 | 1359.3 | 894.4 | 750-3000 |
| Vitamin C (mg) | 379.7 | 270.2 | 266.1 | 167.8 | 198.1 | 200.3 | 102-2000 |
| Vitamin E (mg) | 13.4 | 11.8 | 9.7 | 11.0 | 16.8 | 13.8 | 12-300 |
| Calcium (mg) | 980.9 | 1150.8 | 1295.0 | 1177.1 | 1343.0 | 1604.4 | 950-2500 |
| Iron (mg) | 13.4 | 13.2 | 19.6 | 20.5 | 22.9 | 13.3 | 11-45 |
| Potassium (mg) | 4352.6 | 4508.9 | 4370.1 | 3505.5 | 4740.7 | 4348.3 | 3500 |
| Magnesium (mg) | 348.3 | 360.8 | 430.2 | 359.5 | 461.8 | 420.4 | 300 |
| Limiting nutrients | | | | | | | |
| Saturated fat (g) | 21.3 | 24.3 | 22.2 | 24.4 | 23.6 | 29.7 | 24.8 |
| Added sugar (g) | 0.0 | 0.0 | 0.2 | 3.4 | 0.0 | 0.0 | 55.7 |
| Sodium (g) | 1.4 | 1.5 | 2.0 | 2.1 | 2.5 | 2.1 | 2 |

DDG (Dutch Dietary Guidelines), MD (Mediterranean Diet), NAOS (Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity), IDG (Italian Dietary Guidelines), NND (New Nordic Diet), DGA (Dietary Guidelines for Americans)

**Table 4.18. Nutrient intake. Dietary Guidelines for Americans 2020-2025**

| | Carbohydrates (g) | Total fats (g) | Free sugar (g) | Energy (kcal) | Fibre (g) | Saturated fatty acids (g) | Sodium (mg) | Proteins (g) | Vitamin A ($\mu$g) | Vitamin C (mg) | Vitamin E (mg) | Ca (mg) | Fe (mg) | K (mg) | Mg (mg) | Added sugar (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fruits | 38.62 | 0.22 | 30.25 | 157.07 | 6.47 | 0.22 | 0.01 | 2.15 | 71.68 | 79.61 | 0.69 | 58.97 | 1.20 | 642.08 | 45.71 | 0.00 |
| Vegetables | 13.62 | 0.49 | 8.93 | 70.58 | 4.51 | 0.10 | 0.05 | 3.27 | 417.31 | 85.99 | 2.14 | 60.30 | 1.53 | 648.60 | 27.62 | 0.00 |
| Pulses | 30.97 | 0.80 | 1.12 | 190.19 | 13.28 | 0.16 | 0.01 | 13.87 | 2.66 | 0.74 | 0.05 | 53.13 | 2.92 | 579.06 | 100.94 | 0.00 |
| Starch-based products | 108.26 | 8.15 | 10.97 | 643.09 | 9.60 | 0.98 | 1.19 | 20.42 | 2.36 | 13.60 | 0.16 | 112.22 | 3.87 | 746.05 | 74.63 | 0.00 |
| Nuts | 3.92 | 11.59 | 0.75 | 126.85 | 1.68 | 1.04 | 0.00 | 3.84 | 0.00 | 0.00 | 3.59 | 43.20 | 0.72 | 142.79 | 48.68 | 0.00 |
| Dairy products | 39.75 | 13.49 | 32.08 | 552.55 | 0.00 | 18.13 | 0.73 | 39.54 | 353.83 | 18.94 | 0.88 | 1233.82 | 0.68 | 1147.70 | 89.04 | 0.00 |
| Eggs | 0.13 | 2.60 | 0.24 | 32.48 | 0.00 | 0.67 | 0.03 | 2.71 | 41.14 | 0.00 | 0.24 | 12.34 | 0.41 | 28.15 | 2.60 | 0.00 |
| Meat | 0.00 | 9.58 | 0.00 | 125.13 | 0.00 | 3.67 | 0.06 | 25.50 | 0.00 | 1.42 | 0.17 | 12.30 | 1.07 | 282.85 | 18.99 | 0.00 |
| Fish and seafood | 0.24 | 1.46 | 0.00 | 42.52 | 0.00 | 0.29 | 0.05 | 7.03 | 5.40 | 0.00 | 0.73 | 18.07 | 0.93 | 130.92 | 12.23 | 0.00 |
| Sweets | 4.00 | 0.00 | 4.00 | 16.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.08 | 0.00 | 0.00 |
| Oils and fats | 0.00 | 30.60 | 0.00 | 271.73 | 0.00 | 4.41 | 0.00 | 0.00 | 0.00 | 0.00 | 5.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 239.51 | 78.98 | 88.34 | 2228.50 | 35.54 | 29.67 | 2.12 | 118.33 | 894.38 | 200.30 | 13.78 | 1604.39 | 13.35 | 4348.29 | 420.44 | 0.00 |

**Table 4.19. Nutrient intake. Dutch dietary guidelines 2015**

| | Carbohydrates (g) | Total fats (g) | Free sugar (g) | Energy (kcal) | Fibre (g) | Saturated fatty acids (g) | Sodium (mg) | Proteins (g) | Vitamin A ($\mu$g) | Vitamin C (mg) | Vitamin E (mg) | Ca (mg) | Fe (mg) | K (mg) | Mg (mg) | Added sugar (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fruits | 23.69 | 0.18 | 20.80 | 110.09 | 4.47 | 0.21 | 0.00 | 1.26 | 39.81 | 32.82 | 0.82 | 30.45 | 0.85 | 366.77 | 27.40 | 0.00 |
| Vegetables | 15.30 | 0.64 | 6.84 | 66.78 | 4.92 | 0.11 | 0.05 | 4.16 | 548.33 | 81.46 | 1.49 | 89.79 | 1.95 | 637.84 | 33.01 | 0.00 |
| Pulses | 5.75 | 0.17 | 0.66 | 36.00 | 2.55 | 0.03 | 0.00 | 2.70 | 4.97 | 1.66 | 0.02 | 10.63 | 0.61 | 110.31 | 18.51 | 0.00 |
| Starch-based products | 167.86 | 9.63 | 34.63 | 993.98 | 14.48 | 1.13 | 1.41 | 32.58 | 0.00 | 39.14 | 1.47 | 162.58 | 14.36 | 1176.99 | 156.44 | 3.38 |
| Nuts | 3.47 | 11.26 | 1.09 | 130.61 | 1.67 | 1.31 | 0.00 | 4.34 | 1.42 | 0.00 | 2.30 | 32.98 | 0.91 | 151.27 | 42.08 | 0.00 |
| Dairy products | 27.07 | 7.95 | 20.12 | 371.68 | 0.00 | 11.05 | 0.48 | 26.40 | 214.47 | 11.66 | 0.52 | 821.30 | 0.47 | 775.00 | 60.89 | 0.00 |
| Eggs | 0.11 | 2.14 | 0.20 | 26.79 | 0.00 | 0.55 | 0.03 | 2.23 | 33.93 | 0.00 | 0.20 | 10.18 | 0.34 | 23.21 | 2.14 | 0.00 |
| Meat | 0.00 | 7.01 | 0.00 | 89.99 | 0.00 | 2.67 | 0.05 | 18.43 | 0.00 | 1.05 | 0.12 | 8.94 | 0.78 | 202.89 | 13.69 | 0.00 |
| Fish and seafood | 0.06 | 1.06 | 0.00 | 22.78 | 0.00 | 0.18 | 0.04 | 2.71 | 2.12 | 0.00 | 0.12 | 5.25 | 0.20 | 54.10 | 4.81 | 0.00 |
| Sweets | 5.00 | 0.00 | 5.00 | 20.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | 0.10 | 0.00 | 0.00 |
| Oils and fats | 0.07 | 39.98 | 0.00 | 356.50 | 0.00 | 7.10 | 0.07 | 0.15 | 122.33 | 0.03 | 3.93 | 5.00 | 0.00 | 7.00 | 0.50 | 0.00 |
| Total | 248.36 | 80.03 | 89.34 | 2225.59 | 28.08 | 24.36 | 2.11 | 94.96 | 967.38 | 167.82 | 10.99 | 1177.15 | 20.47 | 3505.49 | 359.48 | 3.38 |

**Table 4.20. Nutrient intake. Italian dietary guidelines 2018**

| | Carbohydrates (g) | Total fats (g) | Free sugar (g) | Energy (kcal) | Fibre (g) | Saturated fatty acids (g) | Sodium (mg) | Proteins (g) | Vitamin A ($\mu$g) | Vitamin C (mg) | Vitamin E (mg) | Ca (mg) | Fe (mg) | K (mg) | Mg (mg) | Added sugar (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fruits | 47.30 | 0.23 | 47.84 | 219.54 | 9.30 | 0.25 | 0.01 | 3.38 | 134.40 | 114.62 | 1.46 | 88.58 | 1.66 | 882.32 | 57.37 | 0.00 |
| Vegetables | 19.39 | 0.88 | 16.22 | 102.33 | 12.21 | 0.13 | 0.08 | 6.51 | 779.76 | 126.06 | 2.58 | 118.80 | 2.57 | 1274.14 | 60.76 | 0.00 |
| Pulses | 19.62 | 0.82 | 1.95 | 126.89 | 7.51 | 0.11 | 0.02 | 9.01 | 10.36 | 3.10 | 0.26 | 36.57 | 2.22 | 348.26 | 56.21 | 0.00 |
| Starch-based products | 179.93 | 11.54 | 15.10 | 994.21 | 14.04 | 2.71 | 1.25 | 33.66 | 12.02 | 11.49 | 0.46 | 189.04 | 7.03 | 859.34 | 152.39 | 0.25 |
| Nuts | 1.62 | 4.63 | 0.28 | 50.73 | 0.65 | 0.44 | 0.00 | 1.48 | 0.00 | 0.00 | 1.10 | 15.10 | 0.28 | 52.35 | 18.01 | 0.00 |
| Dairy products | 25.40 | 6.80 | 17.11 | 367.07 | 0.00 | 10.81 | 0.48 | 26.06 | 208.18 | 9.74 | 0.47 | 796.98 | 0.49 | 704.89 | 58.35 | 0.00 |
| Eggs | 0.13 | 2.57 | 0.24 | 32.14 | 0.00 | 0.66 | 0.03 | 2.68 | 40.71 | 0.00 | 0.24 | 12.21 | 0.41 | 27.86 | 2.57 | 0.00 |
| Meat | 0.00 | 3.60 | 0.00 | 49.36 | 0.00 | 1.27 | 0.02 | 10.33 | 0.00 | 1.05 | 0.09 | 5.51 | 0.45 | 106.17 | 7.51 | 0.00 |
| Fish and seafood | 0.62 | 0.77 | 0.00 | 24.92 | 1.52 | 0.18 | 0.06 | 6.71 | 29.17 | 0.00 | 0.23 | 31.46 | 4.48 | 113.91 | 16.87 | 0.00 |
| Sweets | 4.50 | 0.00 | 4.50 | 18.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.09 | 0.00 | 0.00 |
| Oils and fats | 0.00 | 25.68 | 0.00 | 240.45 | 0.00 | 5.64 | 0.02 | 0.04 | 39.84 | 0.00 | 2.85 | 0.75 | 0.01 | 0.75 | 0.10 | 0.00 |
| Total | 298.51 | 57.51 | 103.23 | 2226.01 | 45.23 | 22.20 | 1.97 | 99.84 | 1254.44 | 266.05 | 9.74 | 1295.05 | 19.60 | 4370.08 | 430.15 | 0.25 |

Regarding the qualifying nutrients, all the diets reported an intake of protein, fibre, vitamin A, vitamin C, calcium, potassium and magnesium above the RDVs (EFSA, 2021; NIH, 2021). Dairy products and starch-based products were the main source of protein in all of them. Protein intake came from dairy products in a range from 18 $g \cdot day^{-1}$ in MD to 40 $g \cdot day^{-1}$ in DGA and from starch-based products in a range from 20 $g \cdot day^{-1}$ in DGA to 34 $g \cdot day^{-1}$ in IDG. Meat was also a significant source of protein for DGA (25 $g \cdot day^{-1}$).

Fibre and potassium intakes came mainly from starch-based products (between 10 $g \cdot day^{-1}$ in DGA and 14 $g \cdot day^{-1}$ in IDG for fibre, and between 689 $mg \cdot day^{-1}$ in MD and 1391 $mg \cdot day^{-1}$ in NAOS for potassium). Fibre and potassium also came from fruits and vegetables for plant-rich diets such as the Southern European dietary recommendations and from pulses in the case of beans-rich diets, such as DGA. Dairy products were also identified as major contributors of dietary potassium.

As for the other elements, the main iron contributions came mainly from starch-based products in general (between 4 $mg \cdot day^{-1}$ in DGA to 14 $mg \cdot day^{-1}$ in DDG), and from cereal-based products (including cereal breakfast) in particular. In the case of the IDG, blue fish (striped Venus) and molluscs (clams) also affected the iron intake ratio (4 $mg \cdot day^{-1}$ of iron from fish and seafood in IDG). On the other hand, starch-based products were the major source of magnesium for all the diets (ranging from 75 $mg \cdot day^{-1}$ in DGA to 179 $mg \cdot day^{-1}$ in DDG), except for DGA, for which beans were the main dietary source rich in magnesium (101 $mg \cdot day^{-1}$).

As for vitamins, the amount of pepper in the diet can result in substantial values of vitamin C. Therefore, the highest intake levels of vitamin C were reported for Southern European dietary guidelines (266, 380 and 270 $mg \cdot day^{-1}$ for IDG, MD and NAOS, respectively). Otherwise, the attainment of adequate amounts of vitamin A in the diets analysed was strongly associated with beta-carotene, the main nutrient in carrots. The diet richest in vitamin A was the MD diet (1557 $\mu g \cdot day^{-1}$). Finally, calcium intake levels were also higher than calcium requirements. The highest intake levels corresponded to the DGA (1604 $mg \cdot day^{-1}$), and the lowest to the IDG (981 $mg \cdot day^{-1}$), which can be explained by comparing the recommended intake of dairy products in DGA and MD.

For the last qualifying nutrient (vitamin E) not all the dietary patterns reached the target levels. According to the DDG, IDG and NAOS guidelines, a citizen would not consume enough vitamin E on average to meet their needs (EFSA, 2021). Plant-based oils (ranging from 2 $mg \cdot day^{-1}$ in NND to 5 $mg \cdot day^{-1}$ in MD) and nuts (ranging from 1 $mg \cdot day^{-1}$ in IDG to 4 $mg \cdot day^{-1}$ NND) were the best dietary sources.

For nutrients associated with adverse health effects, added sugars met the limitations in all dietary patterns. However, saturated fats, obtained mainly from both animal fats (e.g., cheese, butter) and vegetable oils (e.g., olive oil), exceeded dietary requirements in DGA. NND, DDG and DGA also exceeded the recommended daily intake of sodium (EFSA, 2021).

For the three food groups included in the Health Gain Score (vegetables, fruits and fish) (van Dooren et al., 2014), vegetables and fruits consumed were higher than the baseline values (WHO, 2003) for all the dietary patterns. Even the quantity of fruits and vegetables exceeded the recommended amount for all of them, differences between diets could be observed. The vegetable and fruit supply for the Southern European recommendations were higher than for Northern European recommendations. The rationale behind this finding is that the Atlantic region is characterised by a wide availability and a culinary tradition of vegetables and fruits (Esteve-Llorens et al., 2019b). Regarding fish intake, (Brink et al., 2019) set 100 g/week of fish as a minimum restriction and 125 g/week as a maximum in agreement with (Kromhout et al.,

2016). Therefore, DDG was the only one who did not meet the dietary recommendations for fish consumption (van Dooren et al., 2014).

Finally, the assessment of nutritional quality was completed by comparing the NRD9.3 and the Health Gain Score of the different FBDGs. As can be seen in **Fig. 4.6**, MD clearly had the highest NRD9.3 (477) and Health Gain Score (178). IDG and NAOS also showed good results for NRD9.3 (455 and 428) and the Health Gain Score (146 and 159). The NND guidelines had a similar value for NRD9.3 (444) as the Southern European Dietary recommendations, but it did not show a clear correlation with the Health Gain Score, which was lower compared to them (119), mainly due to the low amount of vegetables and fruits. The lowest overall health scores were for DGA (NRD9.3 - 391 and Health Gain Score – 116) and DDG (NRD9.3 – 407 and Health Gain Score – 97). These results can be explained considering the low content of vegetables, fruits, fibre intake and fish in DDG and the high content of SFA and sodium in DGA, despite following sanitary recommendations. Both, DDG and DGA, should adopted the other FBDGs to improve their nutritional profile.

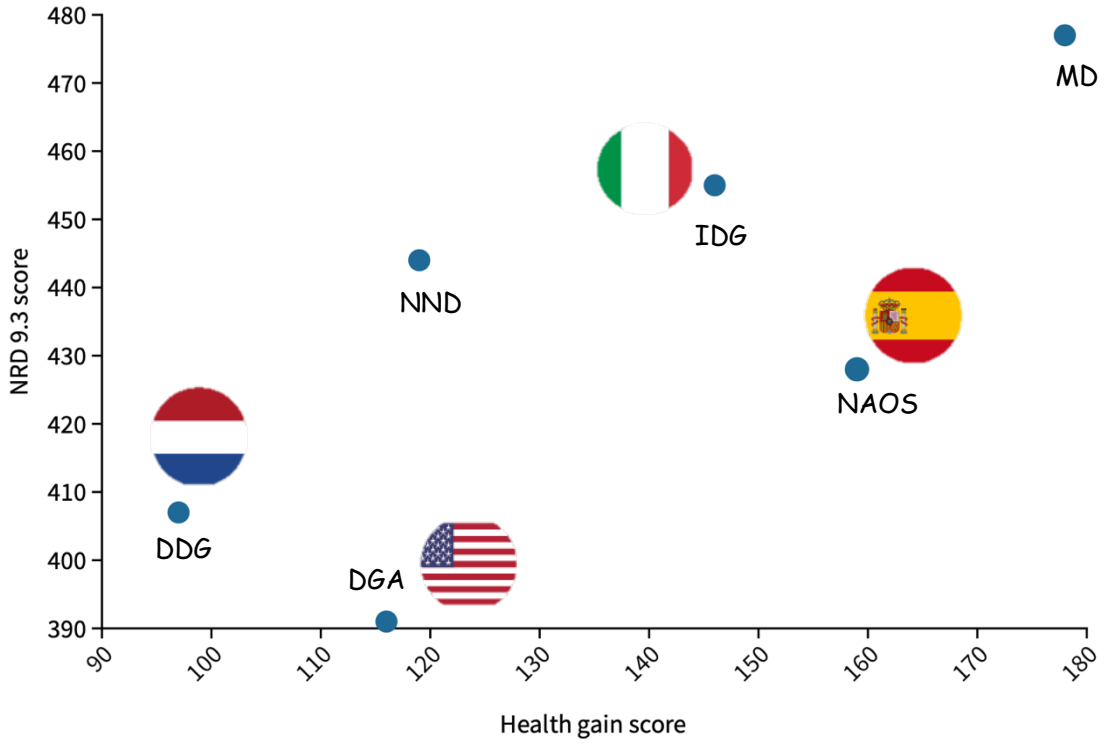


**Fig. 4.6. Comparison between NRD9.3 and Health Gain Score for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020-2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020b) and Ulaszewska et al. (2017).**

### 4.3.5 Comparison of the results with literature data

The findings of this study for CF of DDG, IDG and DGA agree with those reported in the existing literature. Considering the same system boundaries, our result for CF for DDG (2.28 $kgCOeq \cdot day^{-1}$) and DGA (2.98 $kgCO_2eq \cdot day^{-1}$) was considerably lower than that reported by Kovacs et al. (2021) (2.86 and 3.83 $kgCO_2eq \cdot day^{-1}$ for DDG and DGA respectively).

The discrepancy can be attributed to the fact that the GHG emissions estimated by the aforementioned authors not only pertain to an earlier version of the DGA (USDA and HHS, 2015), but also encompass GHG emissions from recommended daily discretionary calories (around 0.43 and 0.52 $kgCO_2eq \cdot day^{-1}$ for DDG and DGA, respectively, considering a caloric intake of 2000 $kcal \cdot person^{-1} \cdot day^{-1}$). Another reason behind these differences is that whereas Kovacs et al. (2021) used the database of Food Impacts of the Environment for Linking to diets (dataFIELD) (OECD-FAO, 2014) as a source for the environmental impact data, we used the same peer-reviewed journal articles as (González-García et al., 2020b) with the main objective of conducting comparative research.

On the other hand, the IDG for healthy eating is based on the well-known MD model. Therefore, their CF was in line with those found in the literature for MD. As an example, (Castañé and Antón, 2017) provided the total GHG emissions of the MD by designing weekly menus. They estimated a CF of 2.06 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ for the food production stage, excluding food waste from the system boundaries. This value was very similar to the one calculated for IDG (2.04 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$) and to the other MD value taken in this study as a basis for comparison (2.21 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$) (González-García et al., 2020b).

The comparison in terms of WF showed the benefits of following the FBDGs for the transition to a fair and efficient use of freshwater resources. Our results regarding WFs for DGA (2583 $L \cdot person^{-1} \cdot day^{-1}$), DDG (2309 $L \cdot person^{-1} \cdot day^{-1}$) and IDG (1761 $L \cdot person^{-1} \cdot day^{-1}$) were considerably lower than those corresponding to the "average" patterns globally. According to the systematic review and meta-analysis by (Harris et al., 2020), the available evidence suggested that total WF of the average dietary patterns was 3227 $L \cdot person^{-1} \cdot day^{-1}$ for Europe and 2617 $L \cdot person^{-1} \cdot day^{-1}$ for North America.

In terms of nutritional quality, the Health Gain Score for DDG (97) and IDG (146) were consistent with the previous recommended DDG score (105) (Health Council, 2006) and with a basic MD (122) (van Dooren et al., 2014). The American Health Gain Score (116) was comparable to the total score of a vegan diet (118) (van Dooren et al., 2014). The NRD9.3 was not directly compared to values reported in the literature due to the variability between the RDVs set depending on the study and different decisions regarding the limitation of nutrients to reference intake levels. In order to facilitate a meaningful comparison, the NRD9.3 was calculated using the average daily nutrient intakes for the MD, vegan and the Atlantic diet, as established by Castañé and Antón (2017) and Esteve-Llorens et al. (2019a), with the considerations taken in this study. The NRD9.3 for IDG (455) was in line with the value for MD recalculated following the results of Castañé and Antón (2017) (477). However, it was lower than the scores for the vegan diet (584) and the Atlantic Diet (550). The NRD9.3 scores for DGA (391) and DDG (407) were lower than the corresponding scores for these three diets.

### 4.3.6 Scalable model for embedding sustainability in global food-based dietary guidelines

The need for a deeper integration of different sustainability domains in FBDGs is a recent issue that should be addressed by governments, international organisations and the food industry. The methodology proposed in this paper for five FBDGs from Northern and Southern Europe and the Americas can be scaled to include sustainability concepts in FBDGs from other

world regions with different cultural traditions and other typical meals. In addition, the approach reported here can be scaled to evaluate other dietary trends that are not country-specific, but widespread, such as the popular Atkins or South Beach diets.

A multilevel database of environmental indicators (such as CF and WFs) and other metrics (nutritional, socioeconomic, and health-related) based on a standardized methodology such as the one described here for FBDGs everywhere would be a good starting point for achieving the SDGs in the food sector. Sharing information through simple indicators would transfer the best features of one FBDG to another, without forgetting the culture of each country or region.

### 4.3.7 Research limitations

Understanding the limitations of this study is important for a correct interpretation of the results. The high variability and geography of the data from the peer-reviewed journal articles on food LCA that were consulted could affect the results. In addition to the high variability, we assigned a single CF to each food item. The diversity of foods included in the FBDGs is too large, and the uncertainty in the CF of each food is unknown to us. Therefore, we cannot provide a reliable and valuable analysis of the uncertainty in the dietary CF. Moreover, since the main purpose of this study is to compare different dietary guidelines, priority was given to using the same LCA for the same food in all FBDGs, leaving geographical considerations and, consequently, local agricultural production methods in the background.

The scarcity of information for estimating the WF of non-aquaculture fish species could also lead to a slight deviation in the results. In addition, transport, food losses and food waste along the food supply chain were not considered, which may underestimate the results in absolute terms, but not for comparison purposes. Finally, the recommended minimum and maximum daily values in the nutrient profiles were mostly taken from European references (EFSA, 2021), without considering differences in the nutritional assessment of the DGA. This fluctuation may be the cause of a slight deviation in the NRD9.3 calculation of the DGA.

## 4.4 Concluding remarks

The links between nutrition and environmental performance in the FBDGs are central to achieving environmental sustainability goals. Despite tremendous variation across countries, the general trend was that high adherence to dietary recommendations was associated with benefits on both nutritional and environmental indicators.

We found that adherence to the DGA was associated with higher carbon emissions compared to recommendations from other high-income countries in Northern and Southern Europe. The CF for the DGA was more than 1.3 times higher when compared with the most plant-rich European diets analysed (e.g., IDG and MD). These findings were related to the higher amounts of dairy products and meat in the DGA.

In contrast, the DGA did not have the highest WF. The two recommended diets in Spain: NAOS and MD had the highest values. To explain these results, special attention was paid not only to the recommended daily intakes of meat, dairy products, starch-based products and fats (main food categories contributing to WF), but also to the different climatic conditions of production, among other agricultural factors and different production systems. The IDG was the best in terms of WF due to its low red meat content and lower national WF for olive oil compared to the Netherlands and Spain.

Although the Italian case study showed the best environmental performance, MD in the Spanish context presented a better nutritional quality, especially when compared to DDG and DGA, the worst according to the two nutritional indicators analysed (NRD9.3 and Health Gain Score). Overall, considering the two nutritional indicators, the dietary patterns of the Southern

European countries showed a better nutritional quality than those of Northern Europe and North America.

Future research on FBDG development can benefit from the findings of this study. Increasing plant-based foods in a manner similar to the IDG or MD may help regions with high dairy and meat consumption, such as North America, without compromising nutritional quality. The main nutrition message of this chapter is that balancing nutrition and sustainability in the FBDGs, with future inclusion of the socio-cultural and economic dimensions, is a key step in translating dietary recommendations into practical consumption patterns. Governments should promote public awareness campaigns and education programs to facilitate the adoption of these healthier and more sustainable dietary recommendations. In summary, governments should provide the public with affordable information on sustainable dietary choices that are consistent with health guidelines.

# 5. UNVEILING THE ENVIRONMENTAL BENEFITS OF THE EAT-LANCET DIET IN THE CONTEXT OF THE SPANISH DIETARY PATTERN[2]

The immediate need to build resilient food systems that reduce greenhouse gas emissions and protect water resources is a global challenge. To address this, the EAT-Lancet Commission described the global reference diet with principles of nutritional quality and environmental sustainability. With this in mind, the carbon and water footprints and the nutritional quality of the current Spanish dietary pattern were compared with the EAT-Lancet global dietary recommendations, taking into account variations in food intake. To provide additional context, the differences between the average Spanish dietary pattern and the dietary guidelines applied in other European countries (Italy, the Netherlands and the Mediterranean region) and America have also been analysed and discussed from a sustainability approach.

We found that the EAT-Lancet diet requires less water resources (3056 $L \cdot person^{-1} \cdot day^{-1}$) and lower level of greenhouse gas emissions (2.13 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$) in comparison with the Spanish dietary pattern (3732 $L \cdot person^{-1} \cdot day^{-1}$ and 3.62 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$, respectively). Starch-based products and oils and fats were identified as the largest contributors to both environmental indicators in the EAT-Lancet diet. On the other hand, meat and dairy products were the environmental hotspots in the Spanish dietary pattern. Comparison with other food-based dietary patterns also raises environmental concerns about the high meat consumption in Spain. In addition, both the EAT-Lancet and the Spanish dietary patterns achieved favourable Health Gain Scores, indicating that they meet nutritional recommendations.

Overall, this analysis suggests that reducing beef and dairy meat consumption to levels consistent with the global environmental targets set by the EAT-Lancet Commission would ensure a shift in Spanish dietary habits towards more environmentally sustainable food consumption patterns.

[2] Cambeses-Franco, C., Feijoo, G., Moreira, M. T., González-García, S., 2022. Co-benefits of the EAT-Lancet diet for environmental protection in the framework of the Spanish dietary pattern. Science of the Total Environment, 836, 155683. https://doi.org/10.1016/j.scitotenv.2022.155683

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## 5.1 INTRODUCTION

The current food system is unsustainable and undermines human well-being and planetary resilience (Fanzo and Miachon, 2023). Primary food production is the main driver of biodiversity loss and puts constant pressure on land, soil and water (Benton et al., 2021). To achieve the United Nations SDGs and the Paris Agreement, it is essential to implement a radical and long-term transformation of conventional food systems (United Nations, 2023b). With these needs and challenges in mind, initiatives have been developed to lay the foundation for public food and nutrition at both the global and national levels.

### 5.1.1 The EAT-Lancet recommendations

At the national level, the Lancet Global Commission has recommended that governments incorporate sustainability principles into national FBDGs to combat the Global Syndemic, a term used to describe three interacting pandemics: obesity, malnutrition and climate change (Kraak and Stanley, 2023). National FBDGs provide a framework for promoting healthy eating habits and lifestyles. In **Chapter 4**, we examined the environmental sustainability of several representative dietary guidelines from Europe and America.

Globally, the EAT-Lancet Commission addresses the need to provide healthy diets for the world's growing population while defining sustainable food systems that minimise damage to our planet in terms of GHG, phosphorus and nitrogen emissions, water scarcity, biodiversity loss and LU change (Springmann et al., 2018a, 2018b).

The EAT-Lancet reference diet is characterised by a high intake of fruits, vegetables, whole grains, legumes, nuts, and unsaturated oils, and a drastic reduction in the consumption of red meat, sugar, and refined grains (Willett et al., 2019b). Recent studies have documented the consequences of adherence to this diet in terms of nutritional quality, health, environmental, and economic criteria. The Cancer and Nutrition (EPIC)-Oxford study reported the association of this reference diet with a lower risk of ischemic heart disease and diabetes (Knuppel et al., 2019) and Hirvonen et al. (2020) compared its affordability in different economic contexts. From a nutritional perspective, Blackstone and Conrad (2020) conducted a comparison between the EAT Lancet diet and the DGA, and Sharma et al. (2020) identified deviations with the Indian diet in terms of caloric intake and dietary composition. From an environmental perspective, Kesse-Guyot et al. (2021) explored the link between the adherence to the EAT-Lancet diet among French adults and three associated environmental pressures (GHG emissions, CED, and land occupation), and Kovacs et al. (2021) modelled the CF of seven FBDGs (Germany, India, The Netherlands, Oman, Thailand, Uruguay and the United States) and compared them with the EAT-Lancet diet.

### 5.1.2 Are current diets in line with the EAT-Lancet recommendations?

The extent to which current diets deviate from the environmental impact of the EAT-Lancet recommendations and national FBDGs remains poorly understood. This question is particularly challenging in Spain, where two omnivorous dietary recommendations that are highly ranked in terms of economic, health and environmental criteria have a strong influence on dietary habits: MD and NAOS (González-García et al., 2020b).

An open debate is how media and educational campaigns to promote these "win-win" diets have affected the increasingly Westernized Spanish consumption pattern in terms of CF and WF. To the best of our knowledge, two papers have examined the impact of dietary patterns in different climatic zones and autonomous communities of Spain on CF and other nutritional and socio-economic criteria (Esteve-Llorens et al., 2020b, 2021). The food habits associated with each climatic zone can be explained on the basis of geoclimatic conditions, food culture and

tradition, and economic level. The assessment of the CF of food habits in northern Spain showed higher CF values in comparison with those obtained from Southern Spain due to the greater consumption of animal-based products and more caloric dietary patterns in the North (Esteve-Llorens et al., 2021). Moreover, seven autonomous communities showed sustainable dietary patterns (Andalusia, Community of Madrid, Basque Country, Navarre, Catalonia, Balearic Islands and Canary Islands (Esteve-Llorens et al., 2020b). On the other hand, a study on the CF of the average Spanish dietary pattern in 2006 and 2016 was carried out without considering water consumption (Batlle-Bayer et al., 2019).

The main objectives of **Chapter 5** were: i) to translate the EAT-Lancet recommendations to the Spanish socio-cultural scenario, ii) to compare the environmental indicators (CF and WF) and the nutritional quality (Health Gain Score) of the EAT-Lancet and the average Spanish dietary pattern, and iii) to discuss the differences between the average Spanish dietary pattern and the FBDGs from Spain (MD and NAOS) and other regions of the world (The Netherlands, United States and Italy). From a public perspective, this may shed light on the changes that may be necessary to transform the current Spanish dietary pattern into a healthy and sustainable universal reference diet.

## 5.2 MATERIALS AND METHODS

### 5.2.1 Description of dietary scenarios: Spanish Food consumption pattern and EAT-Lancet diet

#### 5.2.1.1 Average Spanish dietary pattern

The Spanish average dietary pattern was based on the 2019 Household Consumption Survey of the Ministry of Agriculture, Fisheries and Food (MAPA, 2019). The survey is conducted annually and covers a representative sample of more than 12,000 households. The most recent data, prior to COVID-19, were used, as lockdown conditions such as reduced social activity, may have influenced dietary preferences. The average consumption per capita and year for each food category was obtained from the database, taking into account that 82% of food consumption takes place at home and 18% outside the home (MAPA, 2020b).

Thus, the average Spanish dietary scenario was designed based on the information provided by the aforementioned database on the frequency of intake per food category and the amount in grams of the most consumed foods that make up each food group in the Spanish population. The caloric intake associated with the Spanish dietary pattern was calculated by multiplying the amount of grams of each food by the amount of energy per gram of each food. The BEDCA food composition database was used to determine the caloric content of each food (BEDCA, 2017). Thus, the energy supply estimated considering in-home and out-of-home consumption was estimated on 2214 $kcal \cdot person^{-1} \cdot day^{-1}$. The scenario includes a wide variety of 59 representative foods, grouped into 14 food categories as can be seen in **Table 5.1** according to the classification established by González-García et al. (2020b).

#### 5.2.1.2 EAT-Lancet diet

This scenario corresponds to the EAT-Lancet dietary recommendations defined by Willett et al. (2019b) for an individual intake of 2500 kcal/day. The reference diet proposes flexible intake ranges (weight and caloric intake) for the eight defined food groups (whole grains, tubers or starchy vegetables, vegetables, fruits, dairy, protein sources, added fats and added sugars) and could be adopted for different cultures.

To facilitate a direct comparison with the Spanish average dietary pattern, the eight food groups defined by the EAT-Lancet recommendations were reclassified according to the classification established by González-García et al. (2020b). The EAT-Lancet dietary scenario

has been adjusted to an intake of 2500 kcal/day taking into account the flexible intake ranges for each food category based on EAT-Lancet recommendations for a healthy reference diet.

EAT-Lancet recommendations give advice regarding the macronutrient intake ($g \cdot day^{-1}$) and caloric intake ($kcal \cdot day^{-1}$) per food category. However, it does not take into account the amount of each food in g that makes up each group. This gap in the guidelines was used as a strategy to adapt the EAT-Lancet recommendations to the Spanish socio-cultural scenario. Therefore, the representative foods of each food category have been identified from the most consumed foods of the Spanish population, gathered in the Household Consumption Survey by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2019). **Table 5.1** shows the average daily recommended intake per food group in the Spanish adaptation of the EAT-Lancet recommendations.

Table 5.1. Daily-recommended intake (g·person$^{-1}$·day$^{-1}$) per food group for EAT-Lancet diet and Spanish Dietary Pattern (SDP)

| Fruits | Lancet | SDP |
|---|---|---|
| Oranges | 68.2 | 79.3 |
| Mandarine | 24.5 | 28.4 |
| Banana | 51.6 | 59.9 |
| Apple | 39.9 | 46.4 |
| Pear | 19.7 | 22.9 |
| Melon | 32.7 | 38.0 |
| Watermelon | 34.0 | 39.5 |

| Ready meals | Lancet | SDP |
|---|---|---|
| Soups and creams | - | 24.2 |
| Pizza | - | 10.3 |
| Preserved food | - | 12.3 |
| Sauces | - | 11.2 |

| Sweets | Lancet | SDP |
|---|---|---|
| Honey | 3.4 | 1.4 |
| Sugar | 26.6 | 10.7 |

| Vegetables | Lancet | SDP |
|---|---|---|
| Tomatoes | 125.7 | 97.3 |
| Onion | 67.0 | 51.9 |
| Peppers | 45.5 | 35.3 |
| Lettuce | 37.4 | 29.0 |
| Carrots | 31.8 | 24.6 |
| Courgette | 37.4 | 28.9 |
| Cucumber | 19.2 | 14.8 |

| Oils and fats | EAT-Lancet | SDP |
|---|---|---|
| Palm oil | 6.7 | - |
| Olive oil | 39.9 | 39.0 |
| Lard or tallow | 5.0 | - |

| Pastry | Lancet | SDP |
|---|---|---|
| Biscuits | - | 25.5 |
| Cereal breakfast | - | 7.6 |
| Nougat | - | 3.7 |
| Chocolate | - | 17.0 |
| Snacks | - | 2.7 |

| Nuts | Lancet | SDP |
|---|---|---|
| Olives | - | 12.6 |
| Almonds | 6.8 | 1.3 |
| Walnut | 18.2 | 3.4 |
| Peanut | 26.0 | 1.5 |

| Pulses | Lancet | SDP |
|---|---|---|
| Chickpeas | 20.7 | 4.7 |
| Beans | 13.9 | 3.2 |
| Lentils | 14.5 | 3.3 |

| Meat | Lancet | SDP |
|---|---|---|
| Beef | 9.5 | 27.8 |
| Chicken | 35 | 71.0 |
| Pork | 9 | 55.3 |
| Processed | - | 13.5 |

| Dairy | Lancet | SDP |
|---|---|---|
| Milk | 153.9 | 282.5 |
| Yogurt | 21.8 | 40.0 |
| Cheese | 17.3 | 31.8 |
| Ice-Cream | - | 12.0 |

| Soy foods | Lancet | SDP |
|---|---|---|
| Flour | 12.5 | - |
| Soybean oil | 12.5 | - |

| Starch-based | Lancet | SDP |
|---|---|---|
| Bread | 242.3 | 107.4 |
| Rice | 29.9 | 13.3 |
| Pasta | 32.3 | 14.3 |
| Potatoes | 53.4 | 95.5 |

| Fish | Lancet | SDP |
|---|---|---|
| Hake | 9.1 | 17.6 |
| Mackerel | 1.1 | 2.0 |
| Salmon | 4.5 | 8.7 |
| Pilchard | 4.5 | 8.7 |
| Cod | 3.2 | 6.2 |
| Tuna | 1.7 | 3.4 |
| Prawns | 6.5 | 12.5 |
| Squids | 4.8 | 9.2 |
| Mussels | 3.7 | 7.1 |

| Eggs | Lancet | SDP |
|---|---|---|
| Eggs | 12.5 | 27.9 |

Note: Plant-based foods (dark green), animal-products (light green), other products (blue)

### 5.2.2 Environmental impact assessment: Carbon and water footprints

#### 5.2.2.1 Carbon footprint

The LCA approach was followed to allow a comprehensive assessment of the CF. As aforementioned, the goal of this study was to compare the environmental profile of two dietary patterns from a cradle-to-consumer perspective, the average Spanish dietary patterns and the EAT-Lancet diet. To do so, it is necessary to choose a functional unit. The average daily reference dietary intake per person was chosen as functional unit.

The description of the system under study implies the definition of the system boundaries. The two dietary patterns were analysed with the scope limited to the cradle-to-consumer phases along the life cycle (**Fig. 5.1)**.

Agricultural or industrial production: This subsystem includes all agricultural and industrial activities involved in the transformation of raw agricultural products into food products ready for distribution.

Wholesale and retail distribution: This subsystem includes the delivery of the food products to the wholesale and retail customers. The calculation of the CF corresponding to this subsystem was done taking into account the geographical origin of all food products included in the dietary scenarios. Food waste and losses in the wholesale and retail distribution subsystem were considered.

Household distribution: This subsystem includes transport from supermarkets to households. Household food waste was considered at this stage.

Food preparation at home was not taken into account because both dietary scenarios were adapted to the Spanish food culture and therefore both use similar cooking techniques, avoiding complex cooking methods. In addition, the exclusion of cooking from the system boundaries was also considered in other similar studies available in the literature for other guidelines in Europe and America, facilitating the comparison (Cambeses-Franco et al., 2022; González-García et al., 2020b).

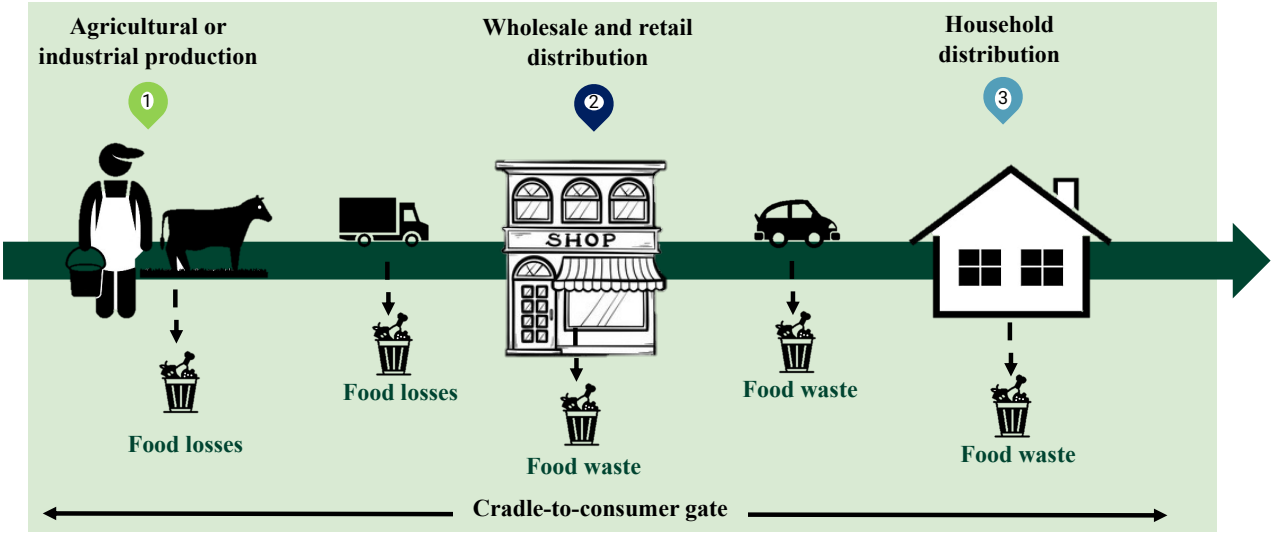


**Fig. 5.1. System boundaries considered in the carbon footprint assessment**

Life cycle inventories for each foodstuff were compiled through a systematic literature review. Priority criteria were: i) scientific peer-reviewed LCA articles, ii) Spain as the country of reference, iii) life cycle studies from a cradle-to-gate perspective (where no or low-quality studies using this LCA approach were available, additional stages have been discarded). A detailed summary of the GHG emissions associated with each food item was gathered in **Table 5.2**.

CF associated to the transportation of a food product from its production site to households was calculated according to the methodology proposed by González-García et al. (2020b). The Multidimensional Datacomex platform provided free access to the origin and volumes of imports and exports per food item and country (for details, see **Table 5.3**). For international logistics, transoceanic vessels (18.60 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$) and trucks (92.10 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$) were considered (González-García et al., 2020b). For national logistics, transport by truck to wholesalers and retailers was assumed to be 400 km by Euro 5 diesel freight trucks (>32 tons) (Castañé and Antón, 2017). A diesel vehicle (106 g $CO_2$eq·km$^{-1}$) was chosen as a means of transport to travel from homes to the nearest supermarket (Batlle-Bayer et al., 2019) with a shopping frequency of once a week (average distribution distance of 3.3 km) (González-García et al., 2020b).

To address the challenge of balancing food waste with food policy and security (Chen et al., 2020), the proportions of food loss and food waste during wholesale and retail transport (Gustavsson et al., 2013) and factors of food waste at the household consumer level (Garcia-Herrero et al., 2018) were included into the CF assessment.

**Table 5.2. Carbon footprint per food item.**

| Foodstuff | Source | Carbon footprint ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|
| Fruits | | |
| Oranges | (Aguilera et al., 2015a) | 0.15 |
| Mandarin | (Aguilera et al., 2015a) | 0.15 |
| Banana | (Aguilera et al., 2015a) | 0.64 |
| Apple | (Aguilera et al., 2015a) | 0.12 |
| Pear | (Aguilera et al., 2015a) | 0.12 |
| Melon | (Clune et al., 2017) | 0.51 |
| Watermelon | (Clune et al., 2017) | 0.32 |
| Vegetables | | |
| Tomato | (Aguilera et al., 2015b) | 0.22 |
| Onion | (Aguilera et al., 2015b) | 0.24 |
| Peppers | (Aguilera et al., 2015b) | 0.22 |
| Lettuce | (Aguilera et al., 2015b) | 0.23 |
| Carrots | (Nemecek et al., 2012) | 0.20 |
| Courgette | (Aguilera et al., 2015a) | 0.20 |
| Cucumber | (Audsley et al., 2009) | 1.30 |
| Soy foods | | |
| Soybean flour | (González et al., 2011) | 0.46 |
| Soybean oil | (Heller et al., 2018) | 0.81 |
| Pulses | | |
| Chickpeas | (Clune et al., 2017) | 0.67 |
| Beans | (Clune et al., 2017) | 0.51 |
| Lentils | (Clune et al., 2017) | 1.03 |
| Starch-based products | | |
| Bread | (Espinoza-Orias et al., 2011; Kulak et al., 2015; Notarnicola et al., 2017) | 1.15 |
| Rice | (Hess et al., 2016) | 2.31 |
| Pasta | (Hess et al., 2016) | 1.28 |
| Potatoes | (Aguilera et al., 2015b) | 0.24 |
| Nuts | | |
| Olives | (Clune et al., 2017) | 0.63 |
| Almond | (Clune et al., 2017) | 1.74 |
| Walnut | (Clune et al., 2017) | 1.62 |
| Peanut | (Volpe et al., 2015) | 0.62 |
| Dairy products | | |
| Milk | (Iribarren et al., 2011a) | 0.77 |
| Yogurt | (González-García et al., 2013a) | 1.50 |
| Cheese | (González-García et al., 2013c) | 10.44 |
| Ice-cream | (Werner et al., 2014) | 2.80 |
| Eggs | | |
| Eggs | (Nielsen et al., 2013) | 1.80 |

**Table 5.2. (cont.) Carbon footprint per food item.**

| Foodstuff | Source | Carbon footprint ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|
| | Meat | |
| Beef | (van Oort and Andrew, 2016) | 24.69 |
| Pig | (Noya et al., 2017) | 2.50 |
| Chicken | (González-García et al., 2014) | 4.96 |
| Processed meat | (Noya et al., 2017) | 14.55 |
| | Fish and seafood | |
| Hake | (Iribarren et al., 2010b) | 5.98 |
| Mackerel | (Vázquez-Rowe et al., 2010a) | 1.54 |
| Salmon | (Sherry and Koester, 2020) | 2.26 |
| Pilchard | (González-García et al., 2015a) | 0.43 |
| Cod | (Ziegler et al., 2013) | 1.20 |
| Tuna | (Hospido and Tyedmers, 2005) | 1.64 |
| Prawns | (Clune et al., 2017) | 14.85 |
| Squids | (Iribarren et al., 2010b) | 3.86 |
| Mussels | (Iribarren et al., 2010a) | 1.42 |
| | Sweets | |
| Honey | (Scarborough et al., 2014) | 1.00 |
| Sugar | (Klenk et al., 2012) | 0.23 |
| | Oils and fats | |
| Olive oil | (Monini, 2014) | 3.73 |
| Palm oil | (Winnipeg, 2012) | 2.93 |
| Lard or tallow | (Noya et al., 2017) | 4.96 |
| | Pastry | |
| Biscuits | (Konstantas et al., 2019) | 1.03 |
| Breakfast cereals | (Jeswani et al., 2015) | 2.64 |
| Nougat (Christmas foods) | (Miah et al., 2018) | 1.75 |
| Chocolate | (Miah et al., 2018) | 3.60 |
| Snacks | (Berners-Lee et al., 2012) | 1.90 |
| | Ready meals | |
| Soups and creams | (Berners-Lee et al., 2012) | 4.00 |
| Pizza | (Werner et al., 2014) | 2.50 |
| Tinned fish | (Berners-Lee et al., 2012) | 4.60 |
| Tinned vegetables | (Berners-Lee et al., 2012) | 4.00 |
| Tinned pasta | (Hess et al., 2016) | 1.28 |
| Sauces | (Berners-Lee et al., 2012) | 2.10 |

**Table 5.3. Importing and exporting volumes, and distribution distances per food item.**

| | Export (t) | Import (t) | Import distance (km) | National distance (km) |
|---|---|---|---|---|
| | | Fruits | | |
| Oranges | 1756863 | 148549 | 412 | 366 |
| Mandarin | 1082744 | 17302 | 32 | 392 |
| Banana | 99999 | 391506 | 4149 | 173 |
| Apple | 127076 | 217563 | 320 | 281 |
| Pear | 137170 | 61334 | 566 | 304 |
| Melon | 455783 | 94671 | 2063 | 273 |
| Watermelon | 910929 | 81709 | 336 | 312 |
| | | Vegetables | | |
| Tomato | 767369 | 198203 | 35 | 382 |
| Onion | 404587 | 81834 | 676 | 371 |
| Peppers | 828961 | 63259 | 69 | 360 |
| Lettuce | 829872 | 23359 | 126 | 353 |
| Carrots | 111023 | 19266 | 56 | 374 |
| Courgette | 414930 | 19548 | 63 | 363 |
| Cucumber | 709190 | 8477 | 202 | 312 |
| | | Soy foods | | |
| Soybean flour | 4953 | 28521 | 485 | 0 |
| Soybean oil | 306158 | 129054 | 4932 | 0 |
| | | Pulses | | |
| Chickpeas | 6019 | 57473 | 6130 | 173 |
| Beans | 4798 | 36524 | 784 | 235 |
| Lentils | 3797 | 48467 | 5575 | 158 |
| | | Starch-based products | | |
| Bread | 24927 | 15473 | 15 | 393 |
| Rice | 291848 | 210227 | 2624 | 288 |
| Pasta | 144239 | 107840 | 562 | 245 |
| Potatoes | 302981 | 839271 | 261 | 280 |
| | | Nuts | | |
| Olives | 12010 | 2685 | 0 | 400 |
| Almond | 107825 | 110464 | 2747 | 271 |
| Walnut | 2527 | 32035 | 6413 | 128 |
| Peanut | 2470 | 50256 | 36526 | 63 |
| | | Dairy products | | |
| Milk | 87853 | 122300 | 15 | 394 |
| Yogurt | 77432 | 130960 | 153 | 348 |
| Cheese | 107581 | 309743 | 657 | 208 |
| Ice-cream | 48569 | 73253 | 1160 | 0 |
| | | Eggs | | |
| Eggs | 119301 | 21334 | 22 | 388 |
| | | Meat | | |
| Beef | 217937 | 136605 | 493 | 304 |
| Pig | 2184047 | 114686 | 12 | 396 |
| Chicken | 180799 | 95870 | 482 | 331 |
| Processed meat | 150182 | 89427 | 86 | 374 |

**Table 5.3. (cont.) Importing and exporting volumes, and distribution distances per food item.**

| | Export (t) | Import (t) | Import distance (km) | National distance (km) |
|---|---|---|---|---|
| | | Sweets | | |
| Honey | 22528 | 26547 | 4176 | 82 |
| Sugar | 165039 | 1739038 | 2022 | 46 |
| | | Oils and fats | | |
| Olive oil | 1077213 | 148562 | 231 | 330 |
| Palm oil | 78913 | 1996387 | 11278 | 0 |
| | | Pastry | | |
| Biscuits | 192876 | 58102 | 250 | 321 |
| Breakfast cereals | 957215 | 15548030 | 2097 | 173 |
| Chocolate | 120671 | 150554 | 993 | 82 |
| | | Ready meals | | |
| Pizza | 144943 | 85402 | 21 | 390 |
| Tinned vegetables | 569754 | 56647 | 18 | 389 |
| Sauces | 85982 | 24323 | 122 | 370 |

Notes:

It was assumed that there was no national production of soy foods and palm oil.
Breakfast cereals were considered as products derived from wheat, rice and corn.
Pizza was assimilated to its main ingredient, wheat flour.
As tomato is by far the most consumed canned vegetable in Spain, data for canned vegetables were related to tomato.
To estimate the data for sauces, tomato sauce was used as a reference.
Due to lack of information, lard or tallow, nougat, snacks and soups and creams were of national origin. Therefore, they were not included in the table.

5.2.2.2 Water footprint

The first two steps of WF assessment, namely goal and scope and WF accounting, were addressed in this study (Muthu, 2020). The three key water components (green, blue and grey) were tracked using the comprehensive study of the agricultural and livestock WFs as a reference dataset (Mekonnen and Hoekstra, 2011, 2012). As climatic and production conditions are the main factors influencing green and blue WF, to ensure the geographical basis of food products, the methodological approach proposed by González-García et al. (2020b) was adopted.

Therefore, the WF of the category j for the food item F ($m^3 \cdot t^{-1}$) nationally produced ($NWF_{j,F}$) ($m^3 \cdot t^{-1}$) was obtained directly from the reported values in the Mekonnen and Hoekstra dataset for Spain (Mekonnen and Hoekstra, 2011, 2012). On the other hand, the imported total $WF_j$ of a food item F ($IWF_{j,F}$) ($m^3 \cdot t^{-1}$) was estimated based on the WF of each category j and country c, considering a representative number of importing countries (n) (the ones that supply a percentage of the total volume of imports superior to 70%), and being $R_{c,F}$, the recalculated importing ratio for a country c taking into account only the representative countries (see **Eq. 5.1**)

$$IWF_{j,F} = \sum_{c=1}^{n} WF_{j,c,F} \cdot R_{c,F} \quad (5.1)$$

The WF per food product F ($m^3 \cdot person^{-1} \cdot day^{-1}$) was calculated based on **Eq. 5.2**.

$$WF_F = \sum_{j=1}^{3} (IWF_{j,F} \cdot X_{I,F} + NWF_{j,F} \cdot X_{N,F}) \cdot M_F \cdot 10^{-6} \quad (5.2)$$

Where $X_{I,F}$ and $X_{N,F}$ are the average ratios of food imported and nationally produced, respectively, and $M_F$ (g·person$^{-1}$·day$^{-1}$) is the food intake by dietary scenario of the food item F. Food losses and food waste along the distribution chain and at the household consumer level were considered as for the CF assessment.

Finally, the WF per dietary scenario was estimated based on **Eq. 5.3**.

$$WF_{diet} = \sum_{F=1}^{k} WF_F \quad (5.3)$$

For aquaculture species, we estimated the WF related to commercial feeds (Pahlow et al., 2015) and for non-aquaculture, a WF of zero was assumed (Blas et al., 2019; Harris et al., 2017).

### 5.2.3 Nutritional quality assessment through the Health Gain Score

The Health Gain Score was used to assess the nutritional quality of the diets (van Dooren et al., 2014). For a deeper understanding, see **Chapter 3 (Section I)**, which unpacks the formula of the score, relevant nutrients and key factors.

## 5.3 Results

### 5.3.1 Carbon footprint comparison between Spanish and EAT-Lancet diets

The GHG emissions value attributed to the current Spanish dietary pattern was 3.62 kg$CO_2$eq·person$^{-1}$·day$^{-1}$. On the other hand, the CF of the EAT-Lancet recommendations was approximately 1.7 times lower (2.13 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). The agricultural or industrial production stage is responsible for the largest share of GHG emissions in both scenarios, accounting for 91% and 96% of the total CF in the EAT Lancet and the current Spanish diet, respectively. In terms of total GHG emissions, the remaining stages of the supply chain make a smaller contribution in the two diets analysed. While the EAT-Lancet diet accounted for 0.13 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ in wholesale and distribution, the GHG emissions derived from this stage in the current Spanish dietary pattern were 0.09 kg$CO_2$eq·person$^{-1}$·day$^{-1}$. The higher levels of peanut consumption per capita in the EAT-Lancet diet, together with the high distribution distances (truck and ship) for this food, could explain the differences in the CF results for the wholesale and the distribution between both dietary patterns.

The CF associated with the household distribution phase was 0.06 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ regardless of the scenario. In terms of food waste, 0.13 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ and 0.21 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ were attributed to food loss and food waste for the EAT Lancet and the current Spanish dietary pattern, respectively. The highest CF relative to food waste for the Spanish dietary pattern was associated with the most significant contribution of dairy, meat, fish and their associated food waste and loss.

The daily CF attributed to both dietary scenarios, broken down by food categories, is shown in **Fig. 5.2.** The CFs for dairy products, eggs, meat, fish and seafood for the average Spanish dietary pattern are higher than the CFs calculated for the EAT-Lancet recommended ranges of macronutrient intakes for these food groups. Foods of animal origin were the main dietary contributors to this environmental metric, accounting for 47% in the EAT-Lancet recommendation and 72% in the current Spanish dietary pattern. Meat and dairy products were the main hotspots in the Spanish dietary pattern (1.42 and 0.70 kg$CO_2$eq·person$^{-1}$·day$^{-1}$, respectively). On the other hand, the CF of starch-based products were quantitatively the most important in the EAT-Lancet recommendations (0.45 kg$CO_2$eq·person$^{-1}$·day$^{-1}$), although closely followed by meat (0.39 kg$CO_2$eq·person$^{-1}$·day$^{-1}$) and dairy (0.35 kg$CO_2$eq·person$^{-1}$·day$^{-1}$).

EAT-Lancet does not publish gram ranges for bakery products and ready meals. In this diet, the CF scores related to total vegetables, pulses, soy foods, starch-based products, nuts, and oils and fats were higher than those of the Spanish pattern. The fact that the EAT-Lancet diet emphasizes the consumption of plant-based foods is behind the higher production-based GHG emissions. The CF for fruits and sweets was similar between the EAT-Lancet pattern and the Spanish pattern.

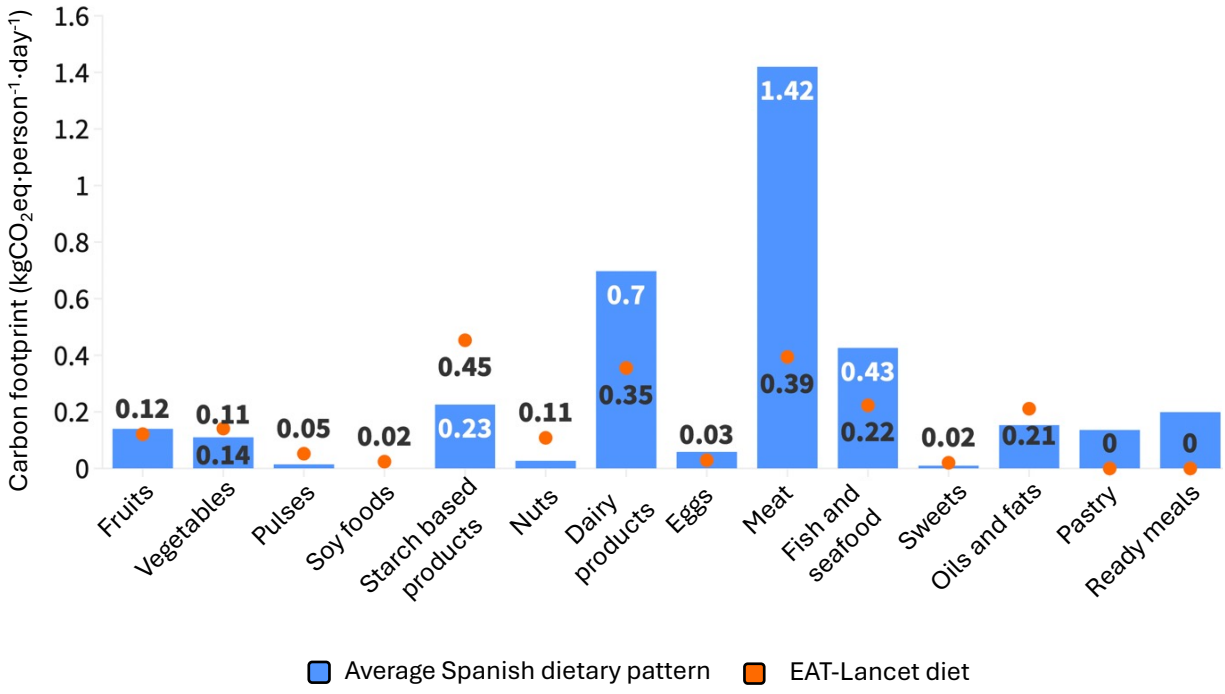


**Fig. 5.2. Carbon footprint estimation ($kgCO_2eq \cdot person^{-1} \cdot day^{-1}$) per food groups for EAT-Lancet diet and average Spanish dietary pattern.**

### 5.3.2 Water consumption of Spanish and EAT-Lancet diets

Our analysis reported the average WF of the Spanish dietary pattern (3732 $L \cdot person^{-1} \cdot day^{-1}$) and that of the EAT-Lancet diet (3057 $L \cdot person^{-1} \cdot day^{-1}$). The dietary green WF represented by far the largest fraction of the total WF for both diets (74% and 79% for the EAT-Lancet diet and the Spanish dietary pattern, respectively). Data on the contribution of food categories to dietary WFs of each dietary pattern are depicted in **Fig. 5.3** and **Table 5.4**.

Dairy products, meat, and oils and fats were the main contributors to dietary WF in the average Spanish diet. However, large differences in the interpretation of WF scores for these three main contributing food groups were explored for both diets. The WF scores for dairy and meat in the average Spanish dietary pattern (834 and 1024 $L \cdot person^{-1} \cdot day^{-1}$, respectively) were significantly higher than the EAT-Lancet recommendations (423 and 297 $L \cdot person^{-1} \cdot day^{-1}$, respectively), while those of oils and fats were slightly lower (679 and 745 $L \cdot person^{-1} \cdot day^{-1}$ for Spanish dietary pattern and EAT-Lancet, respectively). These results could be explained on the basis of the daily intake amounts of these food groups in the definition of the dietary patterns.

Plant-based products, such as starch-based products and nuts, were also presented as large contributors to the dietary WF of the EAT-Lancet recommendations (538 and 470 $L \cdot person^{-1} \cdot day^{-1}$, respectively). However, they were among the lowest WF scores on the average Spanish dietary pattern (253 $L \cdot person^{-1} \cdot day^{-1}$ for starch-based products and 119 $L \cdot person^{-1} \cdot day^{-1}$ for

nuts). The reason behind this finding is that the reference diet is largely plant-based. Other plant-based products with lower WF contributions, legumes and soy foods, also showed higher WF values in the EAT-Lancet reference diet (213 and 90 L·person$^{-1}$·day$^{-1}$, respectively) compared to those of the Spanish average dietary pattern (49 and 0 L·person$^{-1}$·day$^{-1}$, respectively). However, no significant differences were found for the fruits and vegetables categories between the EAT-Lancet recommendation (123 L·person$^{-1}$·day$^{-1}$ for fruits and 60 L·person$^{-1}$·day$^{-1}$ for vegetables) and the Spanish food consumption pattern (143 L·person$^{-1}$·day$^{-1}$ for fruits and 46 L·person$^{-1}$·day$^{-1}$ for vegetables). Although fruits and vegetables contributed in a different proportion to the daily intake in the EAT-Lancet diet (271 and 364 g·person$^{-1}$·day$^{-1}$ for fruits and vegetables, respectively) compared to the Spanish dietary patterns (314 and 282 g·person$^{-1}$·day$^{-1}$ for fruits and vegetables, respectively), their associated water requirements are not so high to account for significative differences. Compared to the reference diet, the WF of other foods of animal origin (eggs, fish and seafood) was higher in the current average Spanish diet. The associated WF of pastries and prepared foods was not included in the EAT-Lancet reference diet.

### 5.3.3 Nutritional quality evaluation of Spanish and EAT-Lancet diets using the Health Gain Score

The Health Gain Score was considered as the metric to compare the nutritional quality of the EAT-Lancet diet and the Spanish dietary patterns. It was observed that both diets yielded similar scores (126 and 130, respectively). This can be attributed to the lower intake of fruits and vegetables in the Spanish diet, which was compensated by the higher consumption of fish and seafood compared to the EAT-Lancet recommendations.

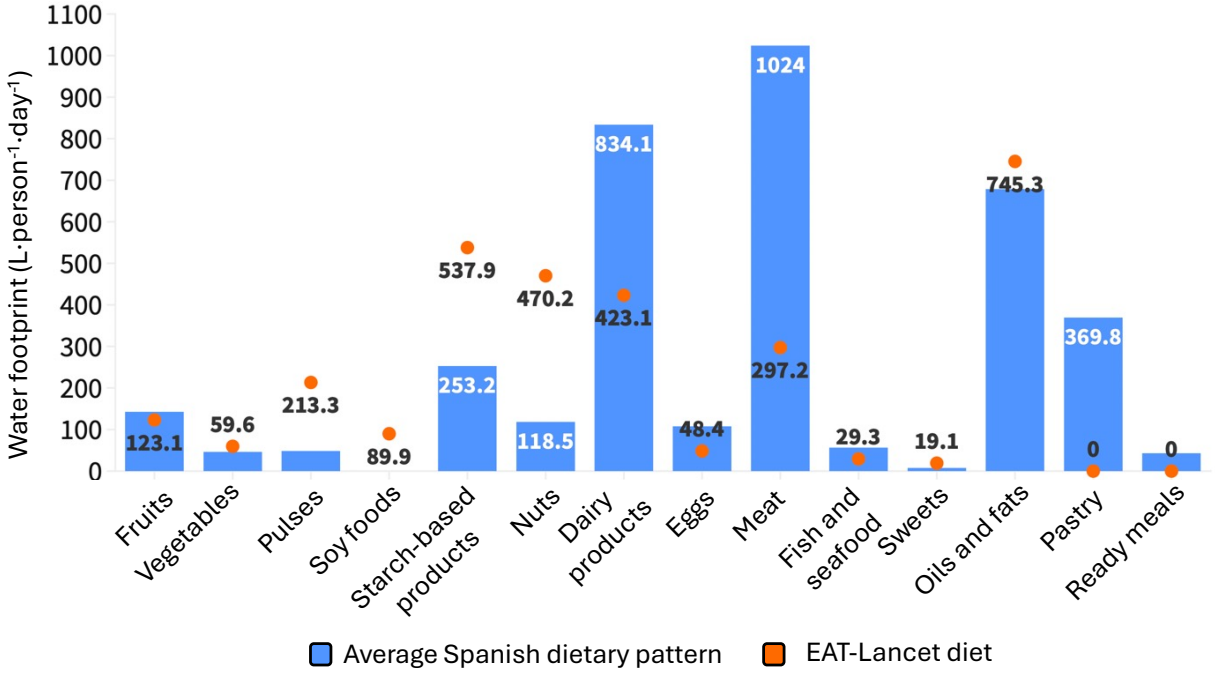


**Fig. 5.3. Water footprint estimation (L·person$^{-1}$·day$^{-1}$) per food groups for EAT-Lancet diet and average Spanish dietary pattern.**

**Table 5.4. Breakdown of water footprints (Green, blue and grey) for food items of both diets analysed (EAT-Lancet diet and Spanish dietary pattern)**

| | EAT-Lancet Diet | | | | Spanish dietary pattern | | | |
|---|---|---|---|---|---|---|---|---|
| | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF(l) | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF (l) |
| **Fruits** | | | | | | | | |
| Oranges | 20.6 | 14.0 | 4.6 | 39.2 | 24.0 | 16.2 | 5.3 | 45.5 |
| Mandarin | 7.0 | 5.0 | 1.7 | 13.7 | 8.2 | 5.8 | 2.0 | 15.9 |
| Banana | 16.2 | 5.1 | 0.8 | 22.1 | 18.8 | 5.9 | 1.0 | 25.7 |
| Apple | 13.5 | 7.4 | 2.3 | 23.2 | 15.7 | 8.6 | 2.7 | 27.0 |
| Pear | 6.3 | 3.6 | 1.1 | 11.0 | 7.3 | 4.2 | 1.3 | 12.8 |
| Melon | 4.2 | 1.6 | 1.5 | 7.3 | 4.9 | 1.9 | 1.7 | 8.5 |
| Watermelon | 3.6 | 1.9 | 1.0 | 6.5 | 4.2 | 2.2 | 1.2 | 7.6 |
| **Vegetables** | | | | | | | | |
| Tomato | 5.0 | 3.3 | 3.5 | 11.7 | 3.9 | 2.5 | 2.7 | 9.1 |
| Onion | 6.3 | 8.7 | 6.8 | 21.8 | 4.9 | 6.7 | 5.2 | 16.8 |
| Peppers | 2.3 | 0.2 | 1.9 | 4.4 | 1.8 | 0.2 | 1.5 | 3.4 |
| Lettuce | 2.3 | 2.9 | 2.5 | 7.7 | 1.8 | 2.3 | 1.9 | 5.9 |
| Carrots | 2.2 | 3.3 | 1.3 | 6.8 | 1.7 | 2.6 | 1.0 | 5.3 |
| Courgette | 2.2 | 1.3 | 1.6 | 5.1 | 1.7 | 1.0 | 1.2 | 3.9 |
| Cucumber | 0.8 | 0.8 | 0.5 | 2.2 | 0.6 | 0.6 | 0.4 | 1.7 |
| **Soybean food** | | | | | | | | |
| Soybean flour | 32.1 | 1.9 | 1.0 | 35.1 | - | - | - | - |
| Soybean oil | 49.0 | 4.4 | 1.5 | 54.9 | - | - | - | - |
| **Pulses** | | | | | | | | |
| Chickpeas | 50.3 | 0.7 | 52.4 | 103.4 | 11.5 | 0.2 | 12.0 | 23.6 |
| Beans | 2.0 | 0.9 | 1.6 | 4.5 | 0.5 | 0.2 | 0.4 | 1.0 |
| Lentils | 49.3 | 2.9 | 53.2 | 105.5 | 11.3 | 0.7 | 12.2 | 24.1 |
| **Starch-based products** | | | | | | | | |
| Bread | 317.6 | 10.9 | 63.3 | 391.9 | 140.9 | 4.9 | 28.1 | 173.8 |
| Rice | 29.2 | 49.3 | 1.1 | 79.5 | 12.9 | 21.8 | 0.5 | 35.3 |
| Pasta | 45.4 | 1.5 | 8.7 | 55.6 | 20.1 | 0.7 | 3.8 | 24.7 |
| Potatoes | 4.9 | 3.4 | 2.6 | 10.9 | 8.8 | 6.0 | 4.7 | 19.5 |
| **Olives and nuts** | | | | | | | | |
| Olives | - | - | - | - | 32.6 | 7.9 | 0.1 | 40.6 |
| Almond | 150.1 | 19.7 | 13.7 | 183.5 | 28.2 | 3.7 | 2.6 | 34.5 |
| Walnut | 85.1 | 62.7 | 57.7 | 205.4 | 16.0 | 11.8 | 10.9 | 38.7 |
| Peanut | 71.6 | 3.4 | 6.3 | 81.3 | 4.1 | 0.2 | 0.4 | 4.7 |
| **Dairy products** | | | | | | | | |
| Milk | 218.3 | 30.7 | 36.9 | 285.9 | 400.7 | 56.3 | 67.8 | 524.8 |
| Yogurt | 23.8 | 3.6 | 4.3 | 31.7 | 43.7 | 6.7 | 7.9 | 58.2 |
| Cheese | 82.0 | 10.5 | 13.0 | 105.5 | 150.5 | 19.3 | 23.9 | 193.7 |
| Ice-cream | - | - | - | - | 43.8 | 6.2 | 7.4 | 57.5 |
| **Eggs** | | | | | | | | |
| Eggs | 37.3 | 4.8 | 6.3 | 48.4 | 83.2 | 10.7 | 14.1 | 107.9 |

**Table 5.4. (cont.) Breakdown of water footprints (Green, blue and grey) for food items of the both diets analysed (EAT-Lancet diet and Spanish dietary pattern)**

| | EAT-Lancet Diet | | | | Spanish dietary pattern | | | |
|---|---|---|---|---|---|---|---|---|
| | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF (l) | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF (l) |
| | | | | Meat | | | | |
| Beef | 106.3 | 8.8 | 10.3 | 125.4 | 311.6 | 25.8 | 30.1 | 367.5 |
| Pig | 38.3 | 5.6 | 5.6 | 49.5 | 235.4 | 34.2 | 34.4 | 304.0 |
| Chicken | 97.0 | 10.4 | 14.9 | 122.4 | 196.9 | 21.1 | 30.3 | 248.3 |
| Processed meat | - | - | - | - | 80.8 | 11.7 | 11.8 | 104.2 |
| | | | | Sweets | | | | |
| Honey | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sugar | 13.3 | 5.0 | 0.8 | 19.1 | 5.3 | 2.0 | 0.3 | 7.6 |
| Oils and fats | | | | | | | | |
| Olive oil | 594.3 | 98.9 | 1.9 | 695.1 | 580.3 | 96.6 | 1.9 | 678.7 |
| Palm oil | 25.3 | 0.0 | 1.5 | 26.8 | - | - | - | - |
| Lard or tallow | 18.1 | 2.2 | 3.0 | 23.4 | - | - | - | - |
| Pastry | | | | | | | | |
| Biscuits | | | | | 28.9 | 1.9 | 0.0 | 30.8 |
| Breakfast cereals | - | - | - | - | 29.8 | 1.0 | 0.1 | 30.9 |
| Nougat (Christmas foods) | - | - | - | - | - | - | - | 2.2 |
| Chocolate | - | - | - | - | 295.6 | 3.5 | 3.4 | 302.5 |
| Snacks | - | - | - | - | - | - | - | 3.4 |
| Ready meals | | | | | | | | |
| Soups and creams | - | - | - | - | 6.4 | 3.2 | 1.2 | 10.8 |
| Pizza | - | - | - | - | 13.8 | 0.5 | 2.8 | 17.1 |
| Tinned vegetables | - | - | - | - | 0.7 | 7.3 | 0.4 | 8.4 |
| Tinned pasta | - | - | - | - | 4.0 | 0.1 | 0.8 | 4.8 |
| Sauces | - | - | - | - | 1.0 | 0.6 | 0.7 | 2.3 |

Notes: WF (Water footprint)

Water footprint for biscuits was taken from Konstantas et al. (2019).

Water footprint for nougat and snacks was taken from Garzillo et al. (2020)

Water footprint for soups and creams was assimilated to gazpacho (Rivas Ibáñez et al., 2017).

Pizza was assimilated into its main ingredient, wheat flour.

As tomato is by far the most consumed canned vegetable in Spain (MAPA, 2020a), water footprint for tinned vegetables as referred to it.

Regarding the water footprint of sauces, tomato sauce was taken as a reference.

## 5.4 DISCUSSION OF RESULTS

### 5.4.1 Comparison with literature

The adoption of the EAT-Lancet recommendations in Spain led to changes in the CF of the Spanish dietary pattern. In this sense, food-related GHG emissions could be reduced by 41% by adopting the recommendations in the Spanish dietary pattern, mostly driven by stricter limits on animal-based products (meat, fish and seafood, and dairy products) and offset by increased consumption of plant-based products (whole grains, vegetables, nuts, seeds and legumes). This is in agreement with the findings of the modelling study by Springmann et al. (2020), who reported large net reductions in GHG emissions of 42% by adopting the EAT-Lancet recommendations.

Furthermore, if the CF score for the EAT-Lancet diet is compared with those estimated in the literature, some differences arise. Kesse-Guyot et al. (2021) observed through a prospective cohort study that participants with higher adherence to the EAT-Lancet diet (ranked by quintiles) were associated with lower GHG emissions. The mean CF for individuals with the highest level of adherence to the EAT-Lancet diet was 2.73 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. Different research boundaries (their results were referred at the farm level), calculation methods and data source were behind the differences in the CF score between both studies. Kovacs et al. (2021) also estimated the GHG emissions associated with the reference EAT Lancet diet, whose CF was on 1.36 kg$CO_2$eq·person$^{-1}$·day$^{-1}$. This score is considerably lower than that reported here (2.13 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). The fact that their assessment was scaled to a 2000 kcal diet and only accounted for GHG emissions from resource extraction to the factory or the farm gate (cradle-to-farm gate) could explain these considerable differences.

As far as the CF for the current Spanish dietary pattern is concerned, comparisons should be made with caution. Our result (1321 kg $CO_2$eq·person$^{-1}$·year$^{-1}$) differs from the ones reported by Esteve-Llorens et al. (2020b) (1024 kg $CO_2$eq·person$^{-1}$·year$^{-1}$) and Batlle-Bayer et al. (2019) (1120 kg $CO_2$eq·person$^{-1}$·year$^{-1}$), which used the same database as in our study (MAPA, 2019), albeit taking 2018 and 2017, respectively, as reference years. On the other hand, although similar data sources were used, food consumption outside the home was not accounted for and the production phase was only considered within the system boundaries. On the other hand, Batlle-Bayer et al. (2019) chose a cradle-to-consumer approach. Regardless of the study, beverages were included as a food category.

Secondly, a switch to the EAT-Lancet diet may reduce the WF for the Spanish dietary habits as also reported by Vanham et al. (2021), who estimated a consumptive WF score (green plus blue WF) for the Spanish dietary pattern of 4238 L·person$^{-1}$·day$^{-1}$, considerably high compared to the EAT-Lancet diet (2414 L·person$^{-1}$·day$^{-1}$). Significant differences were found with our results in terms of the consumptive WF for the EAT-Lancet (2660 L·person$^{-1}$·day$^{-1}$) and the Spanish dietary pattern (3375 L·person$^{-1}$·day$^{-1}$). The rationale behind these results is that Vanham et al. (2021) used the average annual FAO Food Balance Sheets to estimate food supply data for the period 2011-2013, and we used the 2019 Household Consumption Survey (MAPA, 2019) to obtain national food intake data. Moreover, we considered as reference the Multidimensional Datacomex platform regarding the corresponding volumes of imports and exports, and Vanham and colleagues considered proportions of domestic production and imports to the total domestic supply in the FAO Food Balance Sheets.

### 5.4.2 Similarities and differences with other food-based dietary guidelines

A comparative analysis of the current Spanish dietary pattern with other FBDGs in terms of dietary intake, CF and WF was performed, with the aim of contributing information to the literature in this area of research. In particular, the FBDGs selected were MD, IDG (CREA,

2019), NAOS (Neira and de Onis, 2006), DDG (Health Council, 2015) and DGA (USDA and HHS, 2020). These guidelines are not the only ones that include environmental considerations; we chose a purposive sample to prioritise studies that used the same methodology, the same limitations of the system, and the same food categorisation as ours. In addition, these diets cover a sample of countries representing a wide range of the global population, belonging to the northern and southern regions of Europe and America. CF and WF results for these FBDGs were taken from **Chapter 4**. For comparison, our results were adapted to a cradle-to-gate approach (paying attention only to the production stage) with a dietary intake of 2228 kcal·person$^{-1}$·day$^{-1}$. In addition, food waste and food losses throughout the food chain were eliminated to improve comparability. In addition, the designed FBDG scenarios do not include the pastry and prepared meals subgroup in the mass-based recommendations.

5.4.2.1 Dietary intake

The Spanish dietary pattern differs from the recommended intake amounts for each food subgroup in the existing dietary guidelines. Compared to the Southern European FBDGs (MD, NAOS and Italian), the Spanish dietary pattern included, on average, more meat (range among the Southern European FBDGs 2.7 to 3.9 times higher) and fewer fruits (0.6 to 0.7 times lower), vegetables (0.4 to 0.8 times lower) and starch-based products (0.5 to 0.7 times lower) (see **Fig. 5.4a)**. The MD contained lower amounts of dairy (270 g·person$^{-1}$·day$^{-1}$) in comparison with the Spanish dietary pattern (366 g·person$^{-1}$·day$^{-1}$). In contrast, NAOS and the IDG do not suggest limiting dairy intake to a higher percentage than the Spanish dietary pattern.

Compared to the DDG, the Spanish dietary pattern included less starch-based products (0.5 times) and dairy products (0.8 times), and more meat (2.4 times), fruits (1.6 times) and fish and seafood (5.4 times). On the other hand, the main difference between the American FBDGs and the Spanish dietary pattern was the consumption of dairy products. The Spanish population consume lower dairy products (366 g·person$^{-1}$·day$^{-1}$) than the recommended servings in the American Dietary Guidelines (712 g·person$^{-1}$·day$^{-1}$).

The comparison of the Spanish dietary profile not only with the EAT-Lancet recommendations, but also with the rest of the dietary guidelines, showed that the Spanish population could benefit from increasing the consumption of starch-based products, while reducing the consumption of meat, pastries and ready-to-eat meals. On the other hand, the consumption of dairy products remained too high, both in the current Spanish pattern and in the other FBDGs (except MD), compared to the global recommendations of the EAT-Lancet diet.

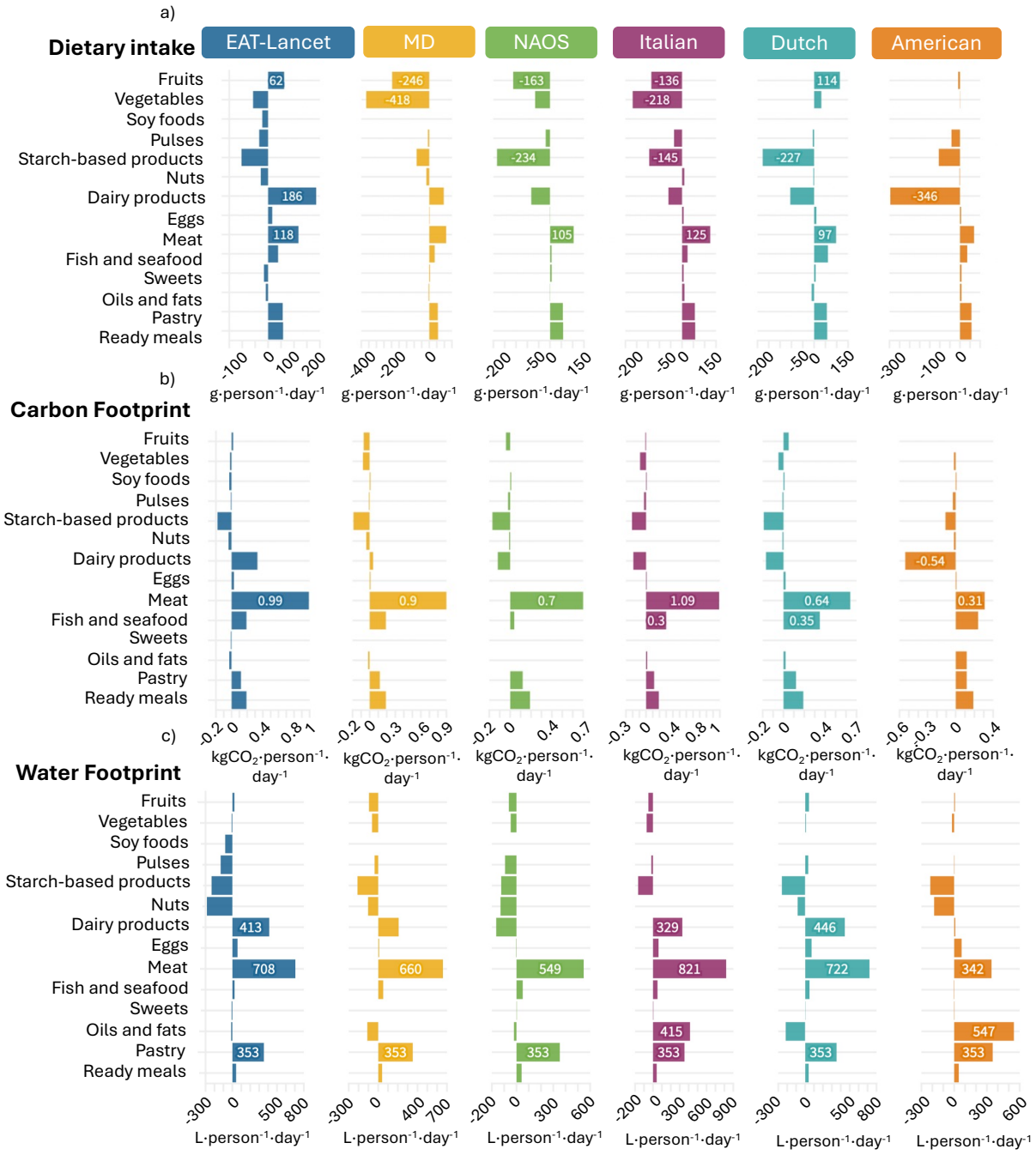


**Fig. 5.4. Differences between Spanish dietary pattern and global and national food based dietary guidelines: EAT-Lancet, Mediterranean Diet (MD), Spanish Strategy for Nutrition, Physical Activity and Obesity Prevention (NAOS), Italian, Dutch and American Dietary Guidelines. Positive values indicate greater intake (a), CF (b) and WF (c) in Spanish dietary pattern and negative ones indicate lower.**

5.4.2.2 Carbon footprint

The GHG emissions associated with the dietary recommendations analysed ranged from 1.69 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ for the EAT-Lancet diet to 2.98 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ for the American dietary guidelines (considering only the production phase, adapted to 2228 kcal· person$^{-1}$·day$^{-1}$ and excluding food losses and food waste) (see **Fig. 5.5a**). With these considerations, the CF for the Spanish dietary pattern was 3.25 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. Therefore, the adoption of some of these FBDGs would allow a reduction in CF related to average Spanish food intake in a range between 9% (adoption of the American dietary guidelines) and 48% (adoption of the EAT-Lancet diet). The CF profiles (estimated as the difference between the associated CF of the current Spanish dietary pattern and the corresponding one for the FBDG by food group) were very similar for all FBDGs as can be seen in **Fig. 5.4b**.

The adoption of FBDGs (national or global) led to significant reductions in CF for meat (ranging from 82% in the Italian guidelines to 24% in the American guidelines) and fish and seafood (ranging from 94% in the Dutch guidelines to 12% in the NAOS) subgroups. The reduction in GHG emissions from meat for the IDG could be explained not only by their limitations on meat consumption (43 g·person$^{-1}$·day$^{-1}$) with a higher CF, but also by their prioritisation of white meat over red meat, as in the EAT-Lancet diet.

On the other hand, the FBDG recommendations were associated with a higher intake of starch-based products (ranging from 315 g·person$^{-1}$·day$^{-1}$ in MD to 465 g·person$^{-1}$·day$^{-1}$ in NAOS) in comparison with the Spanish dietary pattern (231 g·person$^{-1}$·day$^{-1}$). Therefore, adoption of the global EAT-Lancet recommendations or some of the other national or regional FBDGs would result in a moderate increase in CF for this food subgroup.

Comparing the Spanish dietary pattern and the FBDGs in terms of dairy was not straightforward. Negative deviations around the CF for dairy using the Spanish dietary pattern as a reference could be seen for NAOS, the Italian, American and Dutch dietary guidelines and positive deviations for the EAT-Lancet and MD (see **Fig. 5.4b**). This result suggests that reforming the national FBDG with a moderate consumption of dairy products as outlined in the EAT-Lancet recommendations could be beneficial in the transition to more sustainable diets.

In general, limiting meat consumption as recommended by all the FBDGs analysed, and moderating dairy consumption in accordance with the global EAT-Lancet recommendations, would increase the environmental sustainability of the current Spanish dietary pattern.

5.4.2.3 Water footprint

Taking into account that WF depends not only on recommended daily intakes, but also on geographical considerations, local agricultural production methods, and climatic conditions, comparison with the Spanish reference scenarios is the most accurate. We conclude that adherence to the EAT-Lancet, MD or NAOS diets by the Spanish population would result in reductions in water resource demand ranging from 10% in NAOS, which reported the highest WF (3181 L·person$^{-1}$·day$^{-1}$) to 20% in MD, with a WF of 2826 L·person$^{-1}$·day$^{-1}$.

As a first important observation, higher scores were shown for legumes (ranged from 79 L·person$^{-1}$·day$^{-1}$ in MD to 173 L·person$^{-1}$·day$^{-1}$ in EAT-Lancet), starch-based products (ranged from 362 L·person$^{-1}$·day$^{-1}$ in NAOS to 470 L·person$^{-1}$·day$^{-1}$ in EAT-Lancet), and nuts (ranged from 209 L·person$^{-1}$·day$^{-1}$ in MD to 391 L·person$^{-1}$·day$^{-1}$ in EAT-Lancet) in the Spanish reference dietary recommendations in comparison with their corresponding values in the Spanish dietary pattern (42, 237 and 104 L·person$^{-1}$·day$^{-1}$, respectively).

In contrast, meat showed positive deviations as can be seen in **Fig. 5.4c**. For a Spanish citizen, the reduction in WF associated with meat, if the Spanish reference dietary

recommendations were adopted, would range from 57% if the choice was NAOS, to 73% if the EAT-Lancet diet was chosen. On the other hand, considering that EAT-Lancet and MD were associated with more ambitious reductions in dairy consumption than NAOS, the adoption of some of these dietary guidelines would allow a reduction in dairy WF (26% for MD and 52% for EAT-Lancet), which would not happen if the NAOS dietary pattern were followed.

Comparisons with other dietary guidelines not established in Spain should be made with caution. The minimum water required was associated with the adoption of the IDG (1761 $L \cdot person^{-1} \cdot day^{-1}$) (see **Fig. 5.5b**), with a lower WF associated with for oils and fats (250 $L \cdot person^{-1} \cdot day^{-1}$), meat (150 $L \cdot person^{-1} \cdot day^{-1}$) and dairy (470 $L \cdot person^{-1} \cdot day^{-1}$) due to their lower consumption compared to the Spanish dietary pattern. Moreover, the national average values of the total WF of olive oil (9103 $m^3 \cdot t^{-1}$), milk (805 $m^3 \cdot t^{-1}$) and beef (11500 $m^3 \cdot t^{-1}$) in Italy were lower than those in Spain (13190, 1847, 13608 $m^3 \cdot t^{-1}$, respectively) (Mekonnen and Hoekstra, 2011, 2012).

Compared to the Dutch FBDGs, the Spanish dietary pattern showed, on average, a higher WF impact for meat (3.9 times higher) and dairy (2.3 times higher), and a lower impact for starch-based products (0.5 times lower) and oils and fats (0.8 times lower). Although dairy products contributed a high percentage to the daily intake in the Dutch FBDG (471 $g \cdot person^{-1} \cdot day^{-1}$) in comparison with the Spanish dietary pattern (366 $g \cdot person^{-1} \cdot day^{-1}$), a positive difference could be explained in the comparative WF analysis. The total WF of milk at the national level, using the Netherlands instead of Spain as the reference country, explains the resulting deviation profile (Mekonnen and Hoekstra, 2011, 2012).

The Spanish dietary pattern represented a higher WF related to meat and oils and fats compared to American FBDGs. The average meat consumption per capita (168 $g \cdot person^{-1} \cdot day^{-1}$) and the large volumes of water used for beef cattle (13608 $m^3 \cdot t^{-1}$) in Spain explain the deviations from the American FBDGs. Otherwise, soybean oil, with a relatively small WF per gram of fat, may be an olive oil substitute in the American guidelines, which explains the lower WF for this food category.

#### 5.4.2.4 Health Gain Score

**Fig. 5.5c** presents a comparison of the Health Gain Score between the Spanish dietary pattern and other recommended dietary guidelines. By standardising the energy intake to 2228 $kcal \cdot person^{-1} \cdot day^{-1}$ and excluding food waste and food losses, it is observed that the Spanish diet, while exhibiting a lower Health Gain Score than the MD, NAOS and IDG, surpasses the EAT-Lancet diet and the Dutch and American FBDGs. These discrepancies can be attributed to deficiencies in fruit, vegetable and fibre consumption, as outlined in the Dutch FBDGs, and the excessive intake of saturated fat and sodium, as recommended in the American FBDGs.

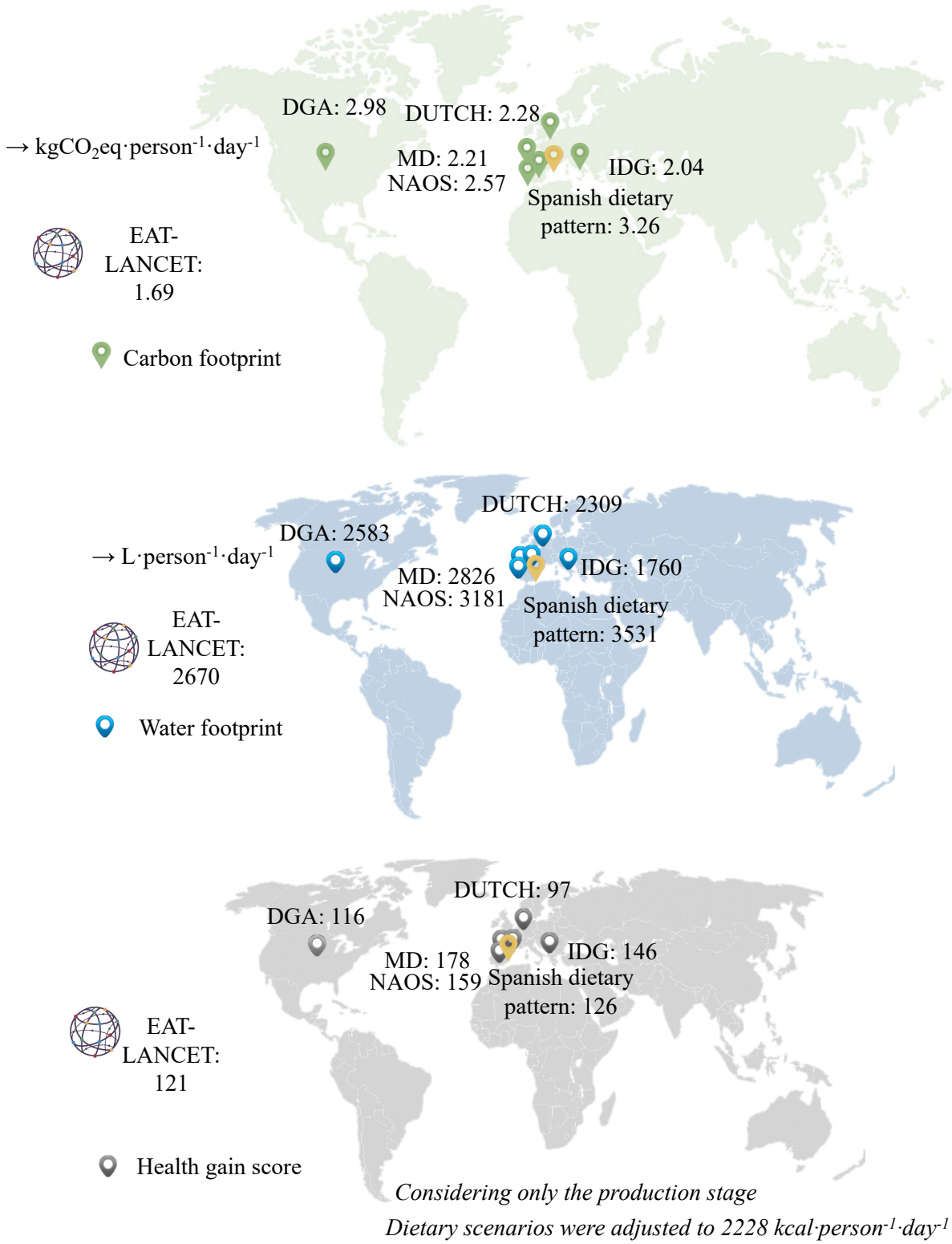


**Fig. 5.5. Comparison of a) the carbon footprint (kg $CO_2$eq·person$^{-1}$·day$^{-1}$), b) the water footprint (L·person$^{-1}$·day$^{-1}$) and c) the Health Gain Score for Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND, Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS, Italian Dietary Guidelines 2018 - IDG, Dietary Guidelines for Americans 2020-2025 - DGA, EAT-Lancet diet and the Spanish dietary pattern.**

### 5.4.3 Key findings and their policy implications

This work builds on the proposition that the EAT-Lancet dietary recommendations can help enable sustainable food transitions in Spain and other European and American countries, reaching children, families and communities. We propose that favouring plant-based over animal-based diets can strengthen the potential of dietary patterns to enable sustainable food systems. However, reducing meat and dairy emissions to meet the EAT-Lancet dietary guidelines seems unlikely without new advances in planning and policy-making.

First, governments should incorporate sustainability considerations into FBDGs, in addition to health and nutrition issues. The approach discussed in this paper could be a good starting point for formulating national FBDGs that are updated to improve their environmental performance.

Second, school cafeterias offer a great opportunity to improve food sustainability education with future implications for food systems. School meals can influence the broader community by providing a broader understanding of nutritional learning experiences for children and their families. In particular, school gardens are a powerful environmental education tool with potential cross-sectoral impacts on environmental awareness, economic development, and health and wellness in the local community.

Third, the development of sustainable, nutritious and healthy meat analogue products that reduce reliance on livestock production and meet the EAT-Lancet and United Nations SDGs. However, plant-based protein meat analogues result in poor nutrient intake, mainly due to amino acid, vitamin and n-3 PUFA deficiencies. Formulation of alternative hybrid meat analogues could be a promising solution for climate change mitigation and water scarcity, without compromising on health and nutritional issues. Therefore, the government should fund academic research on meat substitutes.

## 5.5 CONCLUDING REMARKS

The EAT-Lancet diet is a universal reference diet for people and planetary health. Based on the environmental analysis conducted, it is evident that the current Spanish dietary pattern differs significantly from the EAT-Lancet goals for adopting healthy diets produced in a sustainable manner.

As discussed in the paper, both the EAT-Lancet and the Spanish dietary patterns are nutritionally adequate. However, a shift towards the EAT-Lancet recommendations by the Spanish population will require a significant reduction in animal-based foods (dairy, meat, fish and seafood), pastry and ready-meals, and an increase in plant-based foods (vegetables, pulses, soy foods, starch-based products, nuts, and oils and fats). In particular, the reduction of beef and dairy products has significant potential for the transition to a low CF and low WF diet in Spain.

When comparing the Spanish dietary pattern with other European and American recommended diets, the greatest divergence in terms of CF and WF was in the meat category. Although the FBDGs included, on average, more plant-based products, such as vegetables or starch-based products, compared to the current Spanish intake, their relative impact on CF and WF was not as significant as that of meat, since plant-based products are associated with lower environmental emissions per unit weight.

Understanding the limitations of the study is important to place the research findings in context and to interpret the validity of the results. The wide variety of LCA studies considered in assigning a CF to each foodstuff makes it difficult to know the uncertainty for each value. Therefore, a reliability uncertainty analysis of the CF impact could not be performed. On the other hand, the lack of information in the quantification of the CF of non-aquaculture fish

species and the assumptions made for other foods included in the bakery and convenience food categories could have led to deviations in the assessment of the CF.

In summary, the results of this study can contribute to providing information on the environmental implications (GHG emissions and water demand) of adopting the EAT-Lancet recommendations. Future research could focus on accounting for deviations from the EAT-Lancet targets in other dimensions: diet-health relationships, nutrient needs, economic characteristics, or cultural acceptability. Ensuring compliance with the global targets for achieving sustainable healthy diets outlined by EAT-Lancet will enable the achievement of the SDGs and the Paris Agreement.

# 6. EXPLORING HEALTH AND SUSTAINABILITY IN SOUTHERN EUROPE THROUGH THE NEW NORDIC DIET[3]

The partnership for sustainable and healthy food is a challenge shared by governments, the food industry, environmental science and health care. At the European level, the application of policies based on the Mediterranean-style eating pattern is recommended. In this context, attention is being paid to the New Nordic Diet, which has many similarities with the Mediterranean diet, but includes foods typical of the Nordic countries. Therefore, it could be applied anywhere in the world, including Spain, where it would coexist with the recommendations of the Mediterranean Diet. The main objective of this chapter is to propose the modelling of the health, economic, environmental and nutritional indicators of the Southern version of the New Nordic Diet and to compare, if possible, the results with those of the alternatives.

The environmental metrics for the Southern version of the New Nordic Diet, carbon footprint and water footprint, were estimated at 3.58 kg $CO_2 \cdot person^{-1} \cdot day^{-1}$ and 3528 L$\cdot$ $person^{-1} \cdot day^{-1}$ respectively, a slightly worse environmental profile than for Mediterranean Diet. Regarding economic metrics, the updated cost index to 2019 was 4.30 €$\cdot person^{-1} \cdot day^{-1}$, similar to Mediterranean Diet. The overall dietary quality score was 126, a higher score than the baseline (100), but worse than that identified for Mediterranean Diet. In terms of health outcomes, the New Nordic Diet showed benefits that reduced non-communicable diseases, such as the risk of type 2 diabetes mellitus by 31%, colorectal cancer by 35%, and cardiovascular disease by 7%. Adherence to the New Nordic Diet was also associated with a weight loss of 1.83 kg per person following the diet. Epidemiologic evidence supports greater weight loss when following the New Nordic Diet, but greater reduction in cardiovascular disease risk when following the Mediterranean Diet.

Dissemination of these recommended dietary patterns through educational campaigns and inclusion in dietary guidelines of simple indicators of dietary quality, environmental impact, and health that are easily understood by the general public, is one of the most important challenges of public and environmental health.

[3] Cambeses-Franco, C., González-García, S., Feijoo, G., Moreira, M. T., 2021. Encompassing health and nutrition with the adherence to the environmentally sustainable New Nordic Diet in Southern Europe. Journal of Cleaner Production, 327, 129470. https://doi.org/10.1016/j.jclepro.2021.129470

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## 6.1 INTRODUCTION

Unhealthy diets represent a global health crisis, contributing to the development of chronic diseases such as cancer, CVD, and T2D. In response, researchers have been investigating the potential health benefits of traditional diets around the world. MD, a well-established dietary pattern in several countries, including Spain, Italy, and Greece, has been widely recognized for its role in preventing CVD (Renzella et al., 2018). However, emerging research is shedding light on the potential of traditional diets from other regions of Europe, including the NND, a contemporary adaptation of traditional Nordic cuisine that prioritises both human health and environmental sustainability (Corliss, 2024).

### 6.1.1 Southern version of the New Nordic Diet

Following the philosophy of MD, Nordic nutritionists have developed the NND as a dietary approach tailored to their region (Agnihotri et al., 2021). The NND is a daily reference diet developed within the framework of the project OPUS (Optimal well-being, Development and Health for Danish children through a healthy NND) (Jensen and Poulsen, 2013). The diet consists of locally grown, seasonal, nutritious and environmentally friendly foods, which are consumed mainly in Denmark, Finland, Iceland, Sweden and Norway (Meltzer et al., 2019). It is based upon three principles (Jensen et al., 2015; Mithril et al., 2012).

First, it prioritises a high intake of vegetables, fruits, potatoes, nuts, whole grains and fish and a lower intake of meat compared to the current average Danish diet. This dietary composition is crucial for a healthy lifestyle and has been linked to a lower RR for obesity, T2D, CVD and cancer. Second, the diet promotes a distinct regional cuisine based on foods from the countryside and from the fishing area 27. Third, the diet emphasizes the selection of local products and organic production methods to minimise the use of pesticides.

By combining these principles, the NND exemplifies a dietary approach that is perfectly aligned with the EU Green Deal, the Farm to Fork Strategy, and the EU's decarbonization goals (Galli et al., 2023). The principles can be applied to any region of the world, allowing the creation of a Southern version of the NND (SNND) within the specific context of a country. This new dietary design could be incorporated into the dietary scenario in southern Europe, particularly in northwestern Spain and northern Portugal.

### 6.1.2 A multi-dimensional approach to assessing the sustainability of the Southern version of the New Nordic Diet

In the literature, MD and NND have been analysed from an environmental point of view. Thus, Álvarez-Álvarez et al. (2024) estimated the impact of an intervention promoting a MD among Spanish older adults on five environmental indicators: GHG emissions, LU, energy use, acidification and potential eutrophication (Álvarez-Álvarez et al., 2024). Ulaszewska et al. (2017) used the environmental hourglass approach for the MD and NND. González-García et al. (2020a) incorporated another environmental metric not as widely explored in the assessment of MD, the WF indicator. On the other hand, there is strong scientific evidence, which shows the close relationship between them and a lower risk of diseases such as T2D, obesity, CVD and different types of cancer (Cai et al., 2024; Ramezani-Jolfaie et al., 2020). However, assessing sustainability is a further necessary step that has not yet been fully explored in the literature.

Therefore, this chapter develops an integrated approach based on validated and standardized methods from different disciplines to address the challenge of evaluating the new version of the NND designed for Southern Europe. First, epidemiological descriptors from cohort studies, such as the RR of a health event (diet-disease), are addressed. The usefulness of

cohort studies so far is mainly based on individual foods or nutrients that influence disease risk. However, dietary adequacy is based not only on the selection of individual foods, but also on their nutrient balance in certain diverse diets. Therefore, a more promising approach might focus on using a review of epidemiological studies to analyse which foods should be restricted and promoted to improve health-related diet quality. Second, both the LCA approach used to determine the CF associated with the dietary patterns analysed and the WFA methodology (WFN, 2020) are incorporated to calculate the WF. Third, following van Dooren et al. (2014) for national FBDGs, it complements the environmental assessment with a nutrient-derived metric: the Health Gain Score. Fourth, it examines the economic barriers to healthy eating by estimating the total economic cost of the diet.

In this sense, this study aims to conduct a sustainability assessment integrating environmental, health, nutritional, and economic indicators of the SNND. The assessment includes the quantification of CF and WF, a nutritional quality index, daily cost and health outcomes (association with obesity, CVD, T2D and CRCA incidence. Special attention was given to the comparison with MD based on this multi-perspective approach.

## 6.2 MATERIALS AND METHODS

### 6.2.1 Composition of the Southern version of the New Nordic Diet

The average daily quantification of the most distinct Nordic identity dietary components detailed by Mithril et al. (2013) was consulted to establish the composition of the SNND. Although the recommended average amount per food category was given for the most identifiable components of this diet, no attention was given to the specific amount of each food in units of mass (usually grams) that make up each group. For example, they suggested a recommended fruit intake higher than 400 $g \cdot day^{-1}$ and a minimum average daily intake of berries of 50-100 $g \cdot day^{-1}$, but did not develop a complete daily diet indicating the specific amount of different fruits (e.g., bananas, oranges or apples) that an average person should eat.

Thus, this gap in guidelines was used as a strategy to adapt the NND to the dietary scenarios in the southern Europe, particularly in Spain and Northern Portugal. Galicia is an autonomous community in northwest Spain. Therefore, following the methodology proposed by González-García et al. (2020b), data on current food consumption in Galician households for the year 2019 were managed in order to adapt the NND to the eating habits of this geographical area. The Consumption, Commercialization and Food Distribution: Household Consumption Database Program (MAPA, 2019) provided these updated data to identify the most popular foods by food category in the Galician shopping basket (see **Table 6.1**).

**Table 6.1. Distribution ratios according with MAPA (2019)**

| | Volume (thousands of kg) | % | % Recalculate |
|---|---|---|---|
| Fruits | 284462 | 69.1 | 100.0 |
| Oranges | 57865 | 20.3 | 29.4 |
| Bananas | 40230 | 14.1 | 20.5 |
| Apples | 36084 | 12.7 | 18.4 |
| Mandarin | 18303 | 6.4 | 9.3 |
| Melon | 16350 | 5.7 | 8.3 |
| Pear | 15100 | 5.3 | 7.7 |
| Watermelon | 12689 | 4.5 | 6.5 |
| Vegetables | 148401 | - | - |
| Root vegetables | 30304 | 20.4 | 100.0 |
| Onion | 20790 | 14.0 | 68.6 |
| Carrots | 9515 | 6.4 | 31.4 |
| Others | 65295 | 44.0 | 100.0 |
| Tomatoes | 29678 | 20.0 | 45.5 |
| Lettuce | 14273 | 9.6 | 21.9 |
| Peppers | 14185 | 9.6 | 21.7 |
| Courgette | 7158 | 4.8 | 11.0 |
| Pulses | 7648 | 99.3 | 100.0 |
| Chickpeas | 3173 | 41.5 | 41.8 |
| Lentils | 2430 | 31.8 | 32.0 |
| Beans | 1994 | 26.1 | 26.2 |
| Nuts | 9274 | 38.3 | 100.0 |
| Walnuts | 2049 | 22.1 | 57.7 |
| Peanuts | 982 | 10.6 | 27.7 |
| Almonds | 517 | 5.6 | 14.6 |
| Meat | 195519 | 68.6 | 100.0 |
| Beef | 36127 | 27.1 | 26.9 |
| Pig | 36025 | 27.0 | 26.9 |
| Chicken | 32888 | 24.6 | 24.5 |
| Processed meat | 29062 | 21.8 | 21.7 |
| Fish and seafood | 77791 | 52.0 | 100.0 |
| Hake | 8330 | 10.7 | 20.6 |
| Squids | 6892 | 8.9 | 17.0 |
| Prawns | 5469 | 7.0 | 13.5 |
| Tuna | 5392 | 6.9 | 13.3 |
| Mussels | 4348 | 5.6 | 10.7 |
| Salmon | 3290 | 4.2 | 8.1 |
| Cod | 3105 | 4.0 | 7.7 |
| Pilchard | 2706 | 3.5 | 6.7 |
| Mackerel | 942 | 1.2 | 2.3 |

Note: % Recalculate is the distribution ratio of food items in a food category considering only the selected foodstuffs (the most consumed in Galicia food baskets).

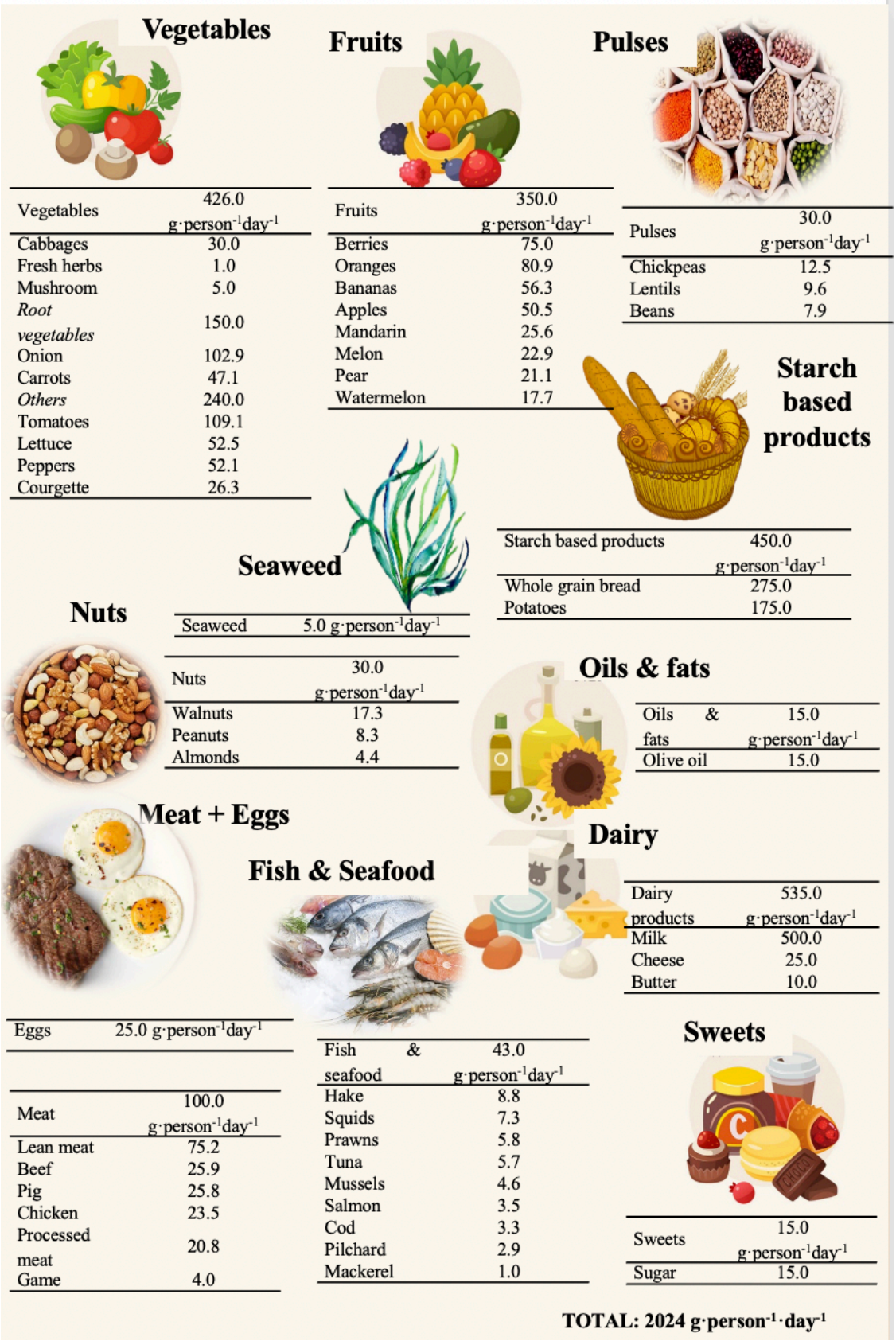
In terms of plant-based foods, the list includes, firstly, different types of fruit: berries, selected for their clear Nordic identity, and seven other fruits (oranges, bananas, apples, mandarins, melons, pears and watermelons), which represent 69% of the total fruit consumed on average in Galicia (MAPA, 2019). Secondly, NND menus include cruciferous vegetables (cabbage), root vegetables (carrots, onions), fresh herbs and mushrooms. Other vegetables such as tomatoes, peppers, lettuce and zucchini have been included in the proposed adoption of the NND by the citizens of southern Europe.

Seaweed and pulses are also part of the composition of the NND diet. Seaweeds are a source of nutrition in NND because of their high content of essential minerals, dietary fibre, vitamins, and bioactive compounds (Cherry et al., 2019). The important role of pulses in the NND has also been established in the guidelines, as well as the recommended amount per day (Mithril et al., 2012). Considering that chickpeas, beans and lentils represented more than 99% of the total legumes consumed in Galicia in 2019 (MAPA, 2019), they were chosen as representative legumes in the designed daily diet.

It should also be noted that the consumption of more nuts, whole grains and potatoes is part of the NND principles (Mithril et al., 2012). Whole grains show an inverse relationship with the risk of developing T2D, CVD and obesity (Ye et al., 2012). On the other hand, in addition to their potential health benefits, potatoes can be grown using sustainable organic cultivation methods. For non-seasoned nuts, the NND pyramid detailed a recommended intake of 30 $g \cdot day^{-1}$. The proportion was distributed among walnuts, peanuts and almonds, which represented 22%, 11% and 6% of the total nuts consumed in Galicia, respectively (MAPA, 2019).

As for food of animal origin, milk products were the food group with the highest intake. Three types of dairy products (milk, cheese and butter) were considered based on the Danish FBDGs. Meat was the second highest intake category. The significance of meat as a source of protein can certainly be achieved with an average meat intake of 85-100 $g \cdot day^{-1}$. The NND typically includes meat from free-range livestock and game due to their nutritional and sustainability advantages (Costa et al., 2016; Elgersma, 2015; Mithril et al., 2013). In addition, beef contributes with a significant percentage (19%) to the total meat consumption in Galicia (MAPA, 2019). Therefore, it was also included in this food category. Finally, eggs were managed separately from meat. The other foods of animal origin are fish and seafood. The NND recommends regular consumption of fish with an average content in the diet higher than 43 $g \cdot day^{-1}$. In order to adapt the NND to the southern regions, it recommends an amount distributed between the most consumed fish (hake, tuna, salmon, cod, sardine and mackerel) and shellfish (squids, prawns and mussels) in Galicia (MAPA, 2019).

Other considerations in the composition of the SNND diet were the type of oil used and the possibility of incorporating sweets. In Galicia, olive oil is the main oil consumed with a representation of 59%. Thus, it was considered the only source of fat. Regarding the latter, the amount of refined sugar in the NND was restricted to 4% as a percentage of total energy intake (Mithril et al., 2013). **Fig. 6.1** displays the recommended daily intake of the food items in the SNND.




| Vegetables | 426.0 g·person⁻¹day⁻¹ |
|---|---|
| Cabbages | 30.0 |
| Fresh herbs | 1.0 |
| Mushroom | 5.0 |
| *Root vegetables* | 150.0 |
| Onion | 102.9 |
| Carrots | 47.1 |
| *Others* | 240.0 |
| Tomatoes | 109.1 |
| Lettuce | 52.5 |
| Peppers | 52.1 |
| Courgette | 26.3 |

| Fruits | 350.0 g·person⁻¹day⁻¹ |
|---|---|
| Berries | 75.0 |
| Oranges | 80.9 |
| Bananas | 56.3 |
| Apples | 50.5 |
| Mandarin | 25.6 |
| Melon | 22.9 |
| Pear | 21.1 |
| Watermelon | 17.7 |

| Pulses | 30.0 g·person⁻¹day⁻¹ |
|---|---|
| Chickpeas | 12.5 |
| Lentils | 9.6 |
| Beans | 7.9 |

| Starch based products | 450.0 g·person⁻¹day⁻¹ |
|---|---|
| Whole grain bread | 275.0 |
| Potatoes | 175.0 |

| Seaweed | 5.0 g·person⁻¹day⁻¹ |
|---|---|

| Nuts | 30.0 g·person⁻¹day⁻¹ |
|---|---|
| Walnuts | 17.3 |
| Peanuts | 8.3 |
| Almonds | 4.4 |

| Oils & fats | 15.0 g·person⁻¹day⁻¹ |
|---|---|
| Olive oil | 15.0 |

| Dairy products | 535.0 g·person⁻¹day⁻¹ |
|---|---|
| Milk | 500.0 |
| Cheese | 25.0 |
| Butter | 10.0 |

| Eggs | 25.0 g·person⁻¹day⁻¹ |
|---|---|

| Meat | 100.0 g·person⁻¹day⁻¹ |
|---|---|
| Lean meat | 75.2 |
| Beef | 25.9 |
| Pig | 25.8 |
| Chicken | 23.5 |
| Processed meat | 20.8 |
| Game | 4.0 |

| Fish & seafood | 43.0 g·person⁻¹day⁻¹ |
|---|---|
| Hake | 8.8 |
| Squids | 7.3 |
| Prawns | 5.8 |
| Tuna | 5.7 |
| Mussels | 4.6 |
| Salmon | 3.5 |
| Cod | 3.3 |
| Pilchard | 2.9 |
| Mackerel | 1.0 |

| Sweets | 15.0 g·person⁻¹day⁻¹ |
|---|---|
| Sugar | 15.0 |

**Fig. 6.1. Overview of the daily-recommended intake per food category (g·person$^{-1}$·day$^{-1}$) for the Southern version of the New Nordic Diet.**

### 6.2.2 Functional Unit

In order to make a common comparison between the SNND and the MD, based on the proposed economic, nutritional quality, environmental and health indicators, it was necessary to define a functional unit. Considering that energy intake (kcal), food consumption (kg) and nutrient intake per person per day were estimated in relation to the guidelines for the NND, the individual recommended daily intake was chosen as the functional unit. Moreover, for the SNND the recommended daily energy intake regardless of drinks was of 2304 kcal·person$^{-1}$·day$^{-1}$, a value very close to 2228 kcal·person$^{-1}$·day$^{-1}$, the recommended value for a Spanish citizen by the Panel on Dietetic Products, Nutrition and Allergies (EFSA, 2017).

### 6.2.3 Environmental outcomes: Carbon and water footprints

#### 6.2.3.1 Carbon Footprint

CF was carried out from a "cradle-to-consumer" approach, i.e., contemplating the whole food supply chain until the foodstuffs were distributed for household consumption. The system boundaries include food loss and food waste. The cooking stage (e.g., boiling or frying) was not included with the aim to facilitate the comparison with the results obtained by González-García et al. (2020 b) for MD. The exclusion of the consumption stage from the scope of the study was also considered in other similar studies available in the literature (Esteve-Llorens et al., 2019b; Van Dooren et al., 2014). Therefore, the system was divided into the following three stages (see **Fig. 6.2**):

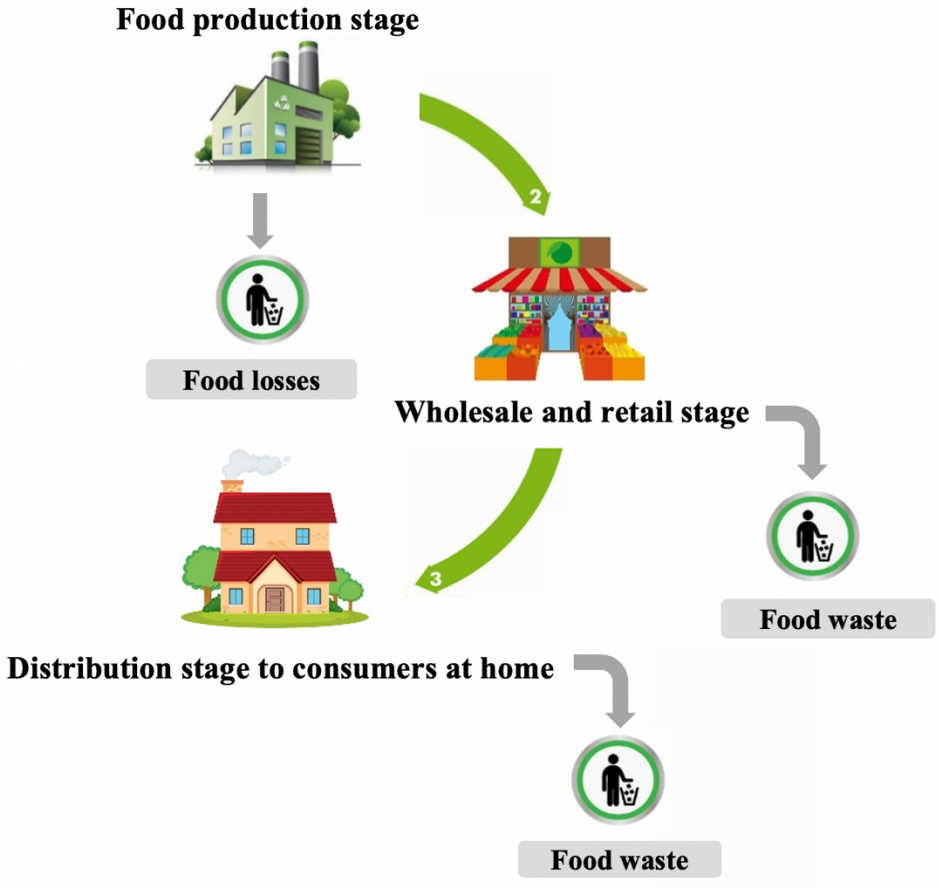



**Fig. 6.2. System boundaries considered in the carbon footprint assessment of the Southern Version of the New Nordic Diet.**

*Food production stage (S1):* This stage includes the production of the dietary components that make up the complete daily diet. In terms of data collection, a total of 27 scientific LCA articles were consulted to estimate the corresponding embodied GHG emissions for each food product. All these LCA studies were managed from a "cradle to gate" approach taking into account that these were the boundaries set for S1. Therefore, when the life cycle studies analysed covered the "cradle-to-grave", "cradle-to-retailer" or "cradle-to-consumer" perspectives, the GHG emissions corresponding to these additional stages were discarded. A detailed summary of the sample of 45 food items grouped into 12 categories and their associated GHG emissions were presented in **Table 6.2**. Due to the lack of information in the literature, some assumptions were made. Thus, cabbage was considered equivalent to cauliflower and broccoli. As for fresh herbs, they were excluded from the analysis because they represent only 0.5% of the total recommended daily intake. In addition, in accordance with the NND guidelines, CF values for organic food production were considered when data were available in the literature.

*Wholesale and retail stage (S2)*: This stage includes the transport from the factory or farm gate to the wholesaler and retailer. The estimation of the CF corresponding to this stage was made considering the amount of food produced in Spain and imported, according to the methodology proposed by González-García et al. (2020b). The corresponding volumes of food imported to Spain were considered following the information of the multidimensional database DATACOMEX, provided by the Spanish Ministry of Economy and Competitiveness (Ministerio de Economia, 2019). In terms of imports, at least the group of countries representing 80% of the total volume of imports was considered. All the data used correspond to the reference year 2019. Transoceanic vessels and lorry were considered in transport activities from the production site to the retailer. An average import distance per food product was also estimated, as detailed in González-García et al. (2020b). For the foodstuffs produced at the national level, an average delivery distance of 400 km by Euro 5 diesel freight lorries (>32 tons) was considered (Castañé and Antón, 2017). The GHG emission factors, which were calculated using the Ecoinvent ® v3.2 database and the characterisation factors of the Intergovernmental Panel on Climate Change (IPCC), were 92.10 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$ and 18.60 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$ for lorry and transoceanic transport, respectively.

This procedure was used to estimate the CF associated with the distribution of all food products, with the exception of fish and shellfish. It was assumed that the production of these seafood includes their landing in a Galician port, according to the LCA studies reviewed (González-García et al., 2015a; Hospido and Tyedmers, 2005; Iribarren et al., 2010a, 2010b; Vázquez-Rowe et al., 2010a). Consequently, the average distance per food product was calculated considering that all the production takes place at the national level. The necessary background information for the estimation of GHG emissions associated with the distribution stage by food, except for fish and shellfish, is summarized in **Table 6.3**. Food waste at the wholesale and retail distribution stage was taken from Gustavsson et al. (2013), who estimated waste percentages for each food category at each step of the food supply chain in Europe (see **Table 6.4**)

*Distribution stage to consumers at home (S3)*. This stage considers the logistics from supermarkets to households. As in the previous stages, the methodology proposed by González-García et al. (2020b) was followed in detail. Household consumption generates food waste. This issue was included in the analysis, although the cooking stage itself was not considered. Regarding logistical activities, the distribution of the total amount of food that makes up the shopping bag from the market to the household was considered. Therefore, it was assumed that a purchase was made every six days, including all the products that make up the diet and

transported from the grocery store in a diesel vehicle over 3.3 km with an emission rate of 106 g $CO_2$eq·km$^{-1}$ (Batlle-Bayer et al., 2019). The average food waste ratios per food item in households were taken from Garcia-Herrero et al. (2018). A detailed description of the food waste ratios at the household level can be found in **Table 6.4**.

**Table 6.2. Life cycle assessments references consulted for the estimation of the carbon footprint values corresponding to the production stage (S1)**

| Foodstuff | Source | Geographic situation | Carbon footprint ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|---|
| | | Fruits | |
| Berries | (Clune et al., 2017) | Global. Strawberries/Raspberries/ Gooseberries/Cranberries/Blueberries | 0.58/0.84/0.84/0.92 0.795 (medium) |
| Oranges | (Aguilera et al., 2015a) | Spain | 0.083 (org) |
| Bananas | (Aguilera et al., 2015a) | Spain | 0.049 (org) |
| Apples | (Aguilera et al., 2015a) | Spain | 0.094 (org) |
| Mandarin | (Aguilera et al., 2015a) | Spain | 0.083 (org) |
| Melon | (Clune et al., 2017) | Global | 0.51 |
| Pear | (Aguilera et al., 2015a) | Spain | 0.094 (org) |
| Watermelon | (Clune et al., 2017) | Global | 0.32 |
| | | Vegetables | |
| Cabbages | (Aguilera et al., 2015b) | Spain | 0.161 (org) |
| Mushrooms | (Leiva et al., 2015) | Spain | 1.82 |
| Onion | (Aguilera et al., 2015b) | Spain | 0.161 (org) |
| Carrots | (Gössling et al., 2011) | Denmark | 0.234 (org) |
| Tomatoes | (Aguilera et al., 2015b) | Spain | 0.178 (org) |
| Lettuce | (Aguilera et al., 2015b) | Spain | 0.178 (org) |
| Peppers | (Aguilera et al., 2015b) | Spain | 0.178 (org) |
| Courgette | (Frankowska et al., 2019b) | United Kingdom | 0.25 |
| | | Seaweed | |
| Seaweed | (Heller et al., 2018) | United States | 0.18 |
| | | Pulses | |
| Chickpeas | (Clune et al., 2017) | Global | 0.67 |
| Lentils | (Clune et al., 2017) | Global | 1.03 |
| Beans | (Clune et al., 2017) | Global | 0.51 |
| | | Starch-based products | |
| Whole grain bread | (Chiriacò et al., 2017) | Italy | 1.55 (org) |
| Potatoes | (Aguilera et al., 2015b) | Spain | 0.161 (org) |
| | | Nuts | |
| Walnuts | (Venkat, 2012) | USA | 2.942 (org) |
| Peanuts | (Clune et al., 2017) | Global | 0.83 |
| Almonds | (Venkat, 2012) | USA | 3.771 (org) |
| | | Dairy products | |
| Milk | (Thomassen et al., 2008) | Portugal | 1.5 (org) |
| Cheese | (González-García et al., 2013c) | Spain | 10.44 |
| Butter | (Barilla Center for Food Nutrition, 2015) | Global | 8.30 |

**Table 6.2. (Cont.) Life cycle assessments references consulted for the estimation of the carbon footprint values corresponding to the production stage (S1)**

| Foodstuff | Source | Geographic situation | Carbon footprint ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|---|
| | | Eggs | |
| Eggs | (Nielsen et al., 2013) | Denmark | 1.80 (org) |
| | | Meat | |
| Beef | (Buratti et al., 2017) | Italy | 24.62 (org) |
| Pig | (Halberg et al., 2010) | Denmark | 3.32 (org) |
| Chicken | (González-García et al., 2014) | Portugal | 2.50 |
| Processed meat | (Noya et al., 2016) | Spain-fuet | 11.33 (fuet) |
| Game | (Saxe, 2015) | Denmark-venison | 21.57 |
| | | Fish and seafood | |
| Hake | (Iribarren et al., 2010b) | Fishing Area: Northern Sock. Discharged: Galician port (Spain), Fishing gear: Lining-Trawling | 5.7-6.26<br>5,98 (Medium value) |
| Squids | (Iribarren et al., 2010b) | Catching Area: Mauritania. Discharged: Galician port (Spain) | 3.86 |
| Prawns | (Clune et al., 2017) | Global | 14.85 |
| Tuna | (Hospido and Tyedmers, 2005) | Catching Area: Atlantic Ocean, Discharged: Galician Port (Spain) | 1.60 |
| Mussels | (Iribarren et al., 2010a) | Galicia (Spain). Cultivate: in rafts | 1.59 |
| Salmon | (Sherry and Koester, 2020) | Atlantic salmon, aquaculture | 2.26 |
| Cod | (Ziegler et al., 2013) | Sweden | 1.2 |
| Pilchard | (González-García et al., 2015a) | Portugal<br>Inventory year: 2011-2012 | 0.354-0.507<br>0.523 (Medium value) |
| Mackerel | (Vázquez-Rowe et al., 2010a) | Fishing Area: Galicia, Discharged: Galician port (Spain), Fishing gear: Purse seiner-Bottom trawlers | 0.80-2.28<br>1.54 (Medium value) |
| | | Sweets | |
| Sugar | (Klenk et al., 2012) | Spain | 0.23 |
| | | Oils and fats | |
| Olive oil | (Sellás Olive Oil, 2013) | Spain | 2.36 |

**Table 6.3. Identification of importing volume, exporting volume, national production, main importing countries, average distribution distances and transport mode per type of food category.**

| | Spanish Production (t) | Export (t) | Import (t) | %N | %A | Import distance (km) | National distance (km) | Total distance (km) |
|---|---|---|---|---|---|---|---|---|
| | | | | Fruits | | | | |
| Berries | 345300[3] | 68479 | 21046 | 93 | 7 | 372 | 135 | 507 |
| Oranges | 3342540[1] | 1756863 | 148549 | 91 | 9 | 412 | 366 | 777 |
| Bananas | 398722[1] | 99999 | 391506 | 43 | 57 | 4149 | 173 | 4323 |
| Apples | 638839[1] | 127076 | 217563 | 70 | 30 | 320 | 281 | 600 |
| Mandarin | 1893951[1] | 1082744 | 17302 | 98 | 2 | 32 | 392 | 424 |
| Melon | 660191[1] | 455783 | 94671 | 68 | 32 | 2063 | 273 | 2336 |
| Pear | 330670[1] | 137170 | 61334 | 76 | 24 | 566 | 304 | 870 |
| Watermelon | 1200093[1] | 910929 | 81709 | 78 | 22 | 336 | 312 | 648 |
| | | | | Vegetables | | | | |
| Cabbages | 517767[1] | 483845 | 22833 | 60 | 40 | 427 | 239 | 666 |
| Mushrooms | 170764[1] | 37934 | 16298 | 89 | 11 | 466 | 356 | 822 |
| Onion | 1443187[1] | 404587 | 81833 | 93 | 7 | 676 | 371 | 1047 |
| Carrots | 384295[1] | 111023 | 19266 | 93 | 7 | 56 | 374 | 429 |
| Tomatoes | 5000559[1] | 767369 | 198203 | 96 | 4 | 35 | 382 | 417 |
| Lettuce | 1004668[1] | 829872 | 23359 | 88 | 12 | 126 | 353 | 479 |
| Peppers | 1399192[1] | 828960 | 63259 | 90 | 10 | 69 | 360 | 429 |
| Courgette | 605527[1] | 414930 | 19548 | 91 | 9 | 63 | 363 | 424 |
| | | | | Seaweed | | | | |
| Seaweed | 140000[5] | 47244 | 41438 | 69 | 31 | 7078 | 276 | 7354 |
| | | | | Pulses | | | | |
| Chickpeas | 49971[1] | 6019 | 57473 | 43 | 57 | 6130 | 173 | 6303 |
| Lentils | 35333[1] | 3797 | 48467 | 39 | 61 | 5575 | 158 | 5733 |
| Beans | 57049[1] | 4798 | 36524 | 59 | 41 | 784 | 235 | 1019 |
| | | | | Starch based products | | | | |
| Whole grain bread | 942675[2] | 24927 | 15473 | 98 | 2 | 15 | 393 | 408 |
| Potatoes | 2259320[1] | 302981 | 839271 | 70 | 30 | 261 | 280 | 541 |
| | | | | Nuts | | | | |
| Walnuts | 17542[1] | 2527 | 32035 | 32 | 68 | 6413 | 128 | 6541 |
| Peanuts | 122071[1] | 2486 | 50256 | 70 | 30 | 2738 | 0 | 2738 |
| Almond | 340421[1] | 107825 | 110464 | 68 | 32 | 2747 | 271 | 3018 |
| | | | | Dairy products | | | | |
| Milk | 8229000[1] | 87853 | 122300 | 99 | 1 | 15 | 394 | 409 |
| Cheese | 442200[1] | 107581 | 309743 | 52 | 48 | 657 | 208 | 865 |
| Butter | 46000[1] | 19980 | 26614 | 49 | 51 | 612 | 198 | 810 |

**Table 6.3. (cont.) Identification of importing volume, exporting volume, national production, main importing countries, average distribution distances and transport mode per type of food category.**

| | National Production (t) | Export (t) | Import (t) | %N | %A | Import distance (km) | National distance (km) | Total distance (km) |
|---|---|---|---|---|---|---|---|---|
| | | | Eggs | | | | | |
| Eggs | 833000[1] | 119301 | 21334 | 97 | 3 | 21 | 388 | 410 |
| | | | Meat | | | | | |
| Beef | 650000[1] | 217937 | 136605 | 76 | 24 | 493 | 304 | 797 |
| Pig | 14261000[1] | 2184047 | 114686 | 99 | 1 | 12 | 396 | 408 |
| Chicken | 643861[1] | 180799 | 95870 | 83 | 17 | 482 | 331 | 813 |
| Processed meat | 1429000[6] | 150182 | 89427 | 93 | 7 | 86 | 374 | 460 |
| Game | 53238[4] | 9979 | 2324 | 95 | 5 | 30 | 380 | 410 |
| | | | Sweets | | | | | |
| Sugar | 390700[3] | 165039 | 1739038 | 11 | 89 | 2022 | 46 | 2068 |
| | | | Oils and fats | | | | | |
| Olive oil | 1780919[1] | 1077213 | 148562 | 83 | 17 | 231 | 330 | 561 |

Notes: % A (share of a food item produced abroad), %N (share of a food item produced at the national level)

1. MAPA (2019)
2. ASEMAC (2019)
3. MERCASA (2019)
4. ASICCAZA (2018)
5. Farré-Rovira et al. (2012)
6. ANICE (2019)
7. INE (2019)

**Table 6.4. Food waste and ratios of food waste in wholesale and retailing and household related stages (S2 and S3, respectively) per foodstuff.**

| Foodstuff | S2 | S3 | Food waste ($g \cdot person^{-1} \cdot day^{-1}$) |
|---|---|---|---|
| | | Fruits | |
| Berries | 0.10 | 0.06 | 13.4 |
| Oranges | 0.10 | 0.13 | 22.4 |
| Bananas | 0.10 | 0.10 | 13.2 |
| Apples | 0.10 | 0.11 | 12.5 |
| Mandarin | 0.10 | 0.02 | 3.4 |
| Melon | 0.10 | 0.02 | 3.1 |
| Pear | 0.10 | 0.02 | 2.8 |
| Watermelon | 0.10 | 0.02 | 2.4 |
| | | Vegetables | |
| Cabbages | 0.10 | 0.14 | 8.8 |
| Mushroom | 0.10 | 0.03 | 0.7 |
| Onion | 0.10 | 0.04 | 16.2 |
| Carrots | 0.10 | 0.08 | 9.8 |
| Tomatoes | 0.10 | 0.02 | 14.6 |
| Lettuce | 0.10 | 0.06 | 9.6 |
| Peppers | 0.10 | 0.05 | 8.8 |
| Courgette | 0.10 | 0 | 2.9 |
| | | Seaweed | |
| Seaweed | 0.10 | 0.03 | 0.7 |
| | | Pulses | |
| Chickpeas | 0.02 | 0.09 | 1.5 |
| Lentils | 0.02 | 0.13 | 1.7 |
| Beans | 0.02 | 0.13 | 1.4 |
| | | Starch based products | |
| Whole grain bread | 0.02 | 0.04 | 17.3 |
| Potatoes | 0.07 | 0.01 | 15.1 |
| Nuts | | | |
| Walnuts | 0.02 | 0.09 | 2.1 |
| Peanuts | 0.02 | 0.09 | 1.0 |
| Almonds | 0.02 | 0.09 | 0.5 |
| | | Dairy products | |
| Milk | 0.005 | 0.01 | 7.6 |
| Cheese | 0.005 | 0.03 | 0.9 |
| Butter | 0.005 | 0 | 0.1 |
| | | Eggs | |
| Eggs | 0.02 | 0.04 | 1.6 |
| | | Meat | |
| Beef | 0.04 | 0.01 | 1.3 |
| Pig | 0.04 | 0.01 | 1.3 |
| Chicken | 0.04 | 0.02 | 1.5 |

**Table 6.4. (cont.) Food waste and ratios of food waste in wholesale and retailing and household related stages (S2 and S3, respectively) per foodstuff.**

| Foodstuff | S2 | S3 | Food waste ($g \cdot person^{-1} \cdot day^{-1}$) |
|---|---|---|---|
| Meat | | | |
| Processed meat | 0.04 | 0.08 | 2.8 |
| Game | 0.04 | 0.0086 | 0.2 |
| Fish and seafood | | | |
| Hake | 0.09 | 0.01 | 1.00 |
| Squids | 0.09 | 0.02 | 0.90 |
| Prawns | 0.09 | 0.01 | 0.60 |
| Tuna | 0.09 | 0.04 | 0.80 |
| Mussels | 0.09 | 0.02 | 0.60 |
| Salmon | 0.09 | 0.02 | 0.40 |
| Cod | 0.09 | 0.02 | 0.40 |
| Pilchard | 0.09 | 0.01 | 0.30 |
| Mackerel | 0.09 | 0.06 | 0.20 |
| Sweets | | | |
| Sugar | 0.02 | 0.03 | 0.80 |
| Oils and fats | | | |
| Olive oil | 0.01 | 0.01 | 0.3 |

6.2.3.2 Water Footprint

Mekonnen and Hoekstra (2011, 2012) provided a comprehensive study of the global green, blue and grey WF of crops and derived crop products, farm animals and animal products between 1996-2005 for different countries. Therefore, the three components of WF for each ingredient (except fish and seafood) were estimated following the procedure indicated by González-García et al. (2020b), which considers the origin of food (domestic or imported production), the food production stage (S1), and the values reported by Mekonnen and Hoekstra (2011, 2012). The detailed WF for the foodstuffs that constitute the NND dietary pattern are reported in **Table 6.5**.

With regard to fish and seafood, Pahlow et al. (2015) determined the WF for the major farmed species cultivated under an aquaculture production regime (e.g. prawns and salmon). For the other non-aquaculture species, which are grown with natural food from the aquatic environment (e.g. hake and sardine), it was assumed that each marine species had a WF of zero.

**Table 6.5. Water footprints (WFs) (green, blue, grey and total) per foodstuff**

| Foodstuff | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF (l) |
|---|---|---|---|---|
| | | Fruits | | |
| Berries | 6.5 | 10.4 | 2.9 | 19.8 |
| Oranges | 24.5 | 16.6 | 5.4 | 46.5 |
| Bananas | 17.7 | 5.6 | 0.9 | 24.2 |
| Apples | 17.0 | 9.4 | 2.9 | 29.3 |
| Mandarin | 7.4 | 5.2 | 1.8 | 14.4 |
| Melon | 3.0 | 1.1 | 1.0 | 5.1 |
| Pear | 6.8 | 3.8 | 1.2 | 11.8 |
| Watermelon | 1.9 | 1.0 | 0.5 | 3.4 |
| | | Vegetables | | |
| Cabbages | 3.8 | 2.5 | 1.8 | 8.1 |
| Mushroom[1] | - | - | - | 0.1 |
| Onion | 9.7 | 13.4 | 10.4 | 33.4 |
| Carrots | 3.2 | 5.0 | 1.9 | 10.1 |
| Tomatoes | 4.3 | 2.9 | 3.0 | 10.2 |
| Lettuce | 3.2 | 4.1 | 3.4 | 10.8 |
| Peppers | 2.6 | 0.3 | 2.2 | 5.0 |
| Courgette | 1.6 | 0.9 | 1.1 | 3.6 |
| | | Seaweed | | |
| Seaweed[2] | - | - | - | $3.6 \cdot 10^{-3}$ |
| Pulses | | | | |
| Chickpeas | 30.5 | 0.4 | 31.8 | 62.7 |
| Lentils | 32.7 | 1.9 | 35.3 | 70.0 |
| Beans | 1.1 | 0.5 | 0.9 | 2.5 |
| | | Starch based products | | |
| Whole grain bread | 360.6 | 12.4 | 71.9 | 444.9 |
| Potatoes | 16.1 | 11.0 | 8.6 | 35.7 |
| | | Nuts | | |
| Walnuts | 81.0 | 59.6 | 54.9 | 195.5 |
| Peanuts | 9.9 | 0.3 | 0.5 | 10.7 |
| Almonds | 96.5 | 12.6 | 8.8 | 118.0 |
| | | Dairy products | | |
| Milk | 709.3 | 99.6 | 120.0 | 928.8 |
| Cheese | 118.2 | 15.2 | 18.8 | 152.1 |
| Butter | 51.2 | 6.0 | 7.7 | 64.9 |
| | | Eggs | | |
| Eggs | 74.7 | 9.6 | 12.6 | 96.8 |
| | | Meat | | |
| Beef | 289.4 | 23.9 | 28.0 | 341.3 |
| Pig | 109.8 | 15.9 | 16.0 | 141.7 |
| Chicken | 65.3 | 7.0 | 10.0 | 82.3 |
| Processed meat | 134.0 | 19.3 | 19.6 | 172.9 |
| Game | 57.4 | 8.5 | 8.3 | 74.2 |

**Table 6.5. (cont.) Water footprints (WFs) (green, blue, grey and total) per foodstuff**

| Foodstuff | Green WF (l) | Blue WF (l) | Grey WF (l) | Total WF (l) |
|---|---|---|---|---|
| | | Fish and seafood | | |
| Hake | 0.0 | 0.0 | 0.0 | 0.0 |
| Squids | 0.0 | 0.0 | 0.0 | 0.0 |
| Prawns | 11.0 | 1.9 | 1.3 | 14.2 |
| Tuna | 0.0 | 0.0 | 0.0 | 0.0 |
| Mussels | 0.0 | 0.0 | 0.0 | 0.0 |
| Salmon | 5.9 | 0.8 | 1.6 | 8.2 |
| Cod | 1.5 | 0.9 | 0.6 | 3.0 |
| Pilchard | 0.0 | 0.0 | 0.0 | 0.0 |
| Mackerel | 0.0 | 0.0 | 0.0 | 0.0 |
| | | Sweets | | |
| Sugar | 7.5 | 2.8 | 0.5 | 10.8 |
| | | Oils and fats | | |
| Olive oil | 223.4 | 37.2 | 0.7 | 261.3 |

1. SureHarvest (2017)

2. Martins et al. (2018)

### 6.2.4 Nutritional Quality Index

The Health Gain Score developed by van Dooren et al. (2014) was proposed for estimation to consider the potential health benefits of a balanced diet. **Chapter 3 (Section I)** provides a detailed explanation of the index. The nutritional values of each food item were presented in **Table 6.6**.

**Table 6.6. Composition values of the foodstuffs that are part of the SNND.**

| | Carbohydrates g/100g | Fats g/100g | Free sugar g/100g | Energy kcal/100g | Fiber g/100g | Sat. fatty acids g/100g | Sodium mg/100g |
|---|---|---|---|---|---|---|---|
| Fruits | | | | | | | |
| Berries | 7.0 | 0.5 | 4.9 | 36.0 | 2.2 | 0.0 | 2.0 |
| Oranges | 8.6 | 0.0 | 9.0 | 38.0 | 2.0 | 0.0 | 3.0 |
| Bananas | 20.0 | 0.3 | 12.0 | 89.0 | 3.4 | 0.1 | 1.0 |
| Apples | 12.0 | 0.0 | 10.0 | 50.0 | 2.0 | 0.2 | 2.0 |
| Mandarin | 6.0 | 0.0 | 11.0 | 40.0 | 1.9 | 0.0 | 2.0 |
| Melon | 90 | 0.0 | 8.0 | 27.0 | 1.0 | 0.0 | 14.0 |
| Pear | 4.5 | 0.0 | 10.0 | 45.0 | 2.3 | 0.0 | 2.0 |
| Watermelon | 10.6 | 0.0 | 6.0 | 20.0 | 0.5 | 0.1 | 4.0 |
| Vegetables | | | | | | | |
| Cabbages | 15.6 | 0.2 | 3.2 | 34.0 | 3.3 | 0.0 | 5.0 |
| Mushroom | 4.0 | 0.3 | 2.0 | 26.0 | 2.5 | 0.1 | 5.0 |
| Onion | 5.3 | 0.0 | 4.2 | 26.0 | 1.8 | 0.0 | 3.0 |
| Carrots | 4.5 | 0.6 | 4.7 | 34.0 | 2.6 | 0.1 | 70.0 |
| Tomatoes | 3.5 | 0.1 | 2.5 | 19.0 | 1.1 | 0.0 | 18.0 |
| Lettuce | 2.0 | 0.1 | 0.8 | 16.0 | 1.5 | 0.1 | 3.0 |
| Peppers | 7.0 | 0.3 | 5.0 | 29.0 | 1.8 | 0.1 | 6.0 |
| Courgette | 6.0 | 0.2 | 2.5 | 12.0 | 1.0 | 0.0 | 3.0 |
| Seaweed | | | | | | | |
| Seaweed | 7.9 | 0.5 | 0.6 | 41.0 | 0.7 | 0.1 | 384.0 |
| Pulses | | | | | | | |
| Chickpeas | 49.2 | 6.3 | 11.0 | 360.0 | 15.0 | 0.4 | 30.0 |
| Lentils | 48.7 | 1.2 | 1.8 | 333.0 | 9.7 | 0.2 | 226.8 |
| Beans | 58.3 | 1.5 | 2.1 | 358.0 | 25.0 | 0.3 | 11.0 |
| Starch based products | | | | | | | |
| Whole grain | 44.0 | 3.0 | 5.0 | 240.0 | 3.5 | 0.4 | 650.0 |
| Potatoes | 1.4 | 1.6 | 0.8 | 73.0 | 1.8 | 0.1 | 7.3 |
| Nuts | | | | | | | |
| Walnuts | 21.0 | 54.0 | 2.6 | 595.0 | 6.7 | 6.1 | 2.0 |
| Peanuts | 7.9 | 43.1 | 6.3 | 544.0 | 8.1 | 6.8 | 2.0 |
| Almonds | 17.0 | 54.0 | 3.9 | 589.0 | 8.4 | 4.3 | 10.4 |
| Dairy products | | | | | | | |
| Milk | 5.0 | 1.7 | 5.0 | 46.0 | 0.0 | 1.0 | 46.0 |
| Cheese | 10.8 | 4.7 | 0.5 | 390.0 | 0.0 | 18.9 | 670.0 |
| Butter | 0.0 | 55.1 | 0.0 | 2095.0 | 0.0 | 34.3 | 450.0 |
| Eggs | | | | | | | |
| Eggs | 0.6 | 12.0 | 1.1 | 150.0 | 0.0 | 3.1 | 140.0 |
| Meat | | | | | | | |
| Beef | 0.0 | 10.0 | 0.0 | 157.0 | 0.0 | 4.4 | 84.0 |
| Pig | 0.0 | 14.3 | 0.0 | 124.0 | 0.0 | 5.5 | 60.0 |
| Chicken | 0.0 | 6.2 | 0.0 | 105.0 | 0.0 | 1.9 | 52.8 |

**Table 6.6. (cont.) Composition values of the foodstuffs that are part of the SNND.**

| | Carbohydrates g/100g | Fats g/100g | Free sugar g/100g | Energy kcal/100g | Fiber g/100g | Sat. fatty acids g/100g | Sodium mg/100g |
|---|---|---|---|---|---|---|---|
| Meat | | | | | | | |
| Processed meat | 1.3 | 24.0 | 0.0 | 288.0 | 0.1 | 9.3 | 900.0 |
| Game | 0.0 | 1.6 | 0.0 | 105.0 | 0.0 | 0.8 | 55.0 |
| Fish and seafood | | | | | | | |
| Hake | 0.0 | 2.0 | 0.0 | 65.0 | 0.0 | 0.4 | 101.0 |
| Squids | 1.1 | 1.5 | 0.0 | 72.0 | 0.0 | 0.5 | 136.5 |
| Prawns | 0.0 | 1.4 | 0.0 | 90.0 | 0.0 | 0.4 | 914.3 |
| Tuna | 0.0 | 3.3 | 0.0 | 119.0 | 0.0 | 1.0 | 47.0 |
| Mussels | 2.2 | 1.9 | 0.0 | 61.0 | 0.0 | 0.4 | 210.0 |
| Salmon | 0.0 | 12.0 | 0.0 | 182.0 | 0.0 | 2.2 | 98.0 |
| Cod | 0.0 | 1.0 | 0.0 | 83.0 | 0.0 | 0.2 | 68.0 |
| Pilchard | 0.0 | 7.5 | 0.0 | 140.0 | 0.0 | 2.6 | 57.5 |
| Mackerel | 0.8 | 10.0 | 0.0 | 182.0 | 0.0 | 0.1 | 84.0 |
| Sweets | | | | | | | |
| Sugar | 100.0 | 0.0 | 100.0 | 408.0 | 0.0 | 0.0 | 0.0 |
| Oils and fats | | | | | | | |
| Olive oil | 0.0 | 99.9 | 0.0 | 888.0 | 0.0 | 17.1 | 0.0 |

### 6.2.5 Health Outcomes: Type 2 diabetes, obesity, cardiovascular diseases and colorectal cancer

The relationship between dietary patterns, food category choices, and the prevalence of major nutrition-related diseases in developed societies was examined. In particular, four health outcomes were included in this analysis: T2D, obesity, CVD and CRCA. To conduct the health evaluation, prospective cohort studies were taken from the literature (Clark et al., 2019).

First, the percentage of disease reduction dependent on eating habits was examined. Specifically, the influence of MD and the SNND on the risks of T2D, obesity, CVD and CRCA was analysed (see **Table 6.7** for the cohort studies included in this analysis).

Secondly, the connection between food consumption present in Spanish dietary patterns and the risk of disease was examined through a dose-response meta-analysis (Springmann et al., 2018b). The health impact is the RR of disease (Clark et al., 2019). Further description of the dose-response meta-analysis considered with their corresponding serving sizes was reported in **Tables 6.8 - 6.11**. More information on cohort studies is provided in **Chapter 3 (Section I)**.

**Table 6.7. Cohort studies and health outcomes examined**

| Mediterranean Diet | | | |
|---|---|---|---|
| Disease | Risk | 95% CI | Source |
| Diabetes (RR) | 0.81 | 0.73, 0.90 | (Schwingshackl et al., 2015) |
| Colorectal Cancer (RR) | 0.82 | 0.75, 0.88 | (Schwingshackl et al., 2017c) |
| Cardiovascular disease (RR) | 0.70 | 0.62. 0.80 | (Rosato et al., 2019) |
| Obesity (Weight loss kg) | -1.75 | -2.86, -0.64 | (Esposito et al., 2011) |
| New Nordic Diet | | | |
| Disease | Risk | 95% CI | Source |
| Diabetes (HR) | 0.69 | 0.57,0.82 | (Lacoppidan et al., 2015) |
| Colorectal Cancer (IRR) | 0.65 | 0.46,0.94 | (Kyro et al., 2013) |
| Cardiovascular disease (RR) | 0.93 | 0.88,0.99 | (Kahleova et al., 2019; Massara et al., 2020) |
| Obesity (Weight loss kg) | -1.83 | -2.94,-0.73 | (Ramezani-Jolfaie et al., 2020) |

RR: Relative Risk, HR: Hazard Ratio, IRR: Incidence Rate Ratio, CI: Confidence Interval

**Table 6.8. Dose-response meta-analysis including 14 dietary factors and the risk of diabetes.**

| | Increment | Diabetes | | Source |
|---|---|---|---|---|
| | | Relative Risk | 95% CI | |
| Fruits | 100 | 0.98 | 0.97, 1.00 | (Schwingshackl et al., 2017a) |
| Vegetables | 100 | 0.98 | 0.96, 1.00 | (Schwingshackl et al., 2017a) |
| Potatoes | 150 | 1.09 | 1.01, 1.18 | (Schwingshackl et al., 2019) |
| Whole grain bread | 30 | 0.87 | 0.82, 0.93 | (Schwingshackl et al., 2017a) |
| Pulses | 50 | 1.00 | 0.92, 1.09 | (Schwingshackl et al., 2017a) |
| Nuts | 28 | 0.89 | 0.71, 0.99 | (Schwingshackl et al., 2017a) |
| Dairy | 200 | 0.97 | 0.94, 0.99 | (Schwingshackl et al., 2017a) |
| Eggs | 50 | 1.08 | 0.95, 1.22 | (Schwingshackl et al., 2017a) |
| Red meat | 100 | 1.31 | 1.19, 1.45 | (Yang et al., 2020) |
| Poultry | 80 | 1.12 | 1.03, 1.21 | (Yang et al., 2020) |
| Processed meat | 50 | 1.46 | 1.26, 1.69 | (Yang et al., 2020) |
| Fish and shellfish | 100 | 1.10 | 0.50, 1.23 | (Yang et al., 2020) |
| Sugar | 25 | 1.27 | 1.10, 1.46 | (Imamura et al., 2015) |
| Olive Oil | 10 | 0.91 | 0.87, 0.95 | (Schwingshackl et al., 2017b) |

**Table 6.9. Dose-response meta-analysis including 14 dietary factors and the risk of obesity**

| | Increment | Obesity | | Source |
|---|---|---|---|---|
| | | Relative Risk | 95% CI | |
| Fruits | 100 | 0.93 | 0.86, 1.00 | (Schlesinger et al., 2019) |
| Vegetables | 100 | 0.98 | 0.93, 1.03 | (Schlesinger et al., 2019) |
| Potatoes | 150 | 0.98 | 0.93,1.03 | (Schlesinger et al., 2019) |
| Whole grain bread | 30 | 0.93 | 0.89, 0.96 | (Schlesinger et al., 2019) |
| Pulses | 50 | 0.88 | 0.84, 0.93 | (Schlesinger et al., 2019) |
| Nuts | 28 | 0.78 | 0.58, 1.06 | (Schlesinger et al., 2019) |
| Dairy | 200 | 0.97 | 0.93, 1.01 | (Schlesinger et al., 2019) |
| Eggs | 50 | 0.95 | 0.63, 1.43 | (Schlesinger et al., 2019) |
| Red meat | 100 | 1.14 | 1.03, 1.26 | (Schlesinger et al., 2019) |
| Poultry | 100 | 1.14 | 1.03,1.26 | (Schlesinger et al., 2019) |
| Processed meat | 50 | 1.18 | 1.02, 1.36 | (Schlesinger et al., 2019) |
| Fish | 100 | 1.06 | 0.99, 1.14 | (Schlesinger et al., 2019) |
| Sugar | 25 | 1.05 | 1.00, 1.11 | (Schlesinger et al., 2019) |
| Olive Oil | 10 | 1.19 | 0.73, 1.95 | (Bes-Rastrollo et al., 2006) |

Note: Due to the lack of information in the literature, the risks of meat, poultry (assimilated as meat) and processed meat are related to the risk of weight gain, not to the risk of obesity. Risk measure for olive oil is an odd ratio (OR), not a relative risk (RR)

**Table 6.10. Dose-response meta-analysis including 14 dietary factors and the risk of colorectal cancer**

| | Increment | Colorectal cancer | | Source |
|---|---|---|---|---|
| | | Relative Risk | 95% CI | |
| Fruits | 100 | 0.96 | 0.93, 1.00 | (Vieira et al., 2017) |
| Vegetables | 100 | 0.98 | 0.96, 0.99 | (Vieira et al., 2017) |
| Potatoes | 150 | 1.05 | 0.92, 1.20 | (Schwingshackl et al., 2019) |
| Whole grain bread | 30 | 0.95 | 0.93, 0.97 | (Schwingshackl et al., 2018) |
| Pulses | 50 | 1.00 | 0.95, 1.06 | (Vieira et al., 2017) |
| Nuts | 28 | 0.93 | 0.76, 1.21 | (Schwingshackl et al., 2018) |
| Dairy | 200 | 0.93 | 0.91, 0.94 | (Schwingshackl et al., 2018) |
| Eggs | 50 | 1.18 | 0.89, 1.56 | (Schwingshackl et al., 2018) |
| Red meat | 100 | 1.12 | 1.00, 1.25 | (Vieira et al., 2017) |
| Poultry | 100 | 0.81 | 0.53, 1.25 | (Vieira et al., 2017) |
| Processed meat | 50 | 1.18 | 1.10, 1.28 | (Vieira et al., 2017) |
| Fish | 100 | 0.89 | 0.80, 0.99 | (Vieira et al., 2017) |
| Sugar | 25 | 1.09 | 0.97, 1.22 | (Schwingshackl et al., 2018) |
| Olive Oil | 10 | 0.92 | 0.86,0.99 | (Clark et al., 2019) |

Note: Due to the lack of information in the literature, the risk of olive oil consumption was assimilated to the risk of total mortality

**Table 6.11. Dose-response meta-analysis including 14 dietary factors and the risk of cardiovascular disease**

| | Increment | Cardiovascular disease | | Source |
|---|---|---|---|---|
| | | Relative Risk | 95% CI | |
| Fruits | 100 | 0.90 | 0.88, 0.92 | (Aune et al., 2017) |
| Vegetables | 100 | 0.93 | 0.92, 0.95 | (Aune et al., 2017) |
| Potatoes | 150 | 1.03 | 0.96, 1.09 | (Schwingshackl et al., 2019) |
| Whole grain bread | 30 | 0.84 | 0.78, 0.90 | (Kwok et al., 2019) |
| Pulses | 50 | 0.90 | 0.84, 0.97 | (Marventano et al., 2017) |
| Nuts | 28 | 0.79 | 0.70, 0.88 | (Kwok et al., 2019) |
| Dairy | 200 | 0.90 | 0.81, 0.99 | (Gholami et al., 2017) |
| Eggs | 50 | 0.98 | 0.93, 1.03 | (Drouin-Chartier et al., 2020) |
| Red meat | 100 | 1.15 | 1.05, 1.26 | (Kwok et al., 2019) |
| Poultry | 100 | 1.00 | 0.87, 1.15 | (Kwok et al., 2019) |
| Processed meat | 50 | 1.24 | 1.09, 1.40 | (Kwok et al., 2019) |
| Fish | 100 | 0.88 | 0.79, 0.99 | (Bechthold et al., 2019) |
| Sugar | 25 | 1.00 | 0.98, 1.02 | (Kwok et al., 2019) |
| Olive Oil | 25 | 0.82 | 0.70, 0.96 | (Kwok et al., 2019) |

Note: Due to the lack of information in the literature, the risks of potatoes and fish were related to the risk of coronary heart disease.

### 6.2.6 Cost index

Price is one of the main pillars of food safety and a key determinant in the selection of a daily diet (FAO, 2019e). Thus, it is of great interest to estimate the theoretical cost (€·person$^{-1}$·day$^{-1}$) of the SNND. For this, the average prices (€·kg$^{-1}$) per foodstuff were collected from the national database Spanish Ministry of Agriculture, Food and Environment (MAPA, 2019). A detailed description of the costs per foodstuff were gathered in **Table 6.12**.

### 6.2.7 Combining health, environmental, nutritional quality and economic outcomes

Radar charts were used to visualize the multivariate outcomes analysed. Therefore, the two environmental parameters calculated (CF and WF), the four health outcomes (T2D, obesity, CVD and CRCA) and the cost index were combined into a radar plot for each food category in the SNND.

**Table 6.12. Average prices per food item for southern version of New Nordic Diet. Source: MAPA (2019)**

| Foodstuff | Average Spain (€/kg) |
|---|---|
| Fruits | |
| Berries | 2.71 |
| Oranges | 0.95 |
| Bananas | 1.6 |
| Apples | 1.45 |
| Mandarin | 1.44 |
| Melon | 1.05 |
| Pear | 1.53 |
| Watermelon | 0.84 |
| Vegetables | |
| Cabbages | 1.17 |
| Mushroom | 4.05 |
| Onion | 1.26 |
| Carrots | 0.93 |
| Tomatoes | 1.69 |
| Lettuce | 2.75 |
| Peppers | 1.94 |
| Courgette | 1.37 |
| Seaweed | |
| Seaweed | |
| Pulses | |
| Chickpeas | 1.85 |
| Lentils | 1.81 |
| Beans | 2.09 |
| Starch-based products | |
| Whole grain bread | 2.42 |
| Potatoes | 0.95 |
| Nuts | |
| Walnuts | 7.95 |
| Peanuts | 4.17 |
| Almonds | 12.82 |
| Dairy products | |
| Milk | 0.69 |
| Cheese | 7.48 |
| Butter | 7.44 |
| Eggs | |
| Eggs | 2.34 |
| Meat | |
| Beef | 9.69 |
| Pig | 6.11 |
| Chicken | 4.33 |
| Processed meat | 7.31 |
| Game | 6.37 |

**Table 6.12. (cont.) Average market prices per food item for southern version of New Nordic Diet. Source: MAPA (2019)**

| Foodstuff | Average Spain (€/kg) |
|---|---|
| Fish and shellfish | |
| Hake | 7.22 |
| Squids | 8.89 |
| Prawns | 11.01 |
| Tuna | 9.64 |
| Mussels | 2.77 |
| Salmon | 10.65 |
| Cod | 9.32 |
| Pilchard | 5.04 |
| Mackerel | 4.31 |
| Sweets | |
| Sugar | 0.93 |
| Oils and fats | |
| Olive oil | 3.21 |

## 6.3 RESULTS

### 6.3.1 Carbon footprint analysis of the Southern version of the New Nordic Diet

The SNND CF was estimated at 3.58 kg $CO_2$eq·person$^{-1}$day$^{-1}$. The food production stage (S1) was by far the main responsible for GHG emissions (i.e. 3.41 kg $CO_2$eq· person$^{-1}$day$^{-1}$) covering 95% of the total CF. The other two main stages, wholesale and retail distribution (S2) and distribution to consumer's households (S3) were responsible for around 3% and 2% of total GHG emissions, respectively (see **Fig. 6.3a**). **Fig. 6.3b** shows the distribution of the CF between the twelve food categories for the food production stage (S1).

Animal-based products were behind 75% of the contributions to the CF in S1. Meat and dairy consumption reported two remarkable shares, approximately 34% for both food categories in S1. Focusing on meat products, although the amount of this food category ingested in terms of the recommended daily intake is low (100 g·person$^{-1}$·day$^{-1}$), it is well-known that meat is associated with higher GHG emissions rates (Clune et al., 2017; Tilman and Clark, 2014). Beef alone accounted for about 0.67 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ due to background issues related to its production, mainly enteric fermentation and manure management, among other factors (Petrovic et al., 2015). Dairy products were the other main contributors to CF, not only because they represented the first pillar in terms of recommended food intake in NND, but also because they are a major source of major GHG emissions (e.g., CF of cheese was 10.44 kg $CO_2$eq·kg$^{-1}$). Other important food categories for CF were starch-based products with an associated CF of 0.51 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and the group of fish and seafood with an associated CF of 0.23 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. In terms of daily consumption, starch-based products contributed 22% to the recommended daily intake and fish and seafood 2%. In contrast, fruits and vegetables, which were considered staple foods in the diet with a total daily dietary intake of 350 and 426 g·person$^{-1}$·day$^{-1}$ respectively, together represented 7% of the total CF.

As for the other stages included in the supply chain, S2 contributed 0.21 kg$CO_2$eq·person$^{-1}$day$^{-1}$ to the total CF, being 49% of the GHG emissions derived from national and international transport and 51% derived from food waste produced at wholesale and retailer levels. On the other hand, S3 accounted for 0.15 kg$CO_2$eq·person$^{-1}$day$^{-1}$ including the transport of foodstuffs

from retail to household (responsible for 40% of GHG emissions) along with the generation of food waste at household (60%). In terms of quantitative waste production ratios, food waste at wholesale and retail distribution (S2) and waste production at household (S3) were around 84.0 and 125.4 g·person$^{-1}$day$^{-1}$, respectively.

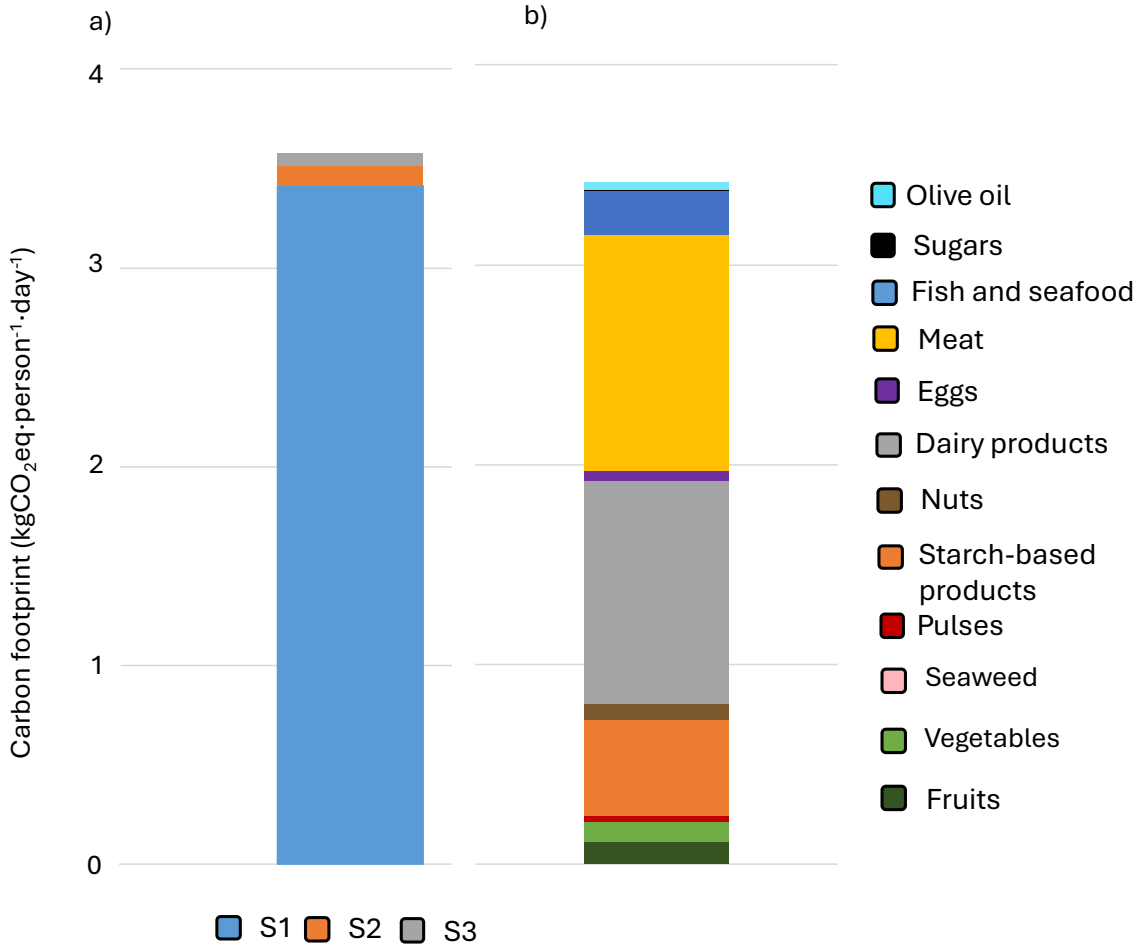



**Fig. 6.3. Carbon footprint estimation (kgCO$_2$eq·person$^{-1}$·day$^{-1}$) of the Southern version of the New Nordic Diet a) distribution per life cycle stages b) distribution per food categories for the food production stage (S1).**

### 6.3.2 Water footprint assessment of the Southern version of the New Nordic Diet

The global average WF related to the SNND was 3528 L per capita and day. **Fig. 6.4a** shows the distribution of WF considering colour (green, blue or grey). WF green contributed to the total WF by more than 74%. In terms of the global average WF by food group, animal-based products make up 59% of the total score (see **Fig. 6.4b**). Dairy products had a WF of 1146 L, the highest proportion among food categories, closely followed by meat with a WF of 812 L. Considering the global WF of food categories, olive oil and nuts showed a remarkable effect with a WF associated of 17 L·g$^{-1}$·day$^{-1}$ and 10 L·g$^{-1}$·day$^{-1}$, respectively. Finally, each foodstuff was analysed separately in terms of WF. The highest WF corresponded to almonds (24 L·g$^{-1}$·day$^{-1}$), game (18 L·g$^{-1}$·day$^{-1}$), olive oil (17 L·g$^{-1}$·day$^{-1}$), beef (13 L·g$^{-1}$·day$^{-1}$) and walnut (10 L·g$^{-1}$·day$^{-1}$).

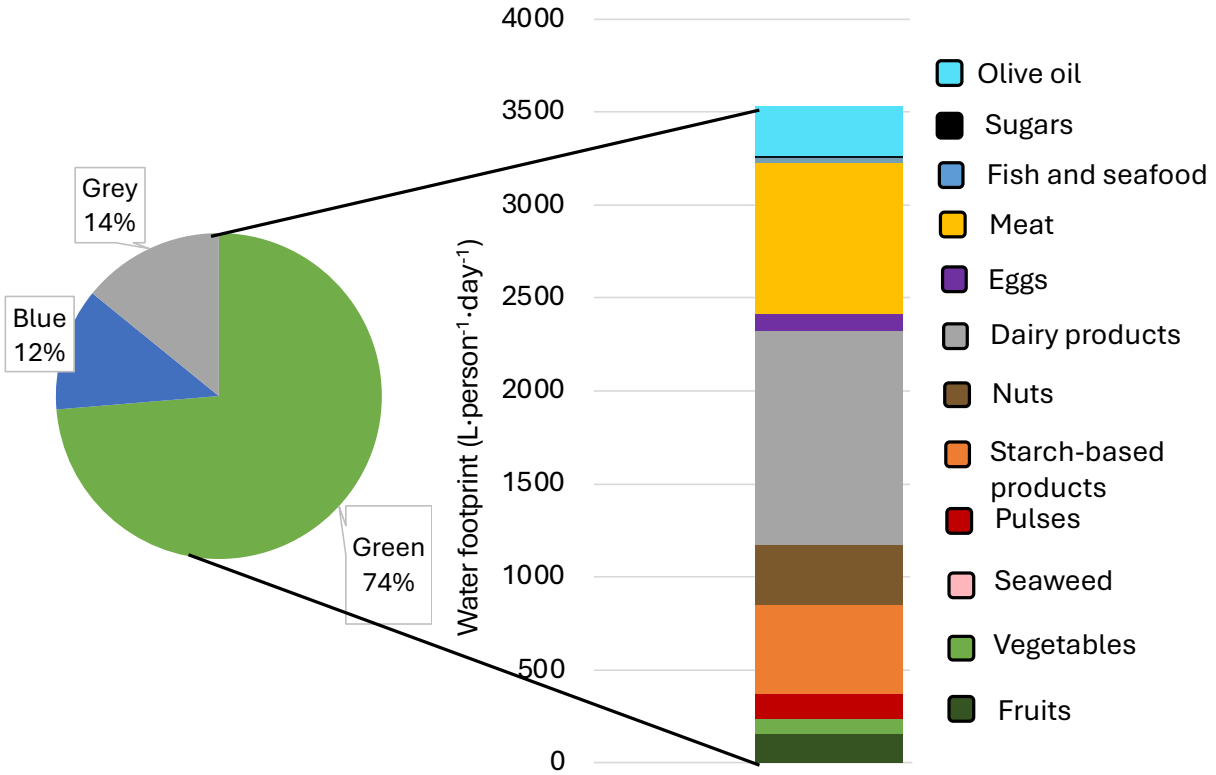



**Fig. 6.4. Water footprint estimation (L·person$^{-1}$·day$^{-1}$) for the Southern version of the New Nordic Diet a) distribution per water footprint colour (green, blue and grey) b) distribution per food categories.**

### 6.3.3 Nutritional Quality Index for the Southern version of the New Nordic Diet

Diets link environment and human health through the nutritional quality of food. In this regard, the NND under assessment in this study is among the most recommended in the Nordic countries (Iriti et al., 2020). Accordingly, a dietary quality index of 126 was calculated for the SNND, exceeding the reference value of 100 for recommended intake. **Table 6.13** compares the recommended and calculated values for SNND, demonstrating its higher overall quality.

**Table 6.13. Recommended and calculated values for Southern Version of the New Nordic Diet (SNND) to estimate the Health Index (van Dooren et al., 2014)**

| | Contributing factors | Recommended | SNND |
|---|---|---|---|
| 1 | Vegetables | >200 g | 425 g |
| 2 | Fruits | >200 g | 350 g |
| 3 | Total fatty acids | <31.5% | 30% |
| 4 | Free sugars | <10.0% | 18% |
| 5 | Fibre | >25 g | 35 g |
| 6 | Sodium | <6 g | 3 g |
| 7 | Carbohydrates | <52% | 43% |
| 8 | Saturated fatty acids | <10% | 10% |
| 9 | Fish | >37 g | 43 g |
| 10 | Energy | 2228 kcal | 2304 kcal |

### 6.3.4 Impact of the Southern version of the New Nordic Diet on non-communicable diseases

The NND has benefits in reducing NCDs (Iriti et al., 2020). Adherence to the NND was related to a weight loss of 1.83 kg per person following the diet (Ramezani-Jolfaie et al., 2020). In addition, it was associated with a significantly lower risk of T2D by 25% in women (Hazard ratio (HR): 0.75, 95% CI: 0.61-0.92) and 38% in men (HR: 0.62; 95% CI: 0.53-0.71) (Lacoppidan et al., 2015) and reduced the risk of CRCA by 35% (IRR=0.65, 95% CI 0.46, 0.94) in women and to a similar extent, in men (Kyro et al., 2013). In terms of CVD risk, the NND pattern improved cardiovascular risk factors by decreasing CVD risk (RR: 0.93, 95% CI, 0.88, 0.99) (Kahleova et al., 2019; Massara et al., 2020).

Having analysed how dietary choices determine human health, efforts focused on studying the impact of different food categories on health outcomes. **Fig. 6.5** shows how the consumption of one extra serving per day of these food groups is linked with the risk of T2D, CVD, CRCA, and obesity. If RR>1, it indicates a positive correlation between a food category and a disease, i.e., the existence of the risk factor is correlated with an increased prevalence of the event. For example, as can be seen in **Fig. 6.5a**, the consumption of processed meat presents a RR>1 (RR=1.46), indicating that processed meat is linked with an elevated risk of T2D. On the other hand, RR<1 indicates a negative association. This is the case of fish in **Fig. 6.5c** (RR=0.89), which implies that fish consumption is associated with decreased CRCA risk.

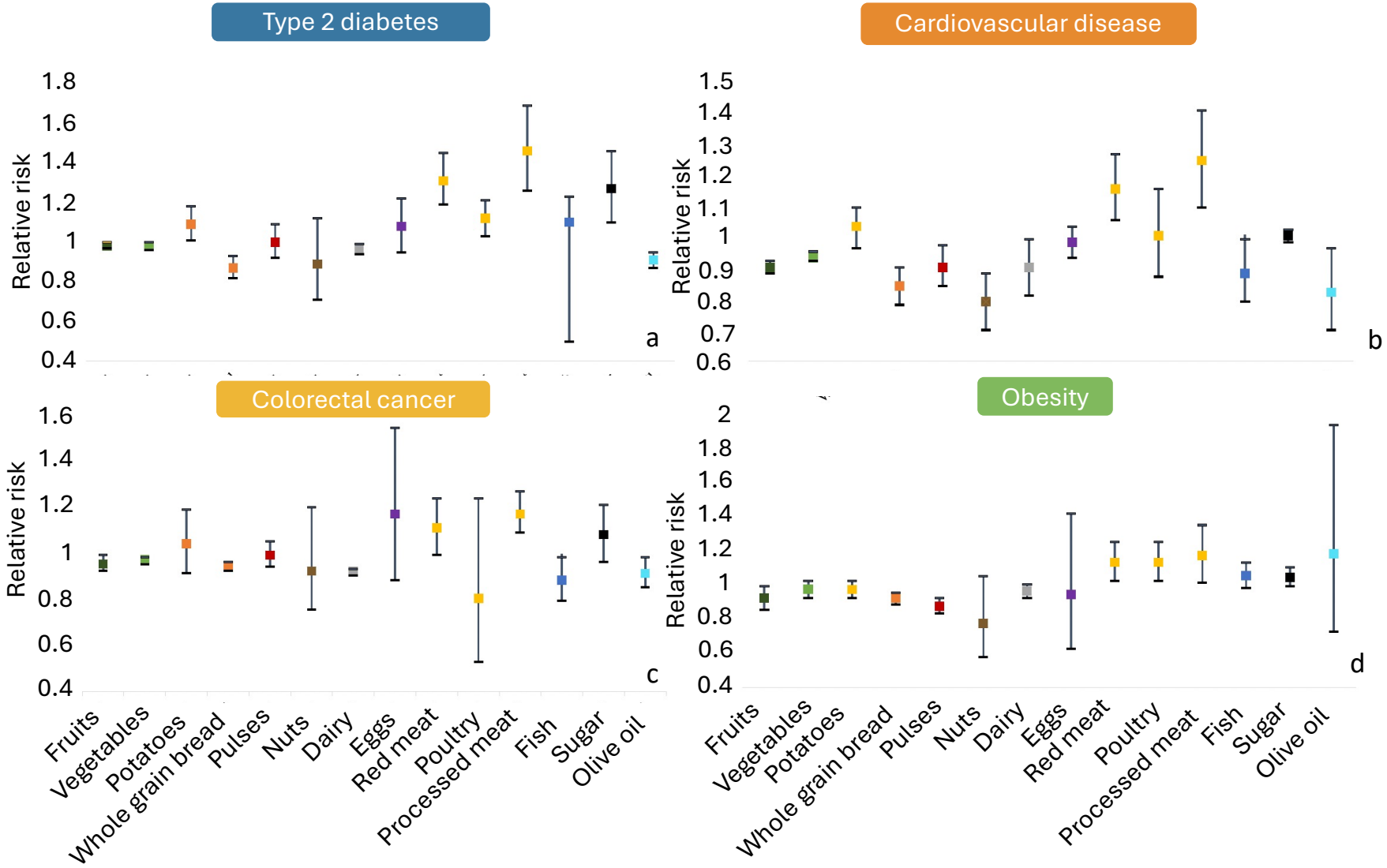



**Fig. 6.5. Relative risk per serving of foodstuff consumed of a) Type 2 Diabetes b) Cardiovascular disease c) Colorectal cancer d) Obesity**

### 6.3.5 Cost of adherence to the Southern version of the New Nordic Diet

This score pays attention to the cost that a consumer should have in his daily diet following the dietary recommendations of SNND. The estimated cost for the SNND was 4.30 €·person$^{-1}$day$^{-1}$. As can be seen in **Fig. 6.6** starch-based products were the largest contribution to the daily food expenses (20%), followed closely by meat (16%), vegetables (17%), dairy products (14%) and fruits (14%).

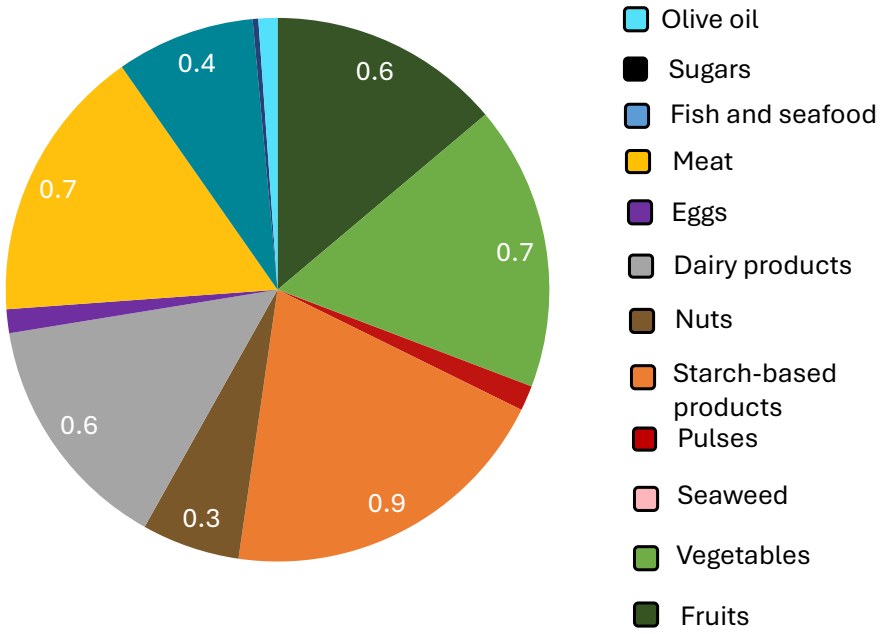



**Fig. 6.6. Daily food expenses per food categories (€·person$^{-1}$·day$^{-1}$) for Southern version of the New Nordic Diet.**

### 6.3.6 Ranking health, environmental and economic impacts of foods in the Southern version of the New Nordic Diet

**Fig. 6.7** plots the two environmental impacts analysed (WF and CF), the cost, the health outcomes (T2D, CVD, obesity and CRCA) for the main plant-based food categories (**Fig. 6.7a**) and the main animal-source food categories (**Fig. 6.7b**) of SNND in axes classified quantitatively. Note that meat was divided into three subgroups (red meat, poultry and processed meat) to match the classification used in the epidemiologic studies analysed. The food categories were ranked from 1 to 12 for each of the environmental, health and economic indicators analysed. A score of 1 indicates the best food category for a given indicator and a score of 12 indicates the worst food category. In general, food categories with low environmental impact had good health indicators, and food categories with high environmental impact were associated with higher RRs of disease.

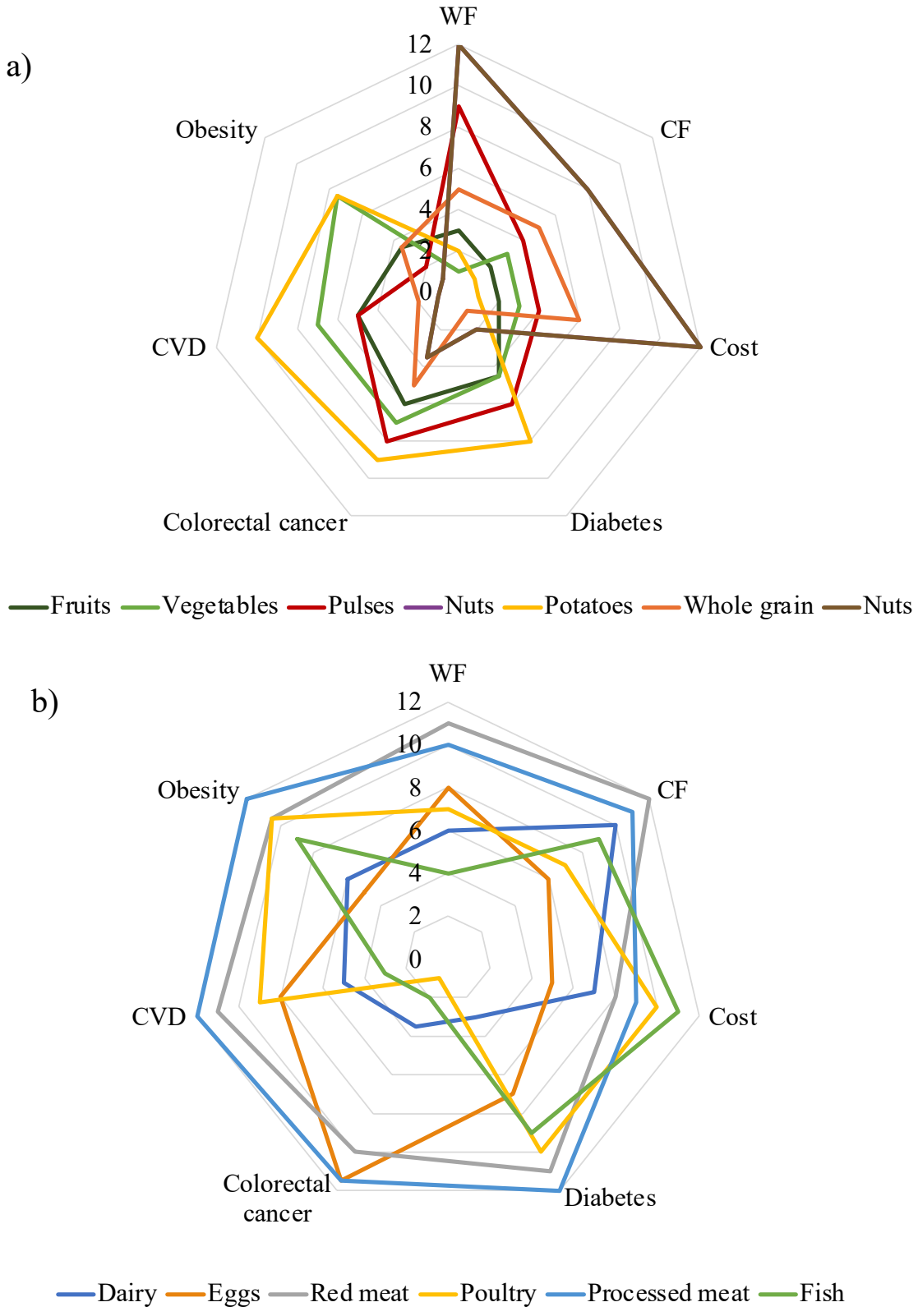



**Fig. 6.7. Radar plot of rank-ordered environmental, health and cost metrics for Southern version of the New Nordic Diet a) per plant-based food category b) per animal source food category.**

As a result, per unit of food category produced, fruits, vegetables, and whole grains had lower impacts on environmental metrics, low costs, and were not associated with a significant RR of suffering from NCDs. Pulses also presented good health, environmental and economic indicators, although they had a relatively high WF. On the other hand, per unit of food category produced, red meat and processed meat were associated with the largest increases in RR of disease and the greatest environmental impacts and economic costs. White meat, eggs and fish did not have environmental indicators as bad as red meat. In addition, poultry helped reduce the risk of CRCA, eggs had an RR of less than one for CVD and obesity, and fish was associated with greater reductions in CRCA and CVD.

Other food categories did not follow this regular trend. Potatoes were associated with an increased risk of T2D, CRCA, and CVD, despite being inexpensive and tending to have a lower environmental impact because they do not contain animal sources. The opposite was true for nuts and dairy products. Although nuts and dairy produced a higher WF, had an average CF per unit of food category of 2.5 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and 6.7 kg $CO_2$eq· person$^{-1}$·day$^{-1}$ and were high cost (8.3 €·kg$^{-1}$ and 5.2 €·kg$^{-1}$), they were not associated with an increasing risk of T2D, CRCA, CVD and obesity.

The data extracted from the SNND multidisciplinary radar diagram can be extrapolated to improve any dietary pattern. Fruits, vegetables, pulses and whole grains are key foods because they benefit planetary and human health without compromising food security. Governments should therefore emphasize the importance of increasing consumption of these healthy and climate-friendly foods in their awareness and education campaigns. Dietary guidelines should also emphasize the importance of eating less meat, especially processed meat and beef, which are drivers of climate change and diet-related diseases. These findings are consistent with the philosophy of the EAT-Lancet Diet, the global reference diet for people and planet (Kesse-Guyot et al., 2021).

## 6.4 Discussion

### 6.4.1 Comparative analysis of the Southern version of the New Nordic Diet, Mediterranean and other diets: Environmental, economic and health perspectives

Bearing in mind the results obtained for the SNND, it is possible to point out the similarities and differences with MD. The comparison in terms of CF and WF was made taking into account the results obtained from González-García et al. (2020b). In addition, the cost index reported in this article for MD was updated to 2019. On the other hand, no health or nutritional quality parameters for MD were analysed by them. Therefore, the nutritional quality index and health outcomes were estimated here in the same way as for the SNND. In **Figs. 6.8 - 6.9** can be seen the coexistence points and differences regarding the contribution of each food category and the mean scores (CF, WF, dietary quality and cost index) for these two omnivorous diets.

Regarding environmental metrics, the GHG emissions for SNND were 3.58 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, in comparison with the CF values reported by González-García et al., (2020b) for MD (2.79 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). This comparison may be perfectly acceptable considering that the same approach was considered (cradle to consumer) and that the cooking stage was excluded from the analysis in both studies. The rationale behind these results is that MD is a more plant-based dietary pattern than SNND. The recommended daily intake of animal products per day per person was higher for SNND (703 g·person$^{-1}$·day$^{-1}$) than for MD (390 g·person$^{-1}$·day$^{-1}$). Concerning food waste produced throughout the supply chain, 278 and 209 g·person$^{-1}$·day$^{-1}$ were produced in MD and SNND scenarios. The fact that MD emphasizes plant-based products, and their perishability explains the higher waste production for this diet (Batlle-Bayer et al., 2019).

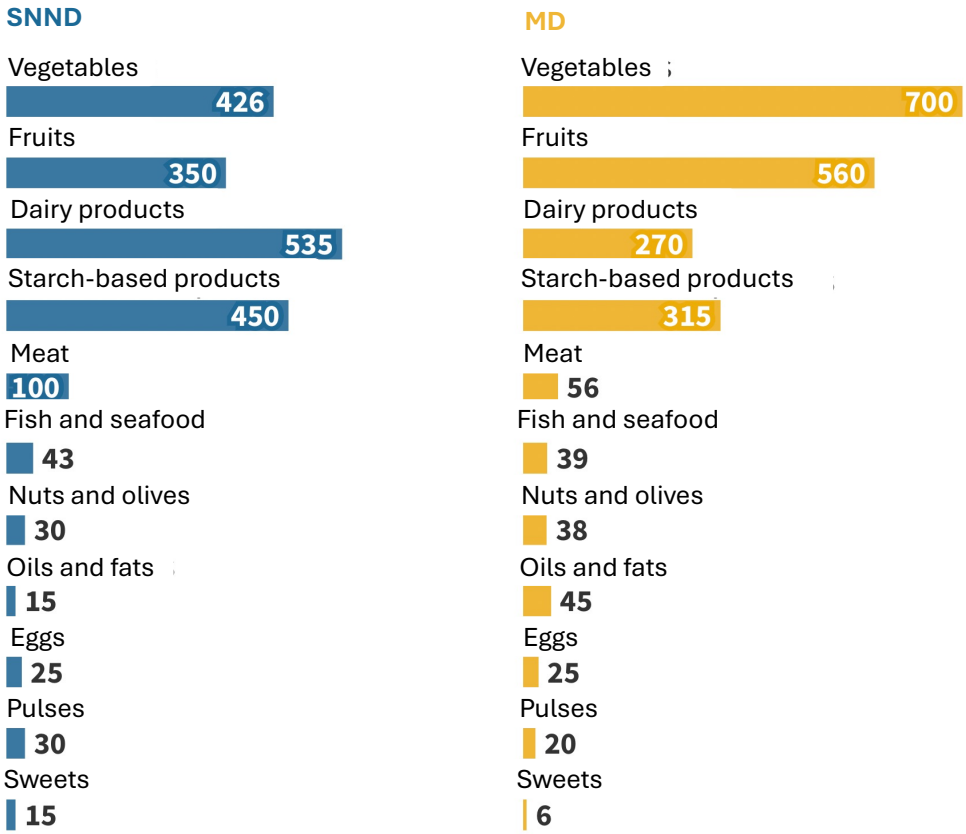



**Fig. 6.8. Similarities and differences regarding the contribution of each food category (g·person$^{-1}$·day$^{-1}$) between Mediterranean Diet (MD) and southern version of the NND (SNND).**

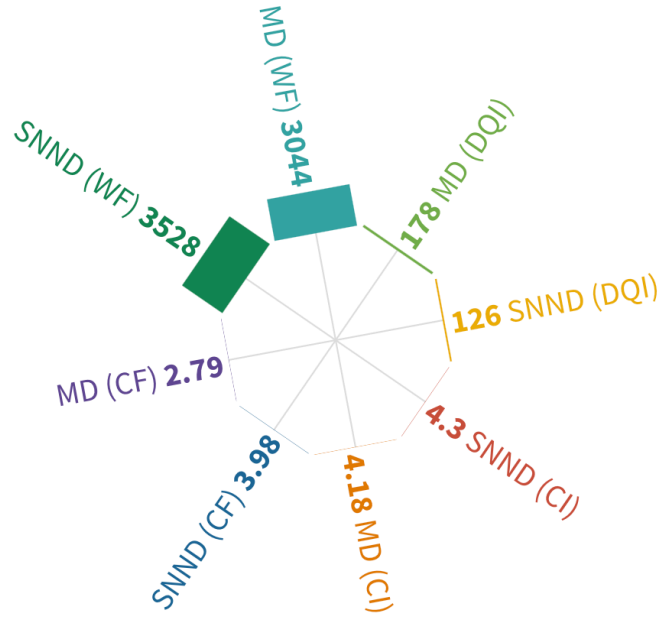



**Fig. 6.9. Mean scores (CF-Carbon footprint, kg$CO_2$eq·person$^{-1}$·day$^{-1}$, WF-Water footprint, L· person$^{-1}$·day$^{-1}$, DQI- Dietary Quality Index, CI-Cost Index, €·person$^{-1}$·day$^{-1}$) for the two omnivorous diets: MD-Mediterranean Diet and SNND-Southern Version of the New Nordic Diet.**

The results for SNND were also broadly consistent with the GHG emissions calculated for other recommended diets at global level. For example, according to Kovacs et al. (2021), the total GHG emissions that could be attributed to consumption of the recommended diet in the

Thailand were 1.83 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. The CF of the German guidelines was 2.25 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, while the GHG emissions of the Indian diet were 0.86 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and for the US Vegetarian diet 1.80 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. For the purpose of comparison with the SNND, differences in boundary conditions have to be taken into account, as Kovacs et al. (2021) focused only on food production without taking into account emissions at household and delivery level. Considering the same system boundaries as they do, the SNND would report 3.32 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. On the other hand, the SNND scores better than other dietary trends associated with a European lifestyle, such as the Caveman Diet (Paleo), whose CF was assessed under the same system boundaries (5.44 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) (Cambeses-Franco et al., 2021a).

SNND achieved a score of 3528 L·person$^{-1}$·day$^{-1}$ for WF in comparison with MD (3044 L·person$^{-1}$·day$^{-1}$). The largest differences between WF for the three dietary options were found in WFgreen. Considering that animal-based eating patterns involve a higher WFgreen (Mekonnen and Hoekstra, 2010), the WFgreen is expected to be higher for SNND than for MD, with values of 2600 L and 2194 L per capita and day, respectively. Moreover, according with the systematic review on global water use of human diets by Harris et al. (2020), the total and green WF values for SNND agree with those for an average dietary pattern in Europe (3227 L·person$^{-1}$·day$^{-1}$).

Regarding economic metrics, the cost index updated to 2019 was 4.18 €·person$^{-1}$·day$^{-1}$ for MD compared to 4.30 €·person$^{-1}$day$^{-1}$ for SNND. The daily cost of SNND per person and day was 1.03 times higher than the cost of MD. Animal-based products accounted for 42% of food expenses in the SNND dietary pattern, and 30% in MD. In SNND, starch-based products represented the highest contribution to the cost index (20%), followed bv vegetables (17%) and fish and seafood (8%). In MD, vegetables and fruit expenses represented the greatest contribution to the cost index (18% and 28% of food expenses, respectively).

The quality index calculation for MD was made based on the average daily recommended intake per foodstuff established by González-García et al. (2020b). These calculations were made due to the absence of these values in the literature and with the aim of subsequently comparing, from a multidisciplinary perspective, the MD with the SNND proposed here. According to the results, the two dietary patterns evaluated had higher overall dietary quality scores than those corresponding to the recommended intake, which has a reference value of 100. The best score was obtained by the MD (178) compared to the SNND (126). The dietary quality index was 0.79 times lower in the SNND than in the MD. Although the SNND reported higher intakes of vegetables and fruits (426 g and 350 g per day, respectively), fiber (35 g) and fish (43 g) than the WHO and EFSA recommendations, the intakes of these elements were generally lower than those of the MD.

On the other hand, the benchmarking between SNND and other dietary patterns at global level, shows the nutritional value of this dietary design approach. The Health Gain Score for the SNND was above other common diets analysed such as vegetarian (100), vegan (118) or the official recommended Dutch (105) (van Dooren et al., 2014). However, its health index is far behind other diets rich in fat, protein and polyunsaturated fatty acids (PUFA) and restricted in carbohydrates such as the Paleo Diet, with a diet quality score of 260 (Cambeses-Franco et al., 2021a).

For the comparison of health among the recommended dietary guidelines in Spain, health outcomes data related to MD were also taken from the bibliography. MD has a beneficial effect on the risk of CVD (RR=0.70, 95% CI: 0.62-0.80) (Rosato et al., 2019), T2D (RR=0.81, 95%CI: 0.73-0.90) (Schwingshackl et al., 2015) and CRCA (RR=0.82, 95% CI, 0.75-0.88) (Schwingshackl et al., 2017c). Similar to the NND, the epidemiological findings support that

MD has also an important repercussion on weight loss (-1.75 kg, 95% CI: -2.86, -0.64 kg) (Esposito et al., 2011). In addition, only one comparison was made between NND and MD with respect to weight loss and CVD. The diet-dependent RR of T2D and CRCA for both diets was not compared because of the variability of the clinical statistical measures in the cohort studies analysed. While RRs were used in the MD cohort studies, risk ratios were used in the NND clinical research. In conclusion, the cardiovascular risk profile of an individual who follows the Mediterranean dietary pattern is better than that of an individual who follows the NND. However, a higher adherence to NND allows a greater weight loss than a higher adherence to MD

### 6.4.2 Limitations and data quality

Limitations are important for proper interpretation of the validity of this scientific work. The estimation of the CF is sensitive to the wide variety of peer-reviewed scientific LCA articles used to estimate the CF of each food item. To determine the reliability and validity of the research, the uncertainty in the dietary CF was quantified using the general equation for error propagation. For the estimation of the uncertainty of the CF of each food, the maximum and minimum values reported by Barilla Center for Food Nutrition (2016) and Clune et al. (2017) were considered (for details, see **Table 6.14**).

From the uncertainty analysis it is concluded that the CF of SNND is mean [SD], 3.58 ± [1,14] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$. The uncertainty range is too large, mainly due to the large variety of CF values collected in meta-analyses and LCA reviews available in the literature for major climate hotspots such as beef (Barilla Center for Food Nutrition, 2016; Clune et al., 2017). Despite the uncertainty, the CF result provides valuable knowledge when trying to inform the public about good dietary choices for environmental purposes.

Regarding the calculation of WF, an important limitation is the lack of data for non-aquaculture fish species. A limitation that must also be taken into account in relation to the health conclusions is that the health data come from cohort studies evaluating the original version of the NND and not the SNND proposed in this chapter.

**Table 6.14. Uncertainty Analysis (Barilla Center for Food Nutrition, 2016; Clune et al., 2017)**

| | Uncertainty carbon footprint ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|
| **Fruits** | 0.59 |
| **Vegetables** | 2.24 |
| **Pulses** | 1.23 |
| **Starch-based products** | |
| Whole grain bread | 1.06 |
| Potatoes | 0.09 |
| **Nuts** | |
| Walnuts | 1.22 |
| Peanuts | 0.15 |
| Almonds | 1.63 |
| **Dairy products** | |
| Milk | 1.36 |
| Cheese | 4.64 |
| Butter | 2.58 |
| **Eggs** | 2.77 |
| **Meat** | |
| Beef | 29.94 |
| Pig | 6.17 |
| Chicken | 7.69 |
| Other meat products | 6.17 |
| **Fish and seafood** | 7.74 |
| Sweets | |
| Sugar | 0.52 |
| **Oils and fats** | |
| Olive oil | 2.43 |

## 6.5 CONCLUDING REMARKS

The concept of NND emerged in the Nordic countries as a way of changing diets in a healthier and more sustainable direction. Its principles can be applied anywhere, including southern European countries such as Spain, where the MD, a recommended omnivorous diet, is widely accepted. The present study evaluates the NND from a multidisciplinary approach, considering economic (cost index), nutritional, environmental (CF and WF) and health indicators (RR).

The results of this chapter support the close relationship between dietary patterns and environmental impacts. Although both diets, MD and SNND, showed protective effects against CVD, T2D, CRCA and demonstrated potential for weight management, MD had a lower CF and WF. In terms of dietary quality, the nutritional quality index of both diets was higher than the recommended intake, with MD showing a slight nutritional advantage. In terms of economic evaluation, the costs were similar for MD and SNND.

In conclusion, although the environmental and nutritional profiles of the SNND are not as good as the MD, it is also a win-win diet. Both scores well on economic, health and environmental criteria and should be part of dietary guidelines promoted by governments and public campaigns to avoid the current shift to an unhealthy Westernized diet.

# SECTION III

## THE ATLANTIC DIET: A PLANETARY HEALTHY DIET

# 7. A DIET IS MORE HEALING THAN TEN PRESCRIPTIONS: CLINICAL TRIAL ADDRESSING THE TRINOMIAL ATLANTIC DIET-HEALTH-ENVIRONMENT (THE GALIAT STUDY)[4]

The universal call to action for healthier and more sustainable dietary choices is the framework of the Sustainable Development Goals. The Atlantic Diet, originating from the northwest of the Iberian Peninsula, represents an example of a traditional diet in line with these principles. This study examines a 6-month intervention based on the effects of the Atlantic Diet on metabolic and environmental health, assessing the incidence of metabolic syndrome and carbon footprint.

The Galician Atlantic Diet study was a 6-month randomised controlled trial designed to evaluate the effects of this regional traditional diet on family eating habits. The study was carried out from March 3, 2014, to May 29, 2015, at a local primary health care center in the rural town of A Estrada, northwestern Spain, with multisectoral collaboration. Families were randomly selected from the records of the National Health System in a rural area and randomised 1:1 to an intervention or control group. This secondary analysis of the trial findings was performed between March 24, 2021, and November 7, 2023.

Over 6 months, families in the intervention group received educational sessions, cooking classes, written support materials, and foods characteristic of the Atlantic diet, while those randomised to the control group continued their usual lifestyle. The main outcomes were the incidence of metabolic syndrome, defined according to the National Cholesterol Education Program Adult Treatment Panel III guidelines, and carbon footprint as an environmental metric using life cycle assessment with daily food intake as the functional unit.

Initially, 250 families were randomised (574 participants, mean [SD] age: 46.8 [15.7] years, 231 males [40.2%] and 343 females [59.8%]). The intervention group included 126 families (287 participants) and the control group, 124 families (287 participants). Ultimately, 231 families completed the trial. The intervention significantly reduced the risk of incident cases of metabolic syndrome (rate ratio: 0.32; 95% CI, 0.13-0.79) and had fewer metabolic syndrome components (proportional odds ratio, 0.58; 95% CI, 0.42-0.82) compared with the control condition. The intervention group did not have a significantly reduced environmental impact in terms of carbon footprint emissions compared with the control group (-0.17 [95% CI, −0.46 to 0.12] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$). These findings provide important evidence that a family-focused intervention based on a traditional diet can reduce the risk of incident metabolic syndrome. Further research is needed to understand the underlying mechanisms and determine the generalizability to other populations, taking into account regional cultural and dietary variations.

Trial registration: ClinicalTrials.gov Identifier: NCT02391701

---

[4] Cambeses-Franco, C., Gude, F., Benítez-Estévez, A. J., González-García, S., Leis, R., Sánchez-Castro, J., Moreira, M.T., Feijoo, G., Calvo-Malvar, M. (2024). Traditional Atlantic Diet and Its Effect on Health and the Environment: A Secondary Analysis of the GALIAT Cluster Randomised Clinical Trial. JAMA Network Open, 7(2), e2354473. 10.1001/jamanetworkopen.2023.54473

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## 7.1 INTRODUCTION

Dietary patterns around the world are changing, often with negative impacts on human and planetary health. A shift toward sustainable, healthy dietary patterns is needed to achieve the United Nations SDGs on reducing NCDs (SDG 3) and mitigating climate change (SDG 13) (FAO and WHO, 2019). These diets should support health and be environmentally friendly, accessible, affordable, safe, equitable, and culturally acceptable as needed. Some traditional regional diets, such as the Atlantic Diet, align with this concept. The Atlantic diet shares similarities with the MD and has been associated with reduced metabolic risk factors (Agostinis-Sobrinho et al., 2019; Calvo-Malvar et al., 2021b; Guallar-Castillón et al., 2013; Moreira et al., 2013; Rodríguez-Martín et al., 2019) and environmental benefits (González-García et al., 2020b).

We hypothesize that a shift to a traditional Atlantic diet would not only improve population health but also contribute to environmental sustainability, taking into account the identity and diversity of the food system and culture of northwestern Spain and northern Portugal.

To date, no clinical trial has been conducted to evaluate the effects of a traditional diet (i.e., the Atlantic diet) from a dual sustainability perspective on human and environmental health, thereby addressing two of the United Nations SDGs. Therefore, in this chapter we address 2 questions: (1) whether an intervention based on a traditional Atlantic diet can reduce the incidence of new cases of MetS or contribute to a higher resolution of existing cases compared to the general population, and (2) whether this intervention would result in a lower environmental impact.

## 7.2 METHODS

### 7.2.1 Study design

This study is a post hoc secondary analysis of the Galicia Atlantic Diet (GALIAT) study, a 6-month community-based randomised clinical trial designed to evaluate the effects of the traditional Atlantic diet on metabolic health and family dietary habits. The GALIAT trial was conducted from March 3, 2014, to May 29, 2015. This trial was based on the traditional diet of the study area and involved a collaborative, multisectoral approach involving citizens, local businesses, researchers, and public institutions (Calvo-Malvar et al., 2016). The trial was deliberately designed to be pragmatic, prioritising effectiveness and practicality in primary care settings (Calvo-Malvar et al., 2021a).

The study procedures are detailed in previous publications (Calvo-Malvar et al., 2016, 2021b). The Galician Autonomous Committee for Research Ethics approved the trial (code 2013/531) and the current study. The study was conducted in accordance with the Declaration of Helsinki and the principles of good clinical practice. The trial was retrospectively registered on ClinicalTrials.gov (NCT02391701) and adhered to the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines (Schulz et al., 2010) (**Table 7.1**) and the Template for Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2014) (**Table 7.2**). The current data analysis was performed between March 24, 2021, and November 7, 2023.

**Table 7.1. CONSORT checklist**

| Section/Topic | Item No | Checklist item | Reported on page No |
|---|---|---|---|
| **Title and abstract** | | | |
| | 1a | Identification as a randomised trial in the title | 163 |
| | 1b | Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts) | 163 |
| **Introduction** | | | |
| Background and objectives | 2a | Scientific background and explanation of rationale | 165 |
| | 2b | Specific objectives or hypotheses | 165 |
| **Methods** | | | |
| Trial design | 3a | Description of trial design (such as parallel, factorial) including allocation ratio | 165,169 |
| | 3b | Major changes to methods after trial commencement (such as eligibility criteria), with reasons | NA |
| Participants | 4a | Eligibility criteria for participants | 169,170 |
| | 4b | Settings and locations where the data were collected | 165,169 |
| Interventions | 5 | The interventions for each group with sufficient details to allow replication, including how and when they were administered | 170-173 |
| Outcomes | 6a | Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed | 175-176 |
| | 6b | Any changes to trial outcomes after the trial commenced, with reasons | NA |
| Sample size | 7a | How sample size was determined | 188 |
| | 7b | When applicable, explanation of any interim analyses and stopping guidelines | NA |
| Randomisation: | | | |
| Sequence generation | 8a | Method used to generate the random allocation sequence | 170 (and Calvo-Malvar et al. (2016)) |
| | 8b | Type of randomisation; details of any restriction (such as blocking and block size) | 170 (and Calvo-Malvar et al. (2016)) |
| Allocation concealment mechanism | 9 | Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned | NA |
| Implementation | 10 | Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions | Calvo-Malvar et al. (2016) |
| Blinding | 11a | If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how | 172 |
| | 11b | If relevant, description of the similarity of interventions | NA |

**Table 7.1. (cont.) CONSORT checklist**

| Section/Topic | Item No | Checklist item | Reported on page No |
|---|---|---|---|
| Statistical methods | 12a | Statistical methods used to compare groups for primary and secondary outcomes | 188-189 |
| | 12b | Methods for additional analyses, such as subgroup analyses and adjusted analyses | NA |
| **Results** | | | |
| Participant flow (a diagram is strongly recommended) | 13a | For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome | 192 and Fig. 7.3. |
| | 13b | For each group, losses and exclusions after randomisation, together with reasons | Fig. 7.3. |
| Recruitment | 14a | Dates defining the periods of recruitment and follow-up | 165 |
| | 14b | Why the trial ended or was stopped | NA |
| Baseline data | 15 | A table showing baseline demographic and clinical characteristics for each group | Table 7.14 |
| Numbers analysed | 16 | For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups | 192 and Fig. 7.3. |
| Outcomes and estimation | 17a | For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval) | 195-199 |
| | 17b | For binary outcomes, presentation of both absolute and relative effect sizes is recommended | NA |
| Ancillary analyses | 18 | Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory | 195-199 |
| Harms | 19 | All important harms or unintended effects in each group (for specific guidance see CONSORT for harms) | NA |
| **Discussion** | | | |
| Limitations | 20 | Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses | 200-201 |
| Generalisability | 21 | Generalisability (external validity, applicability) of the trial findings | 200-201 |
| Interpretation | 22 | Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence | 199-200 |
| **Other information** | | | |
| Registration | 23 | Registration number and name of trial registry | 165 |
| Protocol | 24 | Where the full trial protocol can be accessed, if available | Cambeses-Franco et al. (2024) |
| Funding | 25 | Sources of funding and other support (such as supply of drugs), role of funders | Cambeses-Franco et al. (2024) |

**Table 7.2. TIDIeR checklist**

| Item number | Item | Primary (page or number) |
|---|---|---|
| | BRIEF NAME | |
| 1. | Provide the name or a phrase that describes the intervention. | 163 |
| | WHY | |
| 2. | Describe any rationale, theory, or goal of the elements essential to the intervention. | 165 |
| | WHAT | |
| 3. | Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL). | 170-175 (and Cambeses-Franco et al. (2024)) |
| 4. | Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities. | 170-175 (and Cambeses-Franco et al. (2024)) |
| | WHO PROVIDED | |
| 5. | For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given. | 169 |
| | HOW | |
| 6. | Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group. | 170-175 (and Cambeses-Franco et al. (2024)) |
| | WHERE | |
| 7. | Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features. | 165, 169 |
| | WHEN and HOW MUCH | |
| 8. | Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity or dose. | 170-175 (and Cambeses-Franco et al. (2024)) |
| | TAILORING | |
| 9. | If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how. | 170-175 (and Cambeses-Franco et al. (2024)) |
| | MODIFICATIONS | |
| 10.‡ | If the intervention was modified during the course of the study, describe the changes (what, why, when, and how). | N/A |
| | HOW WELL | |
| 11. | Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them. | Calvo-Malvar et al. (2016, 2021a) |
| 12.‡ | Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned. | Calvo-Malvar et al. (2016, 2021a) |

The GALIAT study was designed by researchers at the University Hospital of Santiago de Compostela and carried out in the local primary health care center in the rural town of A Estrada in north-western Spain. The centre was selected because of its staff's experience in conducting observational studies. A team of 20 family doctors, three paediatricians, and 20 nurses from the health centre participated as collaborating researchers. Prior to the study, these individuals received extensive training on the study protocol and procedures. Furthermore, one doctor, one nurse and four nutritionists were recruited to lead the fieldwork, which included interviewing participants, anthropometric data collection, blood pressure monitoring, biological sampling and data verification and transcription.

All personnel involved underwent theoretical and practical training one month prior to the study to standardise procedures, including trial runs with volunteers. Daily meetings were held to resolve any problems. During the study, daily telephone consultations and weekly meetings ensured smooth operation. The fieldwork took place in two doctors' offices and in a room designated for the collection of biological samples in the health centre.

### 7.2.2 Participants

#### 7.2.2.1 Recruitment

Recruitment within the community was performed through a random representative sample of 3500 individuals, aged 18-85 years and stratified by decade of age, drawn from the Spanish National Health Registry of a single rural population of approximately 20,000 inhabitants. The selected individuals were contacted by telephone to confirm their participation in the study. This process created a list of individuals to whom letters were sent explaining the project and inviting them to participate. These individuals were then contacted again by telephone to confirm their participation, to verify that they met the inclusion criteria, and to document the size of their families. Those who accepted the invitation were scheduled for a pre-assessment session. During the pre-assessment session, participants were informed about the objectives of the project, informed about the methods of subject selection, given detailed information about the participation requirements, and acquainted with their rights as participants. In addition, comprehensive project documentation and informed consent forms for all family members (including adults, children, and guardians) were provided. Participants who chose to continue were then scheduled for an initial evaluation at the health center, where they, accompanied by their families, submitted signed informed consent forms and underwent assessments to confirm compliance with the inclusion/exclusion criteria. The planned recruitment rate was 10 to 15 families per week. To encourage participation, the study was advertised through various media channels, including newspapers, radio and television. The participating family doctors helped by any questions about the project.

#### 7.2.2.2 Eligibility

These index individuals and their household members were invited to participate if they lived in a family unit with at least 2 members aged 3 to 85 years; were not currently taking lipid-lowering medication; were not pregnant; and did not have alcoholism (Bush, 1998), major CVD, dementia, or a life expectancy of less than 1 year, which specifically refers to individuals with a terminal illness. The study included participants of Spanish ethnicity and Caucasian ancestry. Fieldwork staff collected data on participants' specific birthplaces and family histories. Inclusion and exclusion criteria were gathered in **Table 7.3**.

**Table 7.3. Inclusion and exclusion criteria.**

| | Inclusion criteria | Exclusion criteria |
|---|---|---|
| **Individual level** | | |
| **Index subject of each family** | Male or female<br>Age 18-85 years<br>To be part of a family (living together) of at least two members | Alcoholism<br>Pregnancy<br>Cardiovascular disease (ischemic heart disease, heart failure, peripheral vascular disease, cerebrovascular disease)<br>Dementia<br>Predicted survival of less than one year<br>Lipid-lowering treatment |
| **Other family members** | Male or female<br>Age 3-85 years | Alcoholism<br>Pregnancy<br>Cardiovascular disease (ischemic heart disease, heart failure, peripheral vascular disease, cerebrovascular disease)<br>Dementia<br>Predicted survival of less than one year |
| **Cluster (family) level** | | |
| | Two or more members had to meet all inclusion criteria but no exclusion criterion. | |

7.2.2.3 Withdrawals/Loos to follow-up

The study concluded at the six-month mark with regard to family participation. Participants were withdrawn from the study if they met any of the previously outlined exclusion criteria, failed to attend scheduled appointments, or voluntarily withdrew. Individuals who were lost to follow-up were not replaced in the study.

### 7.2.3 Randomisation and Procedures

Families were randomly assigned to the intervention or control group in a 1:1 ratio using a computer-generated random number table. The dietary intervention was based on the Atlantic diet, the traditional diet of northwestern Spain and Portugal, which consists of local, fresh, and minimally processed seasonal foods such as vegetables, fruits, whole grains, beans, and olive oil. The Atlantic diet is also characterised by high consumption of fish and seafood, as well as starchy products, dried fruits (especially chestnuts), milk, cheese, and moderate consumption of meat and wine (Calvo-Malvar et al., 2016; Vaz-Velho et al., 2016).

Dietary counselling aimed to modify eating habits according to the characteristics of the Atlantic diet (**Table 7.4**), but not necessarily to limit energy intake. Dietary recommendations were adapted to the preferences and nutritional needs of each participant. In the intervention group, families attended 3 nutrition education sessions at the health center and received additional support, including a cooking class, written materials, and regular food baskets with traditional Atlantic diet items (**Fig. 7.1**). Participants in the control group were advised to maintain their usual lifestyle. Previous articles assessed dietary patterns, with baseline values showing similarity (Calvo-Malvar et al., 2021a).

**Table 7.4. Food consumption recommendations**

| Food category | Frequency of consumption |
|---|---|
| Bread, cereals, wholegrain cereals, rice, pasta and potatoes | 6-8 servings/day |
| Olive oil | 3-4 servings/day |
| Fruit | ≥3 servings/day |
| Vegetables | ≥ 2 servings/day |
| Dairy products | 3-4 servings/day |
| Nuts, preferably chestnuts, almonds, walnuts and hazelnuts | 4-6 servings/week |
| Fish and seafood | 3-4 servings/week |
| Eggs | 3-4 servings/week |
| Lean meat | 3-4 servings/week |
| Pulses | 2-3 servings/week |
| Fatty meat, cured sausages, margarine, butter | A few times per month |
| Sweets, pastries, cakes, ice cream, etc. | A few times per month |

At the baseline and after 6 months, information was collected on dietary intake, physical activity (Craig et al., 2003), medication use, and other variables (see **Section 7.2.5**). Masking procedures were used during randomisation and data collection to minimise potential bias. However, due to the nature and design of our study, masking at the intervention level was not feasible.

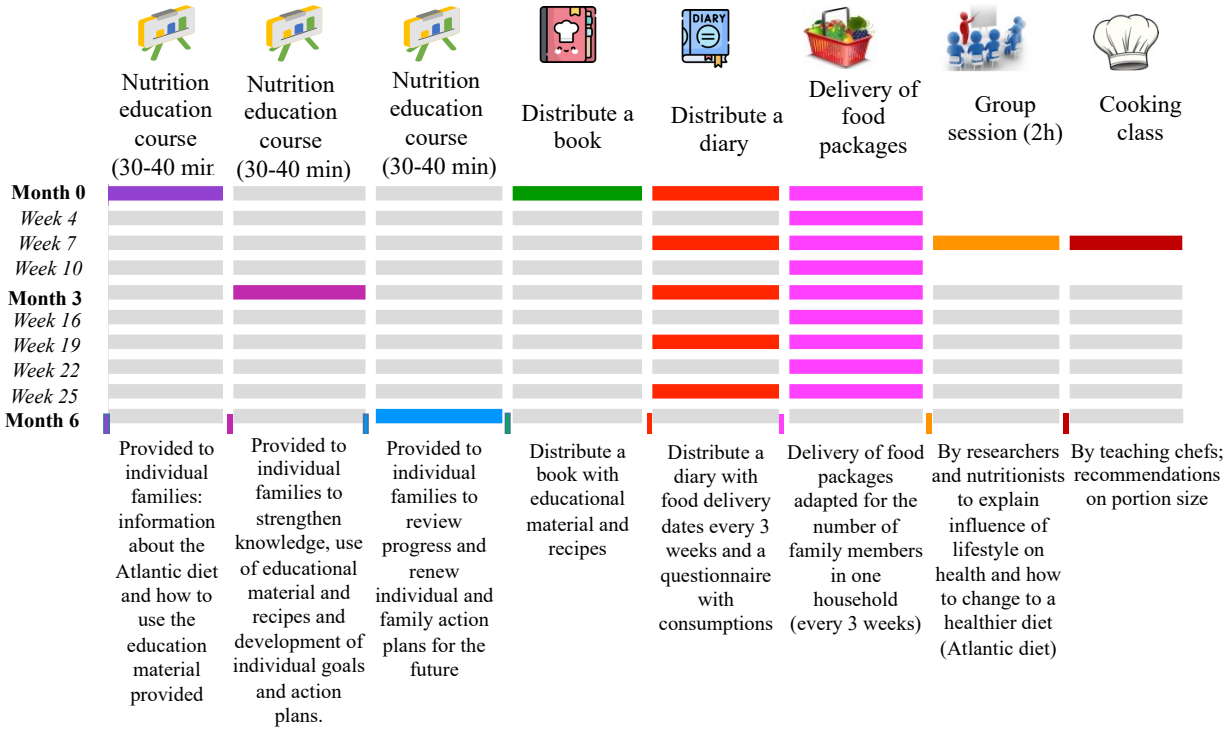


**Fig. 7.1. Intervention components**

### 7.2.4 Trial protocol

**Table 7.5** summarized the study protocol (for details see Supplementary material of Cambeses-Franco et al. (2024)). At the first visit, all participants in the intervention group were given detailed information about the Atlantic diet and instructions on how to follow it. The nutritionists tailored their advice to each participant's clinical condition, personal preferences, needs, beliefs and cultural context. Special attention was given to those who were obese, diabetic or had elevated cholesterol levels. All questionnaires, except the 3-day food diaries, were completed under the supervision of the nutritionists. The 3-day food diaries were submitted independently by the participants and then checked in their presence to correct any

inaccuracies or add missing information. At the 3-month and 6-month follow-up visits, the nutritionists reiterated the key principles of the Atlantic diet and assisted participants in completing their questionaries. Food packages were delivered to participants' homes every three weeks, with the amount calculated to feed the entire family, even if not all members participated in the study. At each delivery, a form was completed to confirm consumption of the previous food allocation and to document any problems.

**Table 7.5. Graphical representation of the intervention**

| Time line | Intervention | Control |
|---|---|---|
| Pre- assessment | A B C | A B C |
| Basal (time 0) | D E F G<br>Randomisation<br>H I J<br>K L M | D E F G<br>Randomisation<br>H I J |
| 1 week | O | |
| 4 weeks | O P | |
| 7 weeks | O | |
| 10 weeks | O | |
| 3 months | F G L | F G |
| 13 weeks | O | |
| 16 weeks | O | |
| 19 weeks | O | |
| 22 weeks | O | |
| 6 months | F G I J<br>L | F G I J<br>L K |
| | Measurement of outcomes | |

**Table 7.5. (cont.) Graphical representation of the intervention**

| | |
|---|---|
| A | Intervention between index subject and physicians at the health center. Verbal explanation of the project. |
| B | Distribution of written project details and consent forms (for children/adults/parents and guardians) |
| C | Upon accepting participation, an appointment is scheduled with the medical team, along with the family, for a baseline assessment and to provide instructions on blood sample extraction. |
| D | Confirm that family members meet the inclusion criteria and are not subject to any exclusion criteria. |
| E | Collect consent forms |
| F | Blood extraction |
| G | Anthropometric measurements, blood pressure |
| H | Complete questionnaire on socioeconomic status and check personal and family medical history |
| I | Complete questionnaire on health-related quality of life, physical activity, sedentarism, diet quality, food consumption patterns, food frequency, alcohol consumption, use of tobacco |
| J | Distribution of 3-day food record forms |
| K | Hand out a book with educational material and recipes |
| L | Nutrition education course (30-40 min) |
| M | Diary with food delivery dates (every 3 weeks) |
| | Begin delivery of food packages |
| O | Complete questionnaire on food habits, consumption of delivered foods, physical activity/sedentarism, answering any questions. |
| P | Group session (2 h) by researcher and nutritionists |
| | Cooking class |
| | Gift of food basket, educational material and recipe book |

### 7.2.5 Data collection

Unless otherwise stated, data were collected at the baseline and at the three- and six-months follow-up visits. The data set comprised a range of sociodemographic information, including place of birth, marital status, level of education, profession, employment status, and characteristics of the home. Personal and family medical histories were recorded, specifically focusing on heart disease, diabetes, hypertension, cancer, hypercholesterolemia, age at menarche and menopause, as well as the use of medications for managing cholesterol and blood pressure. The health-related quality of life was evaluated using the Spanish v.2.0 of the Short Form 12 Health Survey (SF-12) questionnaire (Ware et al., 2002; Ware et al., 1996), with the response interpreted in accordance with the reference values for the Spanish population (Schmidt et al., 2012). Additionally, data were gathered on the subjects' consumption of tobacco and alcohol. **Table 7.6** gives an overview of the data collected and the tests made during the study period.

**Table 7.6. Outcomes and measurement time points.**

| | Baseline | 3 months | 6 months |
|---|---|---|---|
| **Questionnaires & Health Measurements** | | | |
| Sociodemographic data | ✓ | | |
| Health status: personal and family medical history | ✓ | | |
| Quality of life, (SF-12v2 questionnaire) | ✓ | | ✓ |
| Dietary habits, FFQ | ✓ | | ✓ |
| 3-day food record | ✓ | | ✓ |
| Diet quality | ✓ | | ✓ |
| Dietary patterns | ✓ | | ✓ |
| IPAQ-short | ✓ | | ✓ |
| Sedentary behaviour | ✓ | | ✓ |
| Drinking habits (AUDIT-C questionnaire) | ✓ | | ✓ |
| Use of tobacco | ✓ | | ✓ |
| **Anthropometry** | | | |
| Body weight (kg) | ✓ | ✓ | ✓ |
| Height (cm) | ✓ | ✓ | ✓ |
| BMI (kg/m2) | ✓ | ✓ | ✓ |
| Waist circumference (cm) | ✓ | | ✓ |
| Arm circumference (cm) | ✓ | | ✓ |
| Thigh circumference (cm) | ✓ | | ✓ |
| Biceps skinfold thickness | ✓ | | ✓ |
| Triceps skinfold thickness | ✓ | | ✓ |
| Subscapular skinfold thickness | ✓ | | ✓ |
| Suprailia skinfold thickness | ✓ | | ✓ |
| Resting pulse and blood pressure | ✓ | | ✓ |
| **Biomarkers** | | | |
| Total cholesterol | ✓ | ✓ | ✓ |
| High density lipoprotein cholesterol | ✓ | ✓ | ✓ |
| Low density lipoprotein cholesterol | ✓ | ✓ | ✓ |

**Table 7.6. (cont.) Outcomes and measurement time points.**

| | Baseline | 3 months | 6 months |
|---|---|---|---|
| Triglycerides | ✓ | ✓ | ✓ |
| Albumin | ✓ | ✓ | ✓ |
| Aspartate aminotransferase | ✓ | ✓ | ✓ |
| Alanine aminotransferase | ✓ | ✓ | ✓ |
| Gamma-glutamyl transferase | ✓ | ✓ | ✓ |
| Creatinine | ✓ | ✓ | ✓ |
| Urea | ✓ | ✓ | ✓ |
| Glucose | ✓ | ✓ | ✓ |
| Hemoglobin A1C (HbA1c) | ✓ | ✓ | ✓ |
| Insulin | ✓ | | ✓ |
| Fructosamine | ✓ | | ✓ |
| Leptin | ✓ | | ✓ |
| C-reactive protein | ✓ | | ✓ |
| Interleukin 6 | ✓ | | ✓ |
| Tumor necrosis factor α | ✓ | | ✓ |
| 25-OH cholecalciferol | ✓ | ✓ | ✓ |
| Thyrotropin | ✓ | | ✓ |
| Hemogram | ✓ | ✓ | ✓ |

### 7.2.6 Outcomes

7.2.6.1 Metabolic Syndrome

MetS was defined according to the National Cholesterol Education Program Adult Treatment Panel III (ATP III) guidelines (NCEP, 2002) and based on the compliance of at least 3 of the following 5 criteria: (1) waist circumference greater than 102 cm for men or greater than 88 cm for women, (2) triglyceride levels of 150 mg/dL or higher (≥1.7 mmol/L), (3) high-density lipoprotein (HDL) cholesterol less than 40 mg/dL (<1.03 mmol/L) for men or less than 50 mg/dL (<1.3 mmol/L) for women, (4) blood pressure of 130/85 mm Hg or higher, and (5) fasting glucose level of 110 mg/dL or higher (≥6.2 mmol/L). Participants treated with antidiabetic, antihypertensive, or triglyceride-lowering medications were classified as positive for the respective criterion. We investigated (1) whether the intervention can reduce the incidence of new cases (among those participants without MetS at baseline) and (2) whether there were differences in the prevalence of MetS and its components (among all participants) at the end of follow-up between the intervention and control groups.

7.2.6.2 Metabolic variables

Metabolic variables were measured at the primary health care center. All anthropometric measurements were performed in triplicate. Waist circumference was measured at the narrowest point between the bottom of the rib and the top of the iliac crest using a SECA 201 model circumference tape measure (Hamburg, Germany). Blood pressure was measured with an OMRON M3 automatic sphygmomanometer after the subjects were seated for 5 minutes. Blood was collected in the morning after a 10-14 h fast. Plasma glucose, HDL cholesterol, and triglyceride concentrations were measured using an Advia 2400 Clinical Chemistry System (Siemens Healthcare Diagnostics).

7.2.6.3 Dietary intake

A 3-day food diary was used to collect dietary intake data. Participants were asked to provide information such as foods consumed, brand names, and cooking techniques used. They were encouraged to report the weight of all foods consumed, but if this was not possible, they were asked to use measures available at home, such as cups and tablespoons. Participants were given a table of equivalencies to assess hand size, home measurements, and weight. Dietitians verified all records completed by the participants in their presence. Dietary intake was analysed using professional nutritional analysis software (DIAL V.3.3.5.0, Madrid, Spain) (Ortega et al., 2016).

7.2.6.4 Carbon footprint

The LCA approach was used to calculate the dietary CF of each participant, relative to a functional unit, as a baseline for all calculations. The functional unit chosen was the individual daily dietary intake, based on the results of the dietary questionnaires.

The CF framework assessed the $CO_2$ emissions associated with each participant's diet. This well-established indicator was used while accounting for variations in LCA study boundaries. Our approach focused on the life cycle from food production to household consumption, with adjustments for food losses and waste in the supply chain (**Fig. 7.2**) (Castañé and Antón, 2017; Esteve-Llorens et al., 2019a; Wernet et al., 2016).

The food production stage (S1) includes the agricultural or industrial production of the various food ingredients that make up each patient's diet. A systematic literature review was conducted to identify GHG emissions associated with the primary production of different food products. We searched the Scopus and Web of Science databases for English-language studies published or in press between 2010 and 2023. In addition, we searched for LCA studies with Spain as the country of reference, using search terms such as 'CF,' 'Life Cycle,' 'LCA,' and 'LC'. Priority was given to LCA from peer-reviewed journal articles. However, for some specific foods where information was limited, EPDs and conference papers were also managed. To be consistent with the system boundaries, the LCA studies followed the cradle-to-farm gate approach (from raw materials to factory, farm or port), excluding the CF contribution of additional stages. A detailed summary of the sample of 324 food products and their associated GHG emissions is presented in **Table 7.7**.

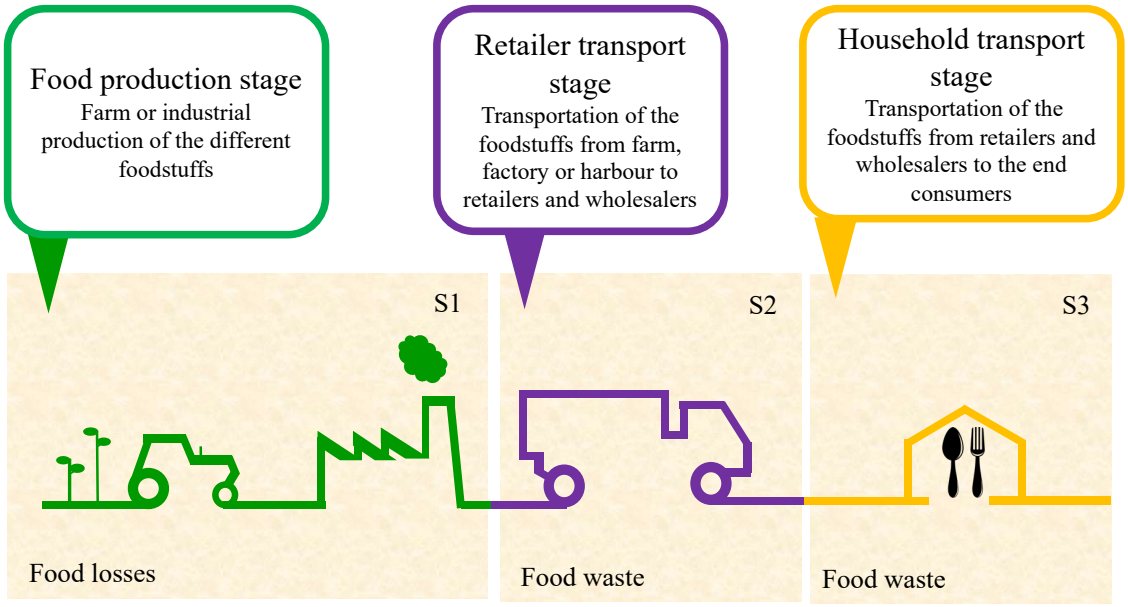


**Fig. 7.2. System boundaries considered in the carbon footprint assessment**

The retail transport stage (S2) includes the transport of food from farm, factory or port to retailers and wholesalers. Euro 5 diesel trucks (N32 tons) were chosen as the transport mode at local and national level. An average truck distance of 60 km was assumed for typical Galician food products (Esteve-Llorens et al., 2019a). For food products produced in Spain (excluding Galicia), an average distance of 400 km was considered (Castañé and Antón, 2017). For international foodstuffs, sea and land distances between the country of origin and the Galician region were calculated. The Ecoinvent v3.8. database was used to calculate $CO_2$ emissions for truck transport and transoceanic shipping (Werner et al., 2014). Priority was given to fresh, artisan, "100% local" or "zero kilometer" food. Families purchased their food from the A Estrada food market, local supermarkets, and village pastry shops. Special attention was paid to the decrease in the amount of food suitable for human consumption along this first stage of the food supply chain (food losses) (Gustavsson et al., 2013). Further description of the food losses percentages per food item is reported in **Table 7.7**.

The household transport stage (S3) includes the second distribution channel, from the producer-retailer to the final consumer. Cooking was not included in the system boundaries as in other similar studies available in the literature (Werner et al., 2014). Groceries consumed by an individual person in a week (every six days) was purchased and transported from the grocery store to the households over a distance of 3.3 km. A typical diesel passenger car emits approximately 106 g $CO_2eq \cdot km^{-1}$ (Batlle-Bayer et al., 2019). The percentage of food waste, which refers to food thrown away in households, was calculated as detailed in **Table 7.7** (Garcia-Herrero et al., 2018).

**Table 7.7. Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Beet | 0.11 | Nacional | 0.10 | 0.03 | (González et al., 2011) |
| Bean Sprout | 0.46 | National | 0.02 | 0.12 | (González et al., 2011) |
| Apple juice | 0.12 | Local | 0.10 | 0.14 | (Aguilera et al., 2015a) |
| Peach juice | 0.12 | Local | 0.10 | 0.14 | (Aguilera et al., 2015a) |
| White grape | 0.12 | Local | 0.10 | 0.06 | (Aguilera et al., 2015a) |
| Fig | 0.12 | Local | 0.10 | 0.03 | (Aguilera et al., 2015a) |
| Pear | 0.12 | Local | 0.10 | 0.02 | (Aguilera et al., 2015a) |
| Apple | 0.12 | Local | 0.10 | 0.14 | (Aguilera et al., 2015a) |
| Peach (including peach in syrup) | 0.12 | National | 0.10 | 0.04 | (Aguilera et al., 2015a) |
| Orange | 0.15 | National | 0.10 | 0.13 | (Aguilera et al., 2015a) |
| Lemon | 0.15 | Local | 0.10 | 0.06 | (Aguilera et al., 2015a) |
| Lemonade | 0.15 | Local | 0.10 | 0.14 | (Aguilera et al., 2015a) |
| Mandarin | 0.15 | Local | 0.10 | 0.02 | (Aguilera et al., 2015a) |
| Banana | 0.64 | National | 0.10 | 0.10 | (Aguilera et al., 2015a) |
| Pumpkin | 0.20 | Local | 0.10 | 0.03 | (Aguilera et al., 2015b) |
| Zucchini | 0.20 | Local | 0.10 | 0.03 | (Aguilera et al., 2015b) |
| Lettuce | 0.22 | Local | 0.10 | 0.06 | (Aguilera et al., 2015b) |
| Green pepper | 0.22 | Local | 0.10 | 0.05 | (Aguilera et al., 2015b) |
| Red pepper | 0.22 | Local | 0.10 | 0.05 | (Aguilera et al., 2015b) |
| Tomato (including crushed tomato) | 0.22 | Local | 0.10 | 0.02 | (Aguilera et al., 2015b) |
| Black pepper | 0.22 | National | 0.10 | 0.05 | (Aguilera et al., 2015b) |
| White pepper | 0.22 | National | 0.10 | 0.05 | (Aguilera et al., 2015b) |
| White bean | 0.23 | National | 0.10 | 0.13 | (Aguilera et al., 2015b) |
| Pinto bean | 0.23 | National | 0.10 | 0.13 | (Aguilera et al., 2015b) |
| Green bean | 0.23 | Local | 0.10 | 0.13 | (Aguilera et al., 2015b) |
| Radish | 0.23 | National | 0.10 | 0.03 | (Aguilera et al., 2015b) |
| Cabbage | 0.24 | Local | 0.10 | 0.14 | (Aguilera et al., 2015b) |
| Potato | 0.24 | Local | 0.07 | 0.01 | (Aguilera et al., 2015b) |
| Celery | 0.24 | Local | 0.10 | 0.03 | (Aguilera et al., 2015b) |
| Onion | 0.24 | Local | 0.10 | 0.04 | (Aguilera et al., 2015b) |
| Cauliflower | 0.24 | Local | 0.10 | 0.14 | (Aguilera et al., 2015b) |
| Endive | 0.24 | Local | 0.10 | 0.03 | (Aguilera et al., 2015b) |
| Kale | 0.24 | Local | 0.10 | 0.14 | (Aguilera et al., 2015b) |
| Green pea | 0.60 | Local | 0.10 | 0.13 | (Aguilera et al., 2015b) |
| Carrot | 0.20 | Local | 0.10 | 0.08 | (Nemecek et al., 2012) |
| Carrot juice | 0.20 | Local | 0.10 | 0.14 | (Nemecek et al., 2012) |
| Dried oregano | 0.22 | National | 0.10 | 0.23 | (Heller et al., 2018) |
| Parsley | 0.23 | Local | 0.10 | 0.23 | (Heller et al., 2018) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Khaki | 0.31 | National | 0.10 | 0.03 | (Heller et al., 2018) |
| Dry bean | 0.31 | National | 0.02 | 0.13 | (Heller et al., 2018) |
| Popcorn | 0.39 | National | 0.02 | 0.62 | (Heller et al., 2018) |
| Flax seed | 0.39 | National | 0.10 | 0.12 | (Heller et al., 2018) |
| Oat bran | 0.50 | National | 0.02 | 0.12 | (Heller et al., 2018) |
| Wheat bran | 0.55 | National | 0.02 | 0.13 | (Heller et al., 2018) |
| Dried peaches | 1.41 | National | 0.10 | 0.04 | (Heller et al., 2018) |
| Crisps | 1.55 | National | 0.00 | 0.00 | (Heller et al., 2018) |
| Dry fig | 1.81 | Local | 0.10 | 0.03 | (Heller et al., 2018) |
| Tea | 3.82 | International | 0.00 | 0.00 | (Heller et al., 2018) |
| Chamomile | 3.82 | National | 0.00 | 0.00 | (Heller et al., 2018) |
| Generic infusion | 3.82 | National | 0.00 | 0.00 | (Heller et al., 2018) |
| Laurel | 0.22 | Local | 0.10 | 0.23 | (Heller et al., 2018) |
| Seaweed | 0.18 | Local | 0.10 | 0.03 | (Heller et al., 2018) |
| Soybean oil | 0.81 | National | 0.01 | 0.01 | (Heller et al., 2018) |
| Valerianella locusta | 0.22 | National | 0.00 | 0.00 | (Heller et al., 2018) |
| Quail meat | 2.83 | Local | 0.04 | 0.01 | (Heller et al., 2018) |
| Honey | 0.23 | National | 0.02 | 0.26 | (Scarborough et al., 2014) |
| Raisin | 0.83 | National | 0.10 | 0.06 | (Scarborough et al., 2014) |
| Hazelnut (with and without shell) | 0.23 | National | 0.02 | 0.09 | (Volpe et al., 2015) |
| Pistachio | 0.53 | National | 0.02 | 0.09 | (Volpe et al., 2015) |
| Peanut (with and without shell) | 0.62 | National | 0.02 | 0.09 | (Volpe et al., 2015) |
| Watermelon | 0.32 | National | 0.10 | 0.02 | (Clune et al., 2017) |
| Leek | 0.39 | National | 0.10 | 0.03 | (Clune et al., 2017) |
| Cherry | 0.48 | Local | 0.10 | 0.11 | (Clune et al., 2017) |
| Melon | 0.51 | National | 0.10 | 0.02 | (Clune et al., 2017) |
| Fresh bean | 0.51 | National | 0.02 | 0.13 | (Clune et al., 2017) |
| Chard | 0.54 | Local | 0.10 | 0.03 | (Clune et al., 2017) |
| Spinach | 0.54 | Local | 0.10 | 0.03 | (Clune et al., 2017) |
| Chickpeas | 0.67 | National | 0.02 | 0.09 | (Clune et al., 2017) |
| Paprika | 0.88 | National | 0.10 | 0.05 | (Clune et al., 2017) |
| Lentils | 1.03 | National | 0.02 | 0.13 | (Clune et al., 2017) |
| Sunflower seed (with and without salt) | 1.41 | National | 0.02 | 0.09 | (Clune et al., 2017) |
| Walnut (with and without shell) | 1.62 | National | 0.02 | 0.09 | (Clune et al., 2017) |
| Almond (with and without shell) | 1.74 | National | 0.02 | 0.09 | (Clune et al., 2017) |
| Bass | 3.55 | Local | 0.09 | 0.01 | (Clune et al., 2017) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Cheddar cheese | 8.70 | National | 0.01 | 0.03 | (Clune et al., 2017) |
| Turbot | 14.51 | Local | 0.09 | 0.01 | (Clune et al., 2017) |
| Goat cheese | 8.03 | Local | 0.01 | 0.03 | (Clune et al., 2017) |
| Turkey (including turkey breast) | 6.04 | Local | 0.04 | 0.03 | (Clune et al., 2017) |
| Camembert Cheese | 8.10 | International | 0.01 | 0.03 | (Clune et al., 2017) |
| Prawn | 6.20 | Local | 0.09 | 0.01 | (Clune et al., 2017) |
| Sugar almond | 1.74 | National | 0.02 | 0.09 | (Clune et al., 2017) |
| Coffee (including cappuccino, decaffeinated, soluble, powdered) | 0.33 | National | 0.02 | 0.11 | (Werner et al., 2014) |
| Coffee liquid | 0.33 | National | 0.00 | 0.00 | (Werner et al., 2014) |
| Marzipan | 1.00 | National | 0.02 | 0.07 | (Werner et al., 2014) |
| Chocolate bonbon | 1.00 | National | 0.00 | 0.00 | (Werner et al., 2014) |
| Plum jam | 1.60 | Local | 0.10 | 0.09 | (Werner et al., 2014) |
| Strawberry jam | 1.60 | Local | 0.10 | 0.06 | (Werner et al., 2014) |
| Raspberry jam | 1.60 | National | 0.10 | 0.06 | (Werner et al., 2014) |
| Apricot and peach jam | 1.60 | National | 0.10 | 0.10 | (Werner et al., 2014) |
| Blackberry jam | 1.60 | National | 0.10 | 0.06 | (Werner et al., 2014) |
| Ketchup | 1.60 | National | 0.10 | 0.00 | (Werner et al., 2014) |
| Fine Wine (Jerez) | 2.20 | National | 0.00 | 0.03 | (Werner et al., 2014) |
| Sweet Wine (Malaga, Oporto) | 2.20 | National | 0.00 | 0.03 | (Werner et al., 2014) |
| White wine | 2.20 | Local | 0.00 | 0.03 | (Werner et al., 2014) |
| Red Wine | 2.20 | Local | 0.00 | 0.03 | (Werner et al., 2014) |
| Sobao | 2.50 | National | 0.02 | 0.07 | (Werner et al., 2014) |
| Cupcake | 2.50 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Cake (different varieties) | 2.50 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Pastry bun | 2.50 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Fritter | 2.50 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Ensaimada | 2.50 | National | 0.02 | 0.07 | (Werner et al., 2014) |
| Palmier | 2.50 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Flan (different varieties) | 2.50 | Local | 0.01 | 0.00 | (Werner et al., 2014) |
| Candy | 2.60 | National | 0.00 | 0.00 | (Werner et al., 2014) |
| Licorice | 2.60 | National | 0.00 | 0.00 | (Werner et al., 2014) |
| Cream Ice Cream | 2.80 | National | 0.01 | 0.30 | (Werner et al., 2014) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Strawberry Ice Cream | 2.80 | National | 0.10 | 0.06 | (Werner et al., 2014) |
| Croissant | 4.00 | Local | 0.02 | 0.07 | (Werner et al., 2014) |
| Strawberry | 0.33 | Local | 0.10 | 0.06 | (Gunady et al., 2012) |
| Strawberry milkshake | 0.33 | Local | 0.10 | 0.06 | (Gunady et al., 2012) |
| Garlic | 0.39 | Local | 0.10 | 0.30 | (Khoshnevisan and Rafiee, 2013) |
| Plum | 0.43 | Local | 0.10 | 0.09 | (Audsley et al., 2009) |
| Avocado | 0.43 | National | 0.10 | 0.31 | (Audsley et al., 2009) |
| Nectarine | 0.43 | National | 0.10 | 0.07 | (Audsley et al., 2009) |
| Quince | 0.43 | National | 0.31 | 0.03 | (Audsley et al., 2009) |
| Apricot/Loquat | 0.43 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Cornmeal | 0.45 | National | 0.02 | 0.62 | (Audsley et al., 2009) |
| Other corn products | 0.45 | National | 0.02 | 0.62 | (Audsley et al., 2009) |
| Turnip | 0.46 | Local | 0.10 | 0.03 | (Audsley et al., 2009) |
| Artichoke | 0.48 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Grapefruit juice | 0.51 | National | 0.10 | 0.14 | (Audsley et al., 2009) |
| Grapefruit | 0.51 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Vermouth/Cava | 0.65 | Local | 0.00 | 0.03 | (Audsley et al., 2009) |
| Cinnamon | 0.87 | National | 0.10 | 0.23 | (Audsley et al., 2009) |
| Date | 0.88 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Raspberry | 0.84 | National | 0.10 | 0.06 | (Audsley et al., 2009) |
| Eggplant | 1.30 | Local | 0.10 | 0.03 | (Audsley et al., 2009) |
| Cucumber | 1.30 | National | 0.10 | 0.11 | (Audsley et al., 2009) |
| Mango | 1.78 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Mango juice | 1.78 | National | 0.10 | 0.14 | (Audsley et al., 2009) |
| Broccoli | 1.94 | Local | 0.10 | 0.14 | (Audsley et al., 2009) |
| Mustard | 2.09 | National | 0.10 | 0.23 | (Audsley et al., 2009) |
| Green asparagus | 2.22 | Local | 0.10 | 0.03 | (Audsley et al., 2009) |
| Olive (different varieties) | 3.66 | Local | 0.10 | 0.05 | (Audsley et al., 2009) |
| Custard apple | 0.43 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Chili | 1.30 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Rapini | 0.46 | Local | 0.10 | 0.03 | (Audsley et al., 2009) |
| Cashew tree | 1.06 | International | 0.02 | 0.09 | (Audsley et al., 2009) |
| Papaya | 0.88 | National | 0.10 | 0.03 | (Audsley et al., 2009) |
| Almond milk | 0.44 | National | 0.01 | 0.38 | (Feraldi et al., 2012) |
| Cider | 0.50 | Local | 0.00 | 0.03 | (Berners-Lee et al., 2012) |
| Soft drink (cola, orange, lemon and tea flavour) | 1.90 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Cheese sauce | 2.10 | Local | 0.01 | 0.03 | (Berners-Lee et al., 2012) |
| Curry sauce | 2.10 | National | 0.10 | 0.23 | (Berners-Lee et al., 2012) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Soy sauce | 2.10 | National | 0.10 | 0.03 | (Berners-Lee et al., 2012) |
| Béchamel sauce | 2.10 | National | 0.01 | 0.01 | (Berners-Lee et al., 2012) |
| Snacks | 2.50 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen meat (others) | 3.70 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen fish (others) | 0.43 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned beet | 4.30 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen tuna pie | 3.70 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen ravioli | 3.70 | International | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen puff pastry | 3.70 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen pizza | 6.00 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned Anchovy | 5.70 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned mussel | 5.70 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned razors | 5.70 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned sautéed eels | 5.70 | Local | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned pickle | 4.30 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Frozen vegetable stew | 4.30 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned heart of palm | 4.30 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Canned mushroom | 4.30 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Soda | 1.90 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Tonic | 1.90 | National | 0.00 | 0.00 | (Berners-Lee et al., 2012) |
| Wheat flour | 0.51 | National | 0.02 | 0.07 | (Lantmännen, 2010) |
| Pomegranate | 0.52 | National | 0.10 | 0.03 | (Vázquez-Rowe et al., 2017a) |
| Pilchard | 0.52 | Local | 0.09 | 0.01 | (González-García et al., 2015a) |
| Sugar (brown and white) | 0.61 | National | 0.03 | 0.03 | (Klenk et al., 2012) |
| Saccharine | 0.61 | National | 0.03 | 0.03 | (Klenk et al., 2012) |
| Orange juice | 0.67 | National | 0.10 | 0.14 | (Doublet et al., 2013) |
| Blueberry | 0.72 | Local | 0.10 | 0.06 | (Venkat, 2012) |
| Anchovy | 0.76 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Scallop | 1.49 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Crab | 1.49 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Crayfish | 1.49 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Chlamys varia | 1.49 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Blue Whiting | 1.54 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Squid | 3.86 | Local | 0.09 | 0.02 | (Iribarren et al., 2010b) |
| Octopus | 4.11 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Hake | 5.98 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Swordfish | 9.27 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Monkfish | 9.38 | Local | 0.09 | 0.01 | (Iribarren et al., 2010b) |
| Sunflower oil | 0.76 | Local | 0.01 | 0.01 | (Muñoz et al., 2014) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste household | Reference |
|---|---|---|---|---|---|
| Oatmeal | 0.77 | National | 0.02 | 0.12 | (Roer et al., 2012) |
| Soy milk | 0.80 | National | 0.01 | 0.38 | (Tesco, 2012) |
| Rice milk | 0.80 | National | 0.01 | 0.38 | (Tesco, 2012) |
| Kiwi | 0.83 | Local | 0.10 | 0.05 | (Zeus, 2012) |
| Commercial juice tropical fruit flavour | 0.85 | National | 0.10 | 0.14 | (Frankowska et al., 2019b) |
| Frozen spinach | 0.94 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Canned asparagus | 1.22 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Frozen pea | 1.35 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Canned bell pepper | 1.43 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Canned piquillo pepper | | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Canned tomato | 1.49 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Frozen green beans | 1.18 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| Canned bean | 1.18 | National | 0.00 | 0.00 | (Frankowska et al., 2019b) |
| White bread fresh | 0.88 | Local | 0.02 | 0.04 | (Barilla Center for Food Nutrition, 2016) |
| Toasted White bread | 0.88 | National | 0.02 | 0.04 | (Barilla Center for Food Nutrition, 2016) |
| Sandwich bread | 0.89 | National | 0.02 | 0.04 | (Barilla Center for Food Nutrition, 2016) |
| Hamburger bun | 0.89 | National | 0.02 | 0.04 | (Barilla Center for Food Nutrition, 2016) |
| Rye bread | 0.72 | Local | 0.02 | 0.04 | (Barilla Center for Food Nutrition, 2016) |
| Oat bread | 0.82 | Local | 0.02 | 0.04 | (Saxe, 2010) |
| Beer (with and without alcohol) | 0.92 | Local | 0.00 | 0.00 | (Saxe, 2010) |
| Cognac | 4.55 | International | 0.00 | 0.02 | (Saxe, 2010) |
| Geneva | 4.55 | National | 0.00 | 0.02 | (Saxe, 2010) |
| Whiskey | 4.55 | National | 0.00 | 0.02 | (Saxe, 2010) |
| Aguardiente | 4.55 | Local | 0.00 | 0.02 | (Saxe, 2010) |
| Vodka | 4.55 | National | 0.00 | 0.02 | (Saxe, 2010) |
| Sweet liquor | 4.55 | Local | 0.00 | 0.02 | (Saxe, 2010) |
| Champagne | 4.55 | International | 0.00 | 0.02 | (Saxe, 2010) |
| Pineapple and pinion | 0.95 | National | 0.10 | 0.08 | (West Africa Fair Fruit, 2011) |
| Pineapple Juice | 0.95 | National | 0.10 | 0.14 | (West Africa Fair Fruit, 2011) |
| Wholemeal Bread Fresh | 0.98 | Local | 0.02 | 0.04 | (Chiriacò et al., 2017) |
| Wholemeal Bread Toasted | 0.98 | National | 0.02 | 0.04 | (Chiriacò et al., 2017) |
| Whole wheat sandwich bread | 0.98 | National | 0.02 | 0.04 | (Chiriacò et al., 2017) |
| Cracker | 1.03 | National | 0.02 | 0.07 | (Konstantas et al., 2019) |
| Tea cookie | 1.03 | Local | 0.02 | 0.07 | (Konstantas et al., 2019) |
| Grain Cracker | 1.03 | National | 0.02 | 0.07 | (Konstantas et al., 2019) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Double cookie filled with chocolate | 0.99 | National | 0.02 | 0.07 | (Konstantas et al., 2019) |
| Maria Cookie | 1.01 | National | 0.02 | 0.07 | (Konstantas et al., 2019) |
| Chocolate covered cookie | 1.54 | National | 0.02 | 0.07 | (Konstantas et al., 2019) |
| Chocolate Ice Cream | 2.27 | National | 0.00 | 0.01 | (Konstantas et al., 2020) |
| Pineapple in syrup | 1.12 | National | 0.10 | 0.08 | (Castillo-González et al., 2020) |
| Cod (fresh and salty) | 1.20 | Local | 0.09 | 0.02 | (Ziegler et al., 2013) |
| Custard-style yogurt | 1.20 | National | 0.01 | 0.05 | (Flysjö, 2012) |
| Cow Milk (skimmed) | 1.23 | Local | 0.01 | 0.01 | (González-García et al., 2013b) |
| Cow milk (semi-skimmed) | 1.23 | Local | 0.01 | 0.00 | (González-García et al., 2013b) |
| Cow milk (whole) | 1.23 | Local | 0.01 | 0.01 | (González-García et al., 2013b) |
| Fermented milk | 1.23 | Local | 0.01 | 0.38 | (González-García et al., 2013b) |
| Pasta | 1.28 | National | 0.02 | 0.04 | (Hess et al., 2016) |
| Rice (including rice pancake and rice black pudding) | 2.31 | National | 0.02 | 0.06 | (Hess et al., 2016) |
| Margarine | 1.36 | National | 0.01 | 0.00 | (Nilsson et al., 2010) |
| Yoghurt (different varieties) | 1.50 | National | 0.01 | 0.05 | (González-García et al., 2013a) |
| Kefir | 1.50 | National | 0.01 | 0.05 | (González-García et al., 2013a) |
| Vanilla | 1.50 | International | 0.01 | 0.30 | (Lantmännen Unibake Denmark A/S, 2010) |
| Mackerel | 1.54 | Local | 0.09 | 0.06 | (Vázquez-Rowe et al., 2010a) |
| Chestnut | 1.57 | Local | 0.02 | 0.09 | (Castanheira and Freire, 2011) |
| Clam | 1.59 | Local | 0.09 | 0.01 | (Iribarren et al., 2010a) |
| Cockle | 1.59 | Local | 0.09 | 0.01 | (Iribarren et al., 2010a) |
| Mussel | 1.59 | Local | 0.09 | 0.02 | (Iribarren et al., 2010a) |
| Tuna | 1.60 | Local | 0.09 | 0.04 | (Hospido and Tyedmers, 2005) |
| Nougat | 1.75 | National | 0.00 | 0.00 | (Miah et al., 2018) |
| Dark Chocolate | 2.63 | National | 0.00 | 0.00 | (Miah et al., 2018) |
| Milk Chocolate | 3.60 | National | 0.00 | 0.00 | (Miah et al., 2018) |
| White Chocolate | 4.10 | National | 0.00 | 0.00 | (Miah et al., 2018) |
| Chocolate bar | 5.30 | National | 0.00 | 0.00 | (Miah et al., 2018) |
| Chocolate powder | 3.60 | National | 0.02 | 0.00 | (Miah et al., 2018) |
| Cocoa | 3.60 | National | 0.02 | 0.00 | (Miah et al., 2018) |
| Cocoa milkshake | 0.95 | National | 0.02 | 0.00 | (Miah et al., 2018) |
| Egg (white and yolk part) | 1.80 | Local | 0.02 | 0.04 | (Nielsen et al., 2013) |
| Mushroom | 1.82 | National | 0.10 | 0.03 | (Leiva et al., 2015) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Mayonnaise | 1.95 | National | 0.00 | 0.00 | (Hetherington et al., 2012) |
| Vinegar | 2.24 | National | 0.00 | 0.00 | (Bartocci et al., 2017) |
| Salmon | 2.26 | Local | 0.09 | 0.02 | (Sherry and Koester, 2020) |
| Sea bream | 2.26 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Mere | 2.26 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Stripe | 2.26 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Trout | 2.26 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Eel | 10.43 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Pomfret | 2.26 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Sepia | 6.39 | Local | 0.09 | 0.02 | (Iribarren et al., 2011b) |
| European Conger | 3.88 | Local | 0.09 | 0.01 | (Iribarren et al., 2011b) |
| Butter | 7.20 | National | 0.01 | 0.00 | (Vergé et al., 2013) |
| Milk powder | 10.80 | Local | 0.01 | 0.55 | (Vergé et al., 2013) |
| Cacao Cream | 2.30 | National | 0.01 | 0.30 | (Vergé et al., 2013) |
| Whipped Cream | 2.30 | Local | 0.01 | 0.30 | (Vergé et al., 2013) |
| Olive oil | 2.36 | Local | 0.01 | 0.01 | (Sellás Olive Oil, 2013) |
| Chicken meat (breast, thigh, wing, liver and whole chicken) | 2.50 | Local | 0.04 | 0.02 | (González-García et al., 2014) |
| Breakfast Cereals (different varieties) | 2.64 | National | 0.02 | 0.12 | (Jeswani et al., 2015) |
| Cereal bar (different varieties) | 2.64 | National | 0.02 | 0.12 | (Jeswani et al., 2015) |
| Muesli | 2.64 | International | 0.02 | 0.12 | (Jeswani et al., 2015) |
| Turkey Breast Sausage | 11.30 | National | 0.04 | 0.03 | (Noya et al., 2016) |
| Fuet | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Cooked Ham | 11.30 | Local | 0.04 | 0.01 | (Noya et al., 2016) |
| Pork Loin | 11.30 | Local | 0.04 | 0.01 | (Noya et al., 2016) |
| Serrano Ham | 11.30 | Local | 0.04 | 0.01 | (Noya et al., 2016) |
| Iberian Ham | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Fresh Sausage | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Mortadella | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Frankfurt type sausage | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Iberian Salami | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Foie Gras | 11.30 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Chorizo | 3.42 | Local | 0.04 | 0.01 | (Noya et al., 2016) |
| Majorcan sausage | 3.42 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Chistorra | 3.42 | National | 0.04 | 0.01 | (Noya et al., 2016) |
| Rabbit | 3.82 | Local | 0.04 | 0.01 | (Schenck and Huizenga, 2014) |
| Whiting | 3.84 | Local | 0.09 | 0.01 | (Winther et al., 2009) |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Pork meat (cutlet, sirloin, rib, hand, bacon, pancetta) | 4.96 | Local | 0.04 | 0.01 | (Noya et al., 2017) |
| Red Shrimp | 6.19 | Local | 0.09 | 0.01 | (Blonk et al., 2008) |
| Canned sardine | 7.60 | Local | 0.00 | 0.00 | (Almeida et al., 2015) |
| Wild boar meat | 10.20 | National | 0.04 | 0.01 | (Saxe, 2015) |
| Canned tuna | 10.23 | Local | 0.00 | 0.00 | (Roibás et al., 2018) |
| Blue cheese | 10.44 | National | 0.01 | 0.03 | (González-García et al., 2013c) |
| Parmesan | 10.44 | International | 0.01 | 0.03 | (González-García et al., 2013c) |
| Emmental cheese | 10.44 | International | 0.01 | 0.03 | (González-García et al., 2013c) |
| Gruyere cheese | 10.44 | International | 0.01 | 0.03 | (González-García et al., 2013c) |
| Arzua cheese | 10.44 | Local | 0.01 | 0.03 | (González-García et al., 2013c) |
| Skim portioned cheese | 10.44 | Local | 0.01 | 0.03 | (González-García et al., 2013c) |
| Cheese in portions | 10.44 | Local | 0.01 | 0.03 | (González-García et al., 2013c) |
| Mozzarella cheese | 6.89 | International | 0.01 | 0.03 | (Head et al., 2014) |
| Lamb meat (paddle, leg) | 10.85 | Local | 0.04 | 0.01 | (Jones et al., 2014) |
| Locust | 11.10 | Local | 0.09 | 0.01 | (Ziegler and Valentinsson, 2008) |
| Lobster | 11.10 | Local | 0.09 | 0.01 | (Ziegler and Valentinsson, 2008) |
| Manchego cheese | 14.66 | National | 0.01 | 0.03 | (Nunes et al., 2020) |
| Burgos' cheese | 14.66 | National | 0.01 | 0.03 | (Nunes et al., 2020) |
| Cow meat (lean, semi-fat, 2ª and 3ª, chop, sirloin) | 24.69 | Local | 0.04 | 0.01 | (van Oort and Andrew, 2016) |
| Yeast | 2.98 | Local | 0.00 | 0.00 | (COFALEC, 2012) |
| Frozen lasagna | 5.00 | National | 0.00 | 0.00 | (Schmidt Rivera and Azapagic, 2019) |
| Sole | 20.86 | Local | 0.09 | 0.01 | (Thrane, 2006) |
| Roosterfish | 14.15 | Local | 0.09 | 0.01 | (Vázquez-Rowe et al., 2012) |
| Couscous | 0.50 | International | 0.02 | 0.12 | (Xu and Lan, 2016) |
| Salt | 0.02 | National | 0.03 | 0.03 | (Winnipeg, 2012) |
| Gilthead Seabream | 7.12 | Local | 0.09 | 0.01 | (García García et al., 2016) |
| Horse meat | 21.45 | Local | 0.04 | 0.01 | (Apostolidis and McLeay, 2016) |
| Fruit salad | 0.35 | Local | 0.10 | 0.03 | (Fusi et al., 2016) |
| Goose barnacle | 5.34 | Local | 0.09 | 0.01 | (Vázquez-Rowe et al., 2013) |
| Young goat | 23.50 | Local | 0.04 | 0.01 | (Opio et al., 2013) |
| Barley | 0.34 | National | 0.10 | 0.03 | (Kramer et al., 1999) |
| Hummus | 0.35 | National | 0.00 | 0.00 | Calculated based on its main ingredients |
| Nachos with cheese | 4.14 | National | 0.00 | 0.00 | Calculated based on its main ingredients |

**Table 7.7. (cont.) Carbon footprint (CF) per foodstuff and their corresponding source, origin and percentages of food loss (Gustavsson et al., 2013) and food waste (Garcia-Herrero et al., 2018)**

| Foodstuff | CF | Origin | Food waste at distribution | Food waste at household | Reference |
|---|---|---|---|---|---|
| Kabab | 9.16 | International | 0.00 | 0.00 | Calculated based on its main ingredients |
| Wafer | 0.81 | National | 0.00 | 0.00 | Calculated based on its main ingredients |
| Aioli | 0.41 | National | 0.00 | 0.00 | Calculated based on its main ingredients |
| Vegetable beef soup | 19.99 | Local | 0.00 | 0.00 | Calculated based on its main ingredients |

*7.2.6.4.1 Considerations for the calculation of the carbon footprint*

i) Food production stage (S1):

The wide variety of existing LCAs consulted (varying e.g. due to system boundaries, production method, region specific conditions, agricultural techniques, climate variations...) makes it difficult to estimate the direct CF values. In addition, due to the complexity and variety of food products in the managed database, the same CF was taken for the different types of coffee, sausages, spirits, wine, infusions, soft drinks, yogurt, olives, sugar and breakfast cereals. Differences in GHG emissions between cuts of beef, chicken and pork were also not taken into account. However, differences between cheeses made from different animal species (cow, sheep, goat) were considered. For bread, a distinction was made between white and whole wheat.

Several assumptions were also necessary due to the scarcity of information for calculating the CF of some specific foods. For these, the GHG emissions were estimated based on data representing a comparable food. This is the case for saccharin (assimilated to sugar), chard (as spinach), cabbage (as cauliflower and broccoli), kefir (as yogurt), cereal (as breakfast cereal), custard apple (as avocado), soda and tonic (as soft drink), Rice milk (as soy milk), couscous (as wheat germ), loquat (as apricot), sugar almond (as almond), "callos" Madrid style or other varieties (as beef meat), sausages (as cold meat), chamomile (as tea) and horse meat (as an average value for meat). In all cases, the similarity between the production chains of the food under study and that to which it was assimilated was evaluated. In addition, due to a lack of information, the CF of fruit juice was assimilated to that of the corresponding fruit. For example, apple juice was assimilated to apple. The same was done for strawberry milkshake and cocoa milkshake.

Finally, CF for hummus, cheesy nachos, kebab, wafer, aioli, and vegetable beef soup was calculated based on its main ingredients according to **Eq. 7.1**:

$$CF_{dish} = \sum_{i=1}^{n} CF_i \cdot m_i \qquad (7.1)$$

Where,

$CF_i$ is the carbon footprint of each ingredient, in $kgCO_2eq \cdot kg^{-1}$

$m_i$ is the weight of each ingredient, in kg

ii) Retailer transport stage (S2):

Food waste was quantified for high-income and low-income regions. Due to the lack of specific data for Spain, the percentage of waste for each food category in the distribution stage of the food supply chain for Europe was adopted in this study. Food waste was considered for

the following food categories (Gustavsson et al., 2013): cereals; roots & tubers; oilseeds & pulses; fruit & vegetables; meat; fish & seafood and milk & eggs.

Categorising the large collection of foods in the database was a complicated task. Some key assumptions had to be made. Food waste was assumed for soft drinks, liquid beverages (alcoholic and non-alcoholic), liquid chocolate, vinegar, infusions, candy, liquorice, canned and frozen foods. Losses from pastry and bakery products were calculated using the waste percentage of cereal losses. The reason for this assumption is that flour is the main component of cakes, cookies and pastries. On the other hand, flan is a dairy dessert and was included in the milk & eggs category. For fruit juices, jams and strawberry milkshakes, the corresponding waste percentage was taken from the fruit & vegetables commodity group. For coffee, cocoa beans and chocolate powder, their physical characteristics are similar to those of cereal grains. Therefore, these three were included in the cereals commodity group to estimate their weight percentage of food waste in the supermarket retail sector. Curry and soy sauce were assigned to the fruit & vegetables food group, and cheese and béchamel sauce were assigned to the milk & eggs food group.

iii) Household transport stage (S3):

Although there may be some economic loss, canned food, candy, liquorice and similar, soft drinks, water, liquid coffee, liquid chocolate, infusions, and frozen food were not considered as quantitative food waste at the household level. On the other hand, information on the percentage of food waste for some food items was scarce. Therefore, some assumptions were necessary to include all food items in the database in the food categories established by Garcia-Herrero et al. (2018). This is the case for alcoholic beverages (included in the group of wine and derivatives); some fruits with unknown waste factor value, such as pomegranate or date (considered as "other vegetables" due to the lack of information of food waste percentages for "other fruits"); cocoa (as cereals); bakery products such as croissant, muffin or pastry bun (their food waste factor was comparable to that of flour, since its main ingredient is pastry flour); strawberry and cocoa milkshake, cream and chocolate ice cream (assimilated to their main ingredients, strawberry, cocoa, cream and chocolate, respectively); fruit jam (waste at home comparable to its corresponding fruit); cheese sauce, béchamel sauce, soy sauce and curry sauce (as cheese, milk and species, respectively).

### 7.2.7 Statistical analysis

Sample size was determined for the primary outcome (see study protocol in the Supplementary material of Cambeses-Franco et al. (2024)). Analyses were conducted for the intention-to-treat population, with missing data imputed using the multivariable imputation by chained equations method (Royston and White, 2011). The main analysis used multiple imputation using Markov chain Monte Carlo method with 30 imputations for each missing measurement. A per-protocol sensitivity analysis was also performed. Baseline comparability was assessed using $\chi^2$ tests (categorical variables) and Student $t$ tests (continuous variables). Modified Poisson regressions with robust error variance were used to estimate rate ratios and their 95% CIs for new MetS cases (in participants without MetS) in the intervention group compared with the control group (Zou, 2004) after adjusting for age and sex. For exploratory purposes, point prevalences (with 95% CIs) for MetS and its components at baseline and after 6 months were estimated.

Cumulative logit regression models for ordered categories were constructed to examine the effect of the intervention on the number of MetS risk factors as an ordinal variable ranging from 0 to 5 compared with the control condition. Mixed-effects linear models were used to assess changes in CF emissions from baseline to 6-month follow-up in all randomised participants and

in those who completed the study. These models were adjusted for age, sex, and baseline values, with intervention as a fixed effect and family as a random effect. The ICC was calculated to examine how much variance in the CF outcome was explained by the family cluster effect. All analyses were performed using Stata, version 16.0 statistical software (StataCorp LLC). The $\chi^2$ test was used for differences between categorical variables, and the Student *t* test for continuous variables. All statistical tests were 2-sided, and $P < 0.05$ was deemed statistically significant. Statistical models and analysis details (stata outputs) can be seen in **Tables 7.8 to 7.13**.

**Table 7.8. Rate ratio for new metabolic syndrome in the intervention group vs. controls adjusted for age and gender (Intention-to-treat data set)**

.mi estimate: glm sm_diag3 sex age group if sm_diag1==0, fam(poisson) link(log) nolog vce(robus) eform

| | |
|---|---|
| Multiple imputation estimates | Imputations=30 |
| Generalized linear models | Number of obs=457 |
| | Average RVI=0.0000 |
| | Largest FMI=0.0000 |
| DJ adjustment: Large sample | DF: min= 4.80·1062 |
| | avg= 4.80·1062 |
| | max= - |
| Model F test: Equal FMI | F(3, 1.1·1064)= 4.98 |
| Within VCE type: Robust | Prob > F= 0.0019 |

| sm_diag3 | Coef. | Std. Err | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| sex | 0.6049632 | 0.4016536 | 1.51 | 0.132 | -0.1822634 | 1.39219 |
| age | 0.0340553 | 0.0138889 | 2.45 | 0.014 | 0.0068336 | 0.061277 |
| group | -1.137757 | 0.4630406 | -2.46 | 0.014 | -2.0453 | -0.2302144 |
| _cons | -4.478517 | 0.7389667 | -6.06 | 0.000 | -5.926865 | -3.030169 |

.
.display=exp(-1.137757)
0.32053718
.display=exp(-2.0453)
0.12934138
.display==exp(-0.2302144)
0.79436327

**Table 7.9. Rate ratio for new metabolic syndrome in the intervention group vs. controls adjusted for age and gender (Per protocol data set)**

.gml sm_diag3 ib0.sex age ib0.group if sm1!=. & sm_diag1==0, fam(poisson) link(log) nolog vce(robust) eform

| | |
|---|---|
| Generalized linear models | Number of obs= 410 |
| Optimisation: ML | Residual df=406 |
| | Scale parameter=1 |
| Deviance= 101.4396413 | (1/df) Deviance=0.2498513 |
| Pearson=383.2985525 | (1/df) Pearson=0.9440851 |
| Variance function: V(u)=u | [Poisson] |
| Link function: g(u)=ln(u) | [Log] |
| | AIC=0.3547308 |
| Log pseudolikelihood= -68.71982067 | BIC=-2341.12 |

| | IRR | Robust Std. Err | z | P>\|z\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| sm_diag3 | | | | | | |
| sex | | | | | | |
| man | 2.169596 | 0.9896968 | 1.70 | 0.090 | 0.8873384 | 5.304793 |
| age | 1.03708 | 0.0162127 | 2.33 | 0.020 | 1.005785 | 1.069348 |
| Intervention group | 0.4029452 | 0.19868 | -1.84 | 0.065 | 0.1533009 | 1.059126 |
| _cons | 0.0075969 | 0.0060869 | -6.09 | 0.000 | 0.0015799 | 0.0365297 |

Note: _cons estimates baseline incidence rate

**Table 7.10. Rate ratio for prevalence of metabolic syndrome in the intervention group vs. controls adjusted for age and gender (Intention-to-treat data set)**

.mi estimate: glm sm_diag3 ib1.sm_diag1 ib0.sex age ib0.group, fam(poisson) link (log) nolog vce(robus) eform

| | |
|---|---|
| Multiple imputation estimates | Imputations=30 |
| Generalized linear models | Number of obs=574 |
| | Average RVI=0.0000 |
| | Largest FMI=0.0000 |
| DF adjustment: Large sample | DF: min= - |
| | avg= - |
| | max= - |
| Model F test= Equal FMI | F( 4, .)=51.83 |
| Within VCE type: Robust | Prob > F= 0.0000 |

| | Coef. | Std. Err | t | P>\|t\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| 0.sm_diag1 | -2.498178 | 0.234497 | -10.65 | 0.000 | -2.957784 | -2.038572 |
| sex | | | | | | |
| man | 0.1179297 | 0.1331356 | 0.89 | 0.376 | -0.01430113 | 0.3788708 |
| age | 0.0121802 | 0.005481 | 2.22 | 0.026 | 0.0014378 | 0.0229227 |
| Intervention group | -0.1971967 | 0.1285203 | -1.53 | 0.125 | -0.4490918 | 0.0546985 |
| _cons | -1.001263 | 0.335664 | -2.98 | 0.003 | -1.659153 | -0.3433739 |

.
.display=exp(-0.1971967)
0.82102912
.display=exp(-0.4490918)
0.63820751
.display=exp(0.0546985)
1.0562221

**Table 7.11. Rate ratio for prevalence of metabolic syndrome in the intervention group vs. controls adjusted for age and gender (Per protocol data set)**

.glm sm_diag3 ib0.sex age ib0.group if sm1!=. & sm3!=. & sm_diag1==0 fam(poisson) link (log) nolog vce(robus) eform

| | |
|---|---|
| Generalized linear models | Number of obs=410 |
| Optimisation: ML | Residual df=406 |
| | Scale parameter=1 |
| Deviance=101.4396413 | (1/df) Deviance= 0.2498513 |
| Pearson=383.2985525 | (1/df) Pearson= 0.9440851 |
| Variance function= V(u)=u | [Poisson] |
| Link function: g(u)=ln(u) | [Log] |
| | AIC=0.3547308 |
| Log pseudolikelihood= -68.71982067 | BIC)-2341.12 |

| sm_diag3 | IRR | Robust Std. Err | z | P>\|z\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| sex | | | | | | |
| man | 2.169596 | 0.9896968 | 1.70 | 0.090 | 0.8873384 | 5.304793 |
| age | 1.03708 | 0.0162127 | 2.33 | 0.020 | 1.005785 | 1.069348 |
| Intervention group | 0.4029452 | 0.19868 | -1.84 | 0.065 | 0.1533009 | 1.059126 |
| _cons | 0.0075969 | 0.0060869 | -6.09 | 0.000 | 0.0015799 | 0.0365297 |

Note: _cons estimates baseline incidence rate

**Table 7.12. Effect of intervention on the number of metabolic syndrome risk factors (Intention-to-treat data set)**

.mi estimate: ologit sm3 sm1 ib0.sex age ib0.group

| | |
|---|---|
| Multiple imputation estimates | Imputations=30 |
| Ordered logistic regression | Number of obs=574 |
| | Average RVI=0.0000 |
| | Largest FMI=0.0000 |
| DF adjustment: Large sample | DF: min= 1.48·1062 |
| | avg= 1.48·1062 |
| | max= - |
| Model F test= Equal FMI | F( 4, 8.1·1063)=96.67 |
| Within VCE type: OIM | Prob > F= 0.0000 |

| | Coef. | Std. Err | t | P>\|t\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| Sm1 | 2.175924 | 0.1165821 | 18.66 | 0.000 | 1.947427 | 2.404421 |
| sex | | | | | | |
| man | 0.2708142 | 0.172639 | 1.57 | 0.117 | -0.067552 | 0.6091804 |
| age | 0.0177044 | 0.0060128 | 2.94 | 0.003 | 0.0059196 | 0.0294892 |
| Intervention group | -0.537541 | 0.1723919 | -3.12 | 0.002 | -0.8754228 | -0.1996591 |
| /cut1 | 1.743191 | 0.2950963 | | | 1.164812 | 2.321569 |
| /cut2 | 3.964724 | 0.3335458 | | | 3.310986 | 4.618461 |
| /cut3 | 6.995174 | 0.430026 | | | 6.152339 | 7.83801 |
| /cut4 | 8.89502 | 0.4952299 | | | 7.924387 | 9.865652 |
| /cut5 | 11.67362 | 0.6518764 | | | 10.39597 | 12.95127 |

.
.display==exp(-0.537541)
0.58418299
.display==exp(-0.8754228)
0.4166581
.display=exp(0.1996591)
0.81900991

**Table 7.13. Effect of intervention on the number of metabolic syndrome risk factors (Per protocol data set)**

```
. ologit sm3 sm1 ib0.sex age ib0.group if sm_diag1! & sm_diag3!=.
Iteration 0: log likelihood=-797.01729
Iteration 1: log likelihood=-542.47886
Iteration 2: log likelihood=-496.21
Iteration 3: log likelihood=-494.55525
Iteration 4: log likelihood=-494.54868
Iteration 5: log likelihood=-494.54868

Ordered logistic regression                     Number of obs=518
                                                LR chi2(4)=604.94
                                                Prob> chi2=0.000
Log likelihood=-494.54868                       Pseudo R2=0.3795
```

| sm3 | Coef. | Std. Err | z | P>\|z\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| sm1 | 2.211633 | 0.1241774 | 17.81 | 0.000 | 1.96825 | 2.455017 |
| sex | | | | | | |
| man | 0.1680473 | 0.1835459 | 0.92 | 0.360 | -0.1916961 | 0.5277907 |
| age | 0.0198391 | 0.0063702 | 3.11 | 0.002 | 0.0073539 | 0.032344 |
| Intervention group | -0.5569498 | 0.1831726 | -3.04 | 0.002 | -0.9159615 | -0.1979381 |
| /cut1 | 1.892966 | 0.3184375 | | | 1.26884 | 2.517092 |
| /cut2 | 4.039085 | 0.3581114 | | | 3.3372 | 4.740971 |
| /cut3 | 7.206805 | 0.467025 | | | 6.291453 | 8.122157 |
| /cut4 | 9.133485 | 0.5355007 | | | 8.083923 | 10.18305 |
| /cut5 | 11.81307 | 0.6865964 | | | 10.46736 | 13.15877 |

```
.
.display==exp(-0.5569498)
0.57295403
.display==exp(-0.9159615)
0.40013171
.display==exp(0.1979381)
0.82042064
```

## 7.3 RESULTS

### 7.3.1 Baseline Characteristics

Of 250 families (720 participants) who were recruited and randomised, a total of 121 families (270 adults [aged ≥18 years]) in the intervention group and 110 (248 adults) in the control group completed the trial (**Fig. 7.3**). Briefly, all participants were white, the mean (SD) number of persons per family unit was 2.3 (0.8), the mean (SD) participant age was 46.8 (15.7) years, and 231 participants (40.2%) were male and 343 (59.8%) female. As previously reported Calvo-Malvar et al. (2021b), the randomisation produced 2 groups with similar characteristics of baseline sociodemographic and potential confounding factors, including education, smoking, alcohol intake, and physical activity, with the exception of age, which was significantly higher in the intervention group (mean [SD], 48.2 [15.8] vs 45.3 [15.4] years for the intervention and control groups, respectively) (**Table 7.14**). All individuals in the intervention group participated in the nutrition education program. A total of 241 of 287 (84.0%) participants in the intervention arm and 238 of 287 (82.9%) in the control group filled out the 3-day food record completely at baseline and 6 months.

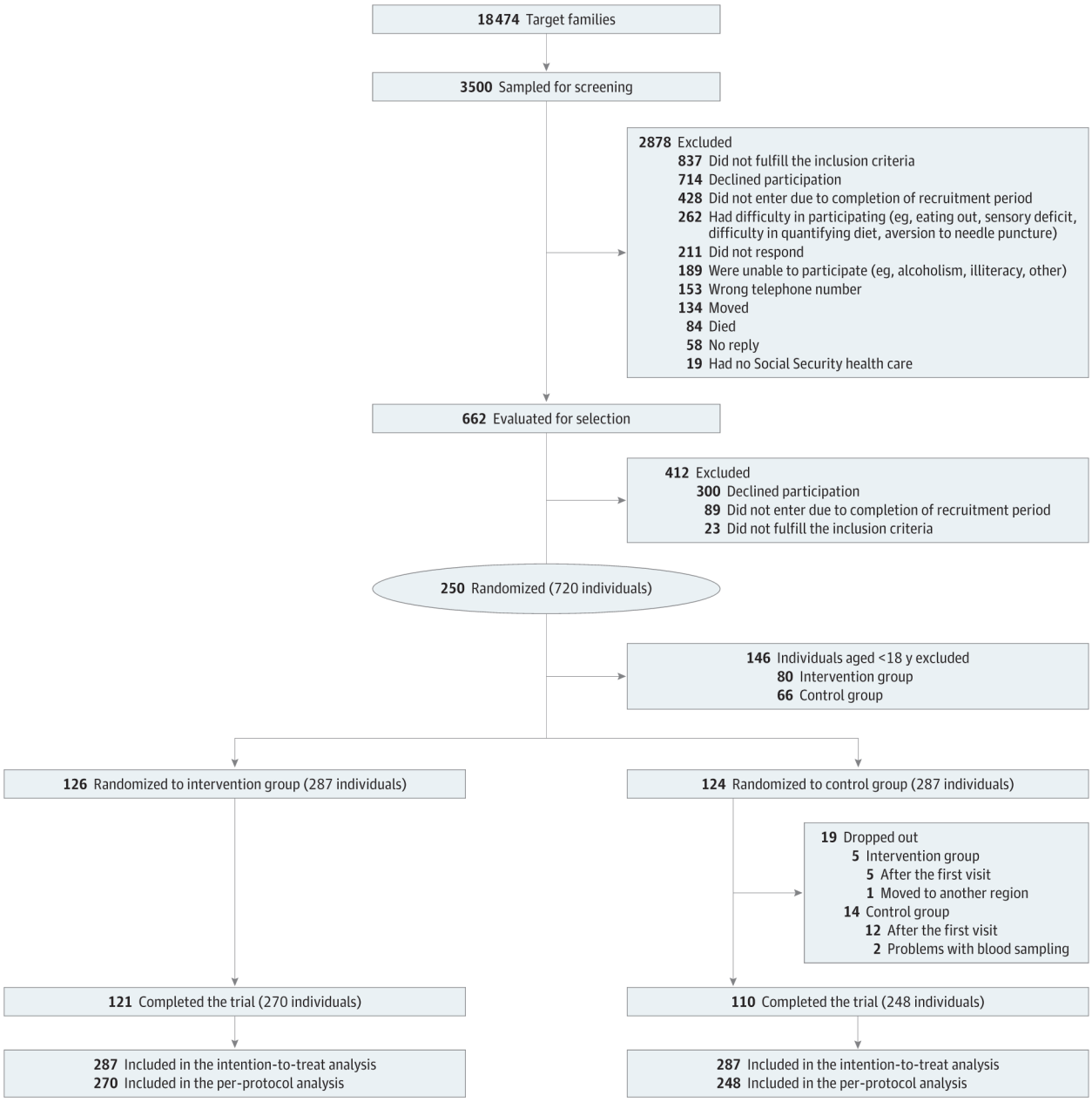


**Fig. 7.3. Overview of the study population**

**Table 7.14. Baseline characteristics of the participants in the study**

| | No. (%)[a] | |
|---|---|---|
| Characteristic | Control group | Intervention group |
| No. of participants | | |
| Families | 124 | 126 |
| Individuals | 287 | 287 |
| Participants per family, mean (SD) | 2.3 (0.8) | 2.3 (0.7) |
| Sex | | |
| Male | 114 (39.7) | 117 (40.8) |
| Female | 173 (60.3) | 170 (59.2) |
| Age, mean (SD), | 45.3 (15.4) | 48.2 (15.8) |
| Marital status | | |
| Married or with partner | 195 (67.8) | 211 (73.4) |
| Divorced, separated or widowed | 33 (11.5) | 28 (9.8) |
| Single | 59 (20.6) | 48 (16.8) |
| Educational level | | |
| None | 29 (10.1) | 30 (10.5) |
| Elementary | 120 (41.8) | 103 (35.9) |
| Secondary | 91 (31.7) | 103 (35.9) |
| University or higher | 47 (16.4) | 51 (17.7) |
| Employment status | | |
| Employed | 148 (51.6) | 139 (48.4) |
| Retired | 40 (13.9) | 56 (19.5) |
| Other[b] | 99 (34.5) | 92 (32.1) |
| Smoking habits | | |
| Never | 128 (44.6) | 120 (41.8) |
| Former | 50 (17.4) | 71 (24.7) |
| Current | 109 (38.0) | 96 (33.5) |
| Alcohol intake | | |
| Abstinent | 125 (43.5) | 124 (43.2) |
| Light (1–140 g/week) | 134 (46.6) | 130 (45.3) |
| Heavy (>140 g/week) | 28 (9.9) | 33 (11.5) |
| Comorbidities | | |
| Cardiovascular disease | 42 (16.0) | 49 (18.3) |
| Cerebrovascular accident | 3 (1.1) | 3 (1.1) |
| Diabetes | 16 (5.9) | 16 (5.9) |
| Current medications | | |
| Cholesterol-lowering | 23 (8.7) | 32 (12.5) |
| Anti-hypertensives | 44 (18.1) | 56 (24.2) |

**Table 7.14. (cont.) Baseline characteristics of the participants in the study**

| | No.(%)[a] | |
|---|---|---|
| Characteristic | Control group | Intervention group |
| International Physical Activity Questionnaire | | |
| Inactive | 56 (19.8) | 44 (15.3) |
| Minimally active | 68 (24.6) | 85 (29.6) |
| Active | 163 (55.6) | 158 (55.1) |

[a] No significant differences were found between the 2 groups, with the exception of age, which was significantly higher in the intervention group ($X^2$ test for differences between categorical variables and Student t test for continuous variables).

[b] The other category accounts for diverse occupational situations not explicitly classified under employed or retired (e.g. students, subsistence farmers, individual with disabilities).

### 7.3.2 Effect of the GALIAT intervention on MetS and its components

Of the 457 participants without MetS at the beginning of the trial, 23 developed MetS during the 6-month follow-up (6 [2.7%] in the intervention group; 17 [7.3%] in the control group). There was a significant reduction in incident MetS cases for the intervention group (rate ratio, 0.32; 95% CI, 0.13-0.79) compared with the control group (**Table 7.15)**.

Initially, 117 subjects (20.4%) met the ATP III criteria for MetS, with 63 (22.0 %) in the intervention group and 54 (18.8 %) in the control group (**Fig. 7.4**). After the 6-month follow-up, 18 individuals in the intervention group (28.6%) and 16 (29.6%) in the control group no longer met these criteria. Therefore, in the whole sample (e.g. participants with and without MetS), the intervention was not significantly associated with a reduced risk in overall MetS prevalence (rate ratio, 0.82; 95% CI: 0.64 - 1.06) (**Table 7.15)**. The most common MetS features were abdominal obesity (46.0%; 95% CI, 41.9%-50.1%) and high blood pressure (45.3%; 41.2% - 49.4%). The intervention group saw a significant decrease in waist circumference (mean [SD] change, -1.79 [0.40] cm; $P < 0.001$), but not significant decreases in blood pressure (systolic: mean [SD] change, -1.4 [1.0] mmHg [P=0.17]; diastolic: mean [SD] change, -0.72 [0.64] mmHg (P=0.27).

For individual MetS components, the intervention reduced the risk of central obesity (rate ratio, 0.90; 95% CI, 0.82–1.00) and low HDL cholesterol (rate ratio, 0.79; 95% CI, 0.64-0.97) compared with the control condition (**Table 7.15)**. The intervention had no significant effect on high blood pressure, high triglyceride levels, or high fasting serum glucose levels compared with the control condition. Per-protocol analysis showed similar results, with the exception of a significant reduction in hypertension risk associated with the intervention (**Table 7.16**).

Multivariable ordered logistic regression analysis revealed that participants in the intervention group had a proportional OR of 0.58 (95% CI, 0.42-0.82) for having more MetS components compared to those in the control group (**Table 7.17**), which means that those in the intervention group were approximately 42% less likely to exhibit an additional MetS component compared with the control group. Sensitivity analysis using the per-protocol population showed similar results in magnitude and direction (**Table 7.18**).

**Table 7.15. Incidence rate, prevalence rate and rate ratios of metabolic syndrome (MetS) and its components by treatment group[a]**

| | %(95% CI) | | | | | |
|---|---|---|---|---|---|---|
| | Control group (n=287) | | Intervention group (n=287) | | Rate ratios (95% CI)[c] | P-value |
| Criteria[b] | Baseline | 6 months | Baseline | 6 months | | |
| Abdominal obesity | 40.1 (34.5-45.8) | 41.8 (36.1-47.5) | 51.9 (46.1-57.7) | 47.0 (41.3-52.8) | 0.90 (0.82-1.00) | 0.04 |
| Hypertriglyceridaemia | 18.5 (14.0-23.0) | 17.4 (13.0-21.8) | 13.9 (9.9-18.0) | 13.9 (9.9-18.0) | 0.95 (0.69-1.30) | 0.74 |
| Low HDL-cholesterol | 18.8 (14.3-23.3) | 27.2 (22.0-32.3) | 19.2 (14.6-23.3) | 21.6 (16.8-23.7) | 0.79 (0.64-0.97) | 0.03 |
| High blood pressure | 40.8 (35.1-46.5) | 42.9 (37.1-48.6) | 49.8 (44.0-55.6) | 44.3 (38.5-50.0) | 0.87 (0.76-1.00) | 0.05 |
| Hyperglycaemia | 17.4 (13.0-21.8) | 15.0 (10.8-19.1) | 17.4 (13.0-21.8) | 13.9 (9.9-18.0) | 0.92 (0.69-1.23) | 0.56 |
| MetS prevalence rate | 18.8 (14.2-23.3) | 19.2 (14.6-23.7) | 22.0 (17.2-26.8) | 17.8 (13.3-22.2) | 0.82 (0.64-1.06) | 0.13 |
| MetS incidence rate | | 7.3 (3.9-10.6) | | 2.7 (0.6-4.8) | 0.32 (0.13-0.79) | 0.01 |

Abbreviations: HDL, high-density lipoprotein; NA, not applicable

[a] Values used from the intention-to-treat data set.

[b] Figures are prevalences and incidence in percentages with 95% confidence intervals (95%CI). Rate ratios are adjusted by sex and age, and were estimated using Poisson regression models for incident cases of MetS per 6 months.

[b] Criteria from the National Cholesterol Education Adult Treatment Panel III for the definition of MetS are as follows: abdominal obesity (waist circumference > 102 cm in males or > 88 cm in females), hypertriglyceridemia (fasting serum triglycerides ≥ 150 mg/dL); low HDL cholesterol levels (fasting HDL-cholesterol < 40 mg/dL in males or < 50 mg/dL in females), high blood pressure (≥ 130/85 mmHg or current anti-hypertensive medication use); and hyperglycaemia (fasting blood glucose ≥ 110 mg/dL or current anti-diabetic therapy). Individuals meeting at least three of these criteria were considered to have MetS.

[c] Adjusted for sex and age and estimated using Poisson regression models for incident cases of MetS per 6 months.

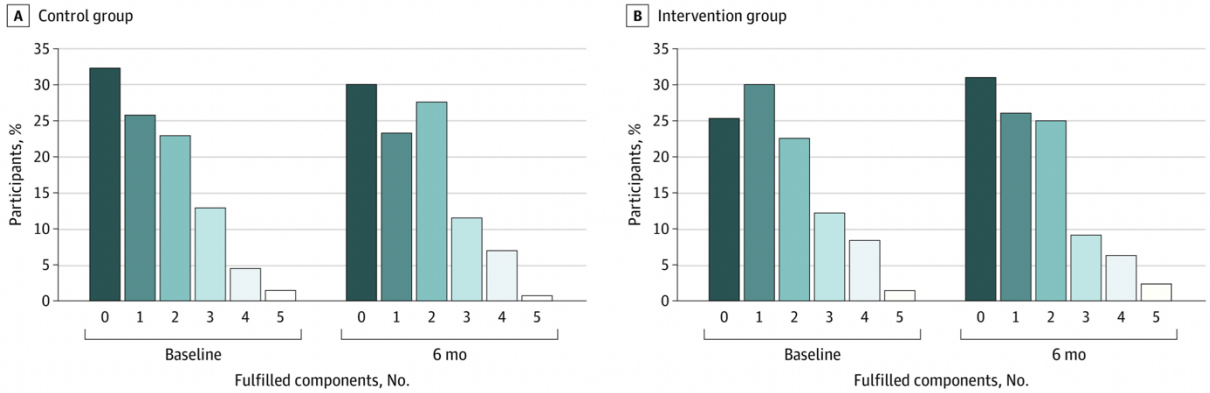


**Fig. 7.4. Distribution of Metabolic Syndrome component score by treatment group.**

**Table 7.16. Incidence rate, prevalence rate and rate ratios of metabolic syndrome (MetS) and its components by treatment group (per protocol data set)**

| Criteria | % (95% CI) | | | | | |
|---|---|---|---|---|---|---|
| | Control group | | Intervention group | | Rate ratios (95% CI) | P-value |
| | Baseline | 6 months | Baseline | 6 months | | |
| Abdominal obesity | 40.3 (34.4-46.6) | 42.3 (36.3-48.6) | 52.6 (46.6-58.5) | 47.8 (41.9-53.8) | 0.90 (0.81-0.99) | 0.04 |
| Hypertriglyceridaemia | 20.2 (15.6-25.6) | 18.5 (14.2-23.9) | 14.1 (10.4-18.8) | 13.3 (9.8-17.9) | 0.89 (0.64-1.24) | 0.49 |
| Low HDL-cholesterol | 17.7 (13.5-23.0) | 26.2 (21.1-32.1) | 18.5 (14.3-23.6) | 21.1 (16.6-26.4) | 0.79 (0.63-0.99) | 0.04 |
| High blood pressure | 41.9 (35.9-48.2) | 43.1 (37.1-49.3) | 50.0 (44.1-55.9) | 43.7 (37.9-49.7) | 0.86 (0.74-0.99) | 0.04 |
| Hyperglycaemia | 17.7 (13.5-23.0) | 14.9 (11.0-19.9) | 17.8 (13.7-22.8) | 14.4 (10.7-19.2) | 0.97 (0.72-1.31) | 0.85 |
| MetS | 19.8 (15.3-25.2) | 19.0 (14.5-24.3) | 21.9 (17.3-27.2) | 18.1 (14.0-23.2) | 0.89 (0.68-1.15) | 0.35 |
| MetS incidence rate | | 6.0 (3.5-10.3) | | 2.8 (1.3-6.2) | 0.40 (0.15-1.06) | 0.07 |

Values used from the intention-to-treat data set. Figures are prevalences and incidence in percentages with 95% confidence intervals (95%CI). Rate ratios are adjusted by sex and age and were estimated using Poisson regression models for incident cases of MetS per 6 months.

Criteria from the National Cholesterol Education Adult Treatment Panel III for the definition of MetS are as follows: abdominal obesity (waist circumference > 102 cm in males or > 88 cm in females), hypertriglyceridemia (fasting serum triglycerides ≥ 150 mg/dL); low HDL cholesterol levels (fasting HDL-cholesterol < 40 mg/dL in males or < 50 mg/dL in females), high blood pressure (≥ 130/85 mmHg or current anti-hypertensive medication use); and hyperglycaemia (fasting blood glucose ≥ 110 mg/dL or current anti-diabetic therapy). Individuals meeting at least three of these criteria were considered to have metabolic syndrome.

**Table 7.17. Distribution of metabolic syndrome (MetS) component score by treatment group among 574 participants**

| Number of fulfilled components of MetS | Control group (n=287) | | Intervention group (n=287) | | POR (95% CI)[a] | P-value |
|---|---|---|---|---|---|---|
| | Baseline | 6 months | Baseline | 6 months | | |
| 0 | 0.32 (0.27-0.38) | 0.30 (0.25-0.35) | 0.25 (0.20-0.31) | 0.31 (0.26-0.36) | 0.58 (0.42-0.82) | 0.002 |
| 1 | 0.26 (0.21-0.31) | 0.23 (0.18-0.28) | 0.30 (0.25-0.35) | 0.26 (0.21-0.31) | | |
| 2 | 0.23 (0.18-0.28) | 0.28 (0.22-0.33) | 0.23 (0.18-0.28) | 0.25 (0.20-0.30) | | |
| 3 | 0.13 (0.09-0.17) | 0.12 (0.08-0.15) | 0.12 (0.08-0.16) | 0.09 (0.06-0.12) | | |
| 4 | 0.05 (0.02-0.07) | 0.07 (0.04-0.10) | 0.08 (0.05-0.12) | 0.06 (0.04-0.09) | | |
| 5 | 0.01 (0.00-0.03) | 0.01 (0.00-0.02) | 0.01 (0.00-0.03) | 0.02 (0.01-0.04) | | |

Abbreviations: POR, proportional odds ratio

[a] Ordered logistic regression modelling was performed to estimate the POR and 95% CI, adjusted for age and sex.

**Table 7.18. Distribution of metabolic syndrome (MetS) component score by treatment group (per protocol data set)**

| Number of fulfilled components of MetS | Control group | | Intervention group | | Rate ratio (95% CI) | P-value |
|---|---|---|---|---|---|---|
| | Baseline (%, 95% CI) | 6 months (%, 95% CI) | Baseline (%, 95% CI) | 6 months (%, 95% CI) | | |
| 0 | 0.33 (0.28-0.39) | 0.31 (0.25-0.37) | 0.25 (0.20-0.31) | 0.32 (0.27-0.38) | 0.57 (0.40-0.82) | 0.002 |
| 1 | 0.24 (0.19-0.30) | 0.21 (0.17-0.27) | 0.30 (0.25-0.36) | 0.25 (0.20-0.31) | | |
| 2 | 0.23 (0.19-0.29) | 0.29 (0.24-0.35) | 0.23 (0.18-0.28) | 0.25 (0.20-0.30) | | |
| 3 | 0.13 (0.10-0.18) | 0.11 (0.08-0.15) | 0.12 (0.09-0.16) | 0.10 (0.07-0.14) | | |
| 4 | 0.05 (0.03-0.08) | 0.07 (0.05-0.11) | 0.09 (0.06-0.13) | 0.06 (0.04-0.10) | | |
| 5 | 0.02 (0.01-0.04) | 0.01 (0.00-0.03) | 0.01 (0.01-0.04) | 0.03 (0.01-0.05) | | |

Figures are proportional prevalences and 95% confidence intervals (95% CI). POR is proportional odds ratio with 95% CI. Ordered logistic regression models was performed to estimate POR and 95% CI, adjusted by age and sex.

### 7.3.3 Effect of the Galiat intervention on carbon footprint

After 6 months, the CF score was reduced in the control group (baseline: mean [SD], 3.71 [1.55] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$; after 6 months: mean [SD], 3.56 [1.50] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$) and the intervention group (baseline: mean [SD], 3.60 [1.44] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$; after 6 months: mean [SD], 3.38 [1.39] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$) (**Table 7.19**). Linear mixed regression analysis did not show a significant between-group difference (-0.17 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$, 95% CI: -0.46, 0.12), after adjusting for baseline values, age and sex, and with the family as random effect. The sensitivity analysis for the CF using the per protocol population showed similar results (**Table 7.20**).

The ICC revealed that approximately 45% of the variability in the CF score was due to family membership, revealing the importance of the family belongingness in the emission of GHG associated with food.

**Table 7.19. Differences in dietary carbon footprint between the intervention and control groups (Intention-to-treat data set)**

| | Control (n=287) | | Intervention (n=287) | | Multilevel mixed-effects linear regression (n=574) | | |
|---|---|---|---|---|---|---|---|
| | Baseline | 6 months | Baseline | 6 months | Coefficient intervention group | p-value | ICC |
| Carbon footprint | 3.71 [1.55] | 3.56 [1.50] | 3.60 [1.44] | 3.38 [1.39] | -0.17 (-0.46, 0.12) | 0.22 | 0.45 |

Carbon footprint expressed in kg $CO_2$ $eq \cdot person^{-1} \cdot day^{-1}$. Baseline and 6-month data are presented as mean and standard deviation. ICC intraclass coefficient.

**Table 7.20. Differences in dietary carbon footprint between the intervention and control groups (per protocol data set)**

| | Control (n=238) | | Intervention (n=241) | | Multilevel mixed-effects linear regression (n=479) | | |
|---|---|---|---|---|---|---|---|
| | Baseline | 6 months | Baseline | 6 months | Coefficient intervention group | p-value | ICC |
| Carbon footprint | 3.70 ± 1.52 | 3.54 ± 1.37 | 3.64 ± 1.43 | 3.37 ± 1.23 | -0.17 (-0.46-0.12) | 0.24 | 0.51 |

Carbon footprint expressed in kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$. Baseline and 6-month data are presented as mean and standard deviation. ICC intraclass coefficient.

## 7.4 DISCUSSION

In a community-based sample from the GALIAT randomised clinical trial, we jointly examined the effects of a nutritional intervention based on a traditional Atlantic diet on MetS and associated changes in its components and the environmental outcomes associated with the Atlantic diet in terms of CF. Our main finding was that the 6-month nutritional intervention showed a lower risk of developing MetS among participants in the intervention group compared with the control group. Furthermore, individuals in the intervention group were approximately 42% less likely to exhibit an additional MetS component than those in the control group, although there was no evidence of a reduction in the rate ratios of high blood pressure, hypertriglyceridemia, or hyperglycaemia, separately. Finally, the comparison between food consumption in the intervention and control groups did not achieve a statistically significant reduction in environmental impact.

Our study provides important contributions to the field. First, the positive outcomes for MetS and CF emissions were observed in a community-based sample following a diet that aligns with their cultural heritage. Second, the evidence provided for a randomised clinical trial that includes environmental parameters offers unique and valuable insight into how traditional diets can promote both health outcomes and environmental sustainability in line with the UN 2030 Agenda. Finally, the ICCs indicate that the cluster (family) factor had an important influence on the mean change of GHG emissions, supporting the effectiveness of family-based approaches for mitigating the impact of food-related GHG emissions.

It is well established that weight loss has a great benefit for the treatment of all the components of the MetS, which are excessive adiposity, dyslipidaemia, hypertension, insulin resistance, and hyperglycaemia (Case et al., 2002; Stevens, 2001; Van Gaal et al., 1997). Approximately 20% of the study participants had MetS at baseline, consistent with the prevalence observed in a large study of 24670 individuals from the general Spanish population, aged 35 to 74 years, without diabetes or CVD (Fernández-Bergés et al., 2012). Similarly, the findings of this study on abdominal obesity closely match the 51% prevalence reported in a sample of 17980 individuals aged 18 to 80 years in Spain according to ATP III criteria (Casanueva et al., 2010).

On the other hand, our study is also critical to understanding the implications of dietary choices on environment-related SDGs, especially SDG 13 (health and climate action). This relationship was shown through the randomised controlled nutritional intervention, where we observed a reduction of 0.17 $kgCO_2eq$/person/d in the intervention group compared with the control group. We believe that the lack of statistical significance can be attributed to the limited statistical power, since the sample size was primarily determined to detect changes in cholesterol levels (see study protocol in the supplementary material of Cambeses-Franco et al. (2024)). We have estimated that a study with approximately 2000 participants would be necessary for this reduction to reach statistical significance with a $P < 0.05$. Therefore, the observed outcome supports our expectation that adherence to the Atlantic diet in the broader target population could significantly enhance the CF metric, contributing to efforts to achieve net-zero $CO_2$ emissions by 2050 in line with SDG 13 (United Nations, 2018) .

These findings are broadly consistent with research showing that the traditional Atlantic diet is a climate-friendly diet, well ranked under environmental criteria (González-García et al., 2020b). Moreover, results from previous work that mainly focused on CF emissions of the Atlantic diet based on bibliographic recommendations (Esteve-Llorens et al., 2019a; González-García et al., 2020b) fall within the range of our average CF calculated for the intervention group after 6 months, taking into consideration associated deviations. For example, González-García et al. (2020b) designed a dietary scenario based on serving sizes as defined by the Spanish Society of Community Nutrition and data on current food consumption in Galician households and obtained a CF for the Atlantic diet of 3.62 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$.

### 7.4.1 Strengths and limitations

This study has several strengths, including a randomised design, high retention rates, objective clinical and environmental measures, and a representative random sample from the general population. Our data offer valuable clinical insight into MetS and its prevention in a population-based context. We intentionally chose a community with moderate socioeconomic and educational levels to enhance generalizability, aligning with Organisation for Economic Co-operation and Development indicators at the time of study design (OECD, 2020). Baseline data suggest minimal bias, as randomisation resulted in only slight group differences.

The study also has several limitations. Various unknown factors aside from the dietary intervention could have influenced clinical outcomes. In addition, the study intervention was complex, and it is not possible to determine which actions of the intervention may have contributed to the results. Thus, unmeasured aspects may exist. Contamination bias might be present, as the study received media attention, potentially influencing individuals' lifestyles. The strategy of providing food baskets served as an incentive for session attendance and adherence but may limit generalizability to populations with food access challenges. The broad variety of CF emissions usually reported in published LCAs of food products, together with the diversity of food items in participant data, could have contributed to the environmental outcome. Moreover, 6 months may not have been long enough to properly assess metabolic changes. Follow-up of participants over a number of years could strengthen our results. Finally, the sample size of this study might lack the statistical power required to detect a significant reduction in $CO_2$ emissions, indicating a potential need for larger-scale studies.

## 7.5 CONCLUDING REMARKS

As far as we are aware, the GALIAT study is the first community-based randomised clinical trial that, taking into account the identity and diversity of the region food system and culture, has shown the positive effect of a traditional diet intervention on the incidence of new cases of MetS, as well as on limiting GHG emissions. Our findings provide important evidence for the potential of traditional diets to accelerate progress toward achieving SDGs. Further research is needed to thoroughly understand the underlying mechanisms behind the observed outcomes and to determine the generalizability of these findings to other populations, taking into account the cultural and dietary variations of each region.

# 8. CLUSTER ANALYSIS OF GALICIAN RECIPES: CARBON FOOTPRINT, ENERGY EFFICIENCY AND COST[5]

The definition of gastronomy encompasses the knowledge of food as well as its handling, preparation and consumption. Beyond a sense of cultural identity and tradition, gastronomy also represents a pole of tourist attraction. This is the case of Galicia, a region in the northwest of Spain. In this context, local dishes that include distinctive elements of the Atlantic diet have gained popularity. This chapter examines the sustainability of 60 Galician recipes by performing a hierarchical cluster analysis to study their carbon footprint, energy return on investment ratio and cost.

The life cycle assessment methodology was followed to consider the carbon footprint and energy return on investment ratio of the recipes. The scope was limited to the cradle-to-fork phases of the life cycle: production of ingredients, transportation, and meal preparation. The functional unit chosen was a portion of a Galician meal.

The results suggest that the recipes could be classified into three main groups, according to the presence of a greater or lesser amount of animal products. Cluster 1 includes 10 meat recipes. Cluster 2 includes 31 recipes rich in fish with some vegetables and moderate consumption of red meat and dairy products. Cluster 3 contains 22 vegetable-based recipes. The higher the proportion of animal products (mainly red meat) in the recipes, the higher the cost and carbon footprint, and the lower the energy return on investment ratio. Conversely, plant-based recipes tend to reduce greenhouse gas emissions and increase cost competitiveness and energy efficiency indicators.

Based on this study, the foodservice industry could promote eco-labels that support and certify restaurant menus. This research could also provide transformative climate education on sustainable food for consumers, providing advice to improve food-based dietary guidelines in Spain.

[5] Cambeses-Franco, C., González-García, S., Calvo-Malvar, M., Benítez-Estévez, A. J., Leis, R., Sánchez-Castro, J., Gude, F., Moreira, M. T., 2023. A clustering approach to analyse the environmental and energetic impacts of Atlantic recipes - A Galician gastronomy case study. Journal of Cleaner Production, 383, 135360. https://doi.org/10.1016/j.jclepro.2022.135360

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## 8.1 INTRODUCTION

Gastronomy is the comprehensive study and practice of food selection, preparation and consumption. In the midst of food globalization, it is necessary to preserve those unique elements that ensure compliance with the basic principles of a healthy diet in a global context of gastronomic heritage, nutritional quality and environmental preservation. Therefore, food products and services with low environmental impact must contribute to the achievement of sustainable tourism (Chiang and Sheu, 2020), involving food producers, restaurants, hotels, tour guides and local businesses (Kumar, 2019).

In this context, actions have been developed to promote sustainable diets and eating habits. At the global level, the EAT-Lancet diet is a global planetary healthy diet (Willett et al., 2019b). At national level, some current FBDGs have integrated nutrition, health, and sustainability considerations (FAO, 2021b). At the regional level, adherence to traditional patterns has been shown to have environmental, health and cultural benefits for the region. This is the case of the well-known MD (Finicelli et al., 2022) or the NND (Mithril et al., 2012). The Atlantic diet, typical of the regions of Northwest Spain and Northern Portugal, was also included within this group of traditional diets (García-Gómez et al., 2022).

### 8.1.1 The Atlantic Diet on Trial: A cornerstone of sustainable Galician tourism

Galicia, a region located in the northwest of Spain, is part of the Atlantic dietary pattern, which is characterised by the consumption of locally grown, seasonal foods, prepared with simple cooking processes to ensure the best flavour and aroma of the dishes. The range of products includes fruits, vegetables, breads, cereals and legumes, as well as fresh fish and seafood and dairy products. Olive oil is widely used for cooking and seasoning, fried foods are avoided, and consumption of meat and eggs is moderate (Calvo-Malvar et al., 2016). However, in recent decades, Galician cuisine is moving away from the recommendations, which are evolving towards a globalized diet rich in meat, packaged foods, refined sugars and out-of-season foods. Therefore, adherence to and knowledge of the Atlantic dietary pattern is very important in order to fully exploit its potential.

In Galicia, cultural tourism with special mention of the “Camino de Santiago”, is combined with gastronomic and oenological tourism (Xunta de Galicia, 2024). As a result of this gastronomic heritage, Galicia has developed a hospitality industry with 19770 establishments, of which 88.9% are in the catering sector. In 2021, this sector will have a turnover of 3438 million euros (Hostelería de España, 2022). Due to its significant role in the Galician economy, the strengthening, sustainable growth, improvement and competitiveness and internationalization of the Galician food sector are key issues.

Despite the growing importance of gastronomic tourism in Galicia, to date there is little information on the environmental impact and nutritional dimensions of traditional recipes, with only some LCAs of typical complete daily menus of the Atlantic region (Esteve-Llorens et al., 2019a; González-García et al., 2021). To ensure the market position of Galician food companies, it is necessary to incorporate multi-criteria analysis in the food industry. The goal of restaurant management should be to implement green and energy-efficient regional dishes at affordable prices. The CF has been used as an environmental indicator to evaluate carbon emissions associated with tourism activities (Gössling et al., 2023). Previous studies have estimated that tourism accounts for about 8% of the global $CO_2$ emissions. Therefore, the CF can be used as a metric to evaluate cooking recipes in Galician food tourism, following the path already started by other authors, such as Schmidt Rivera and Azapagic (2019), who evaluated the environmental burdens of ready-made meals recipes or Kolbe (2020), who analysed the $CO_2$ emissions of cooking vegan, ovo-lactovegetarian or meat-containing recipes in Germany. In

addition, the EROI ratio, a widely used indicator, could provide information on the energy balance. Finally, considering that monetary variables can also influence food choices (Rummo et al., 2023), a cost index could be calculated for each traditional Galician recipe (MAPA, 2019).

To address these multivariate issues, the appropriateness of multicriteria analysis was considered. Addressing multicriteria analysis for the large number of recipes requires the use of multivariate mathematical-statistical methods. Hierarchical cluster analysis and the resulting dendrograms are a widely used branch in many areas of the scientific literature, including the food sector (Bonadonna et al., 2022) and could be used as a simple way of grouping the recipes through their similarities (Wilks, 2011). Although previous research has not used cluster analysis to assess the sustainability of recipes, hierarchical cluster analysis has been used to analyse the chemical composition of foods (Balakrishna et al., 2022). In addition, other statistical analyses, such as data envelopment analysis, have been used to measure the level of sustainability of recipes (Chiang et al., 2020).

With this approach to the problem, this work is expected to provide a solid basis on which consumers and food services can decide which type of recipes should be supported in order to fight climate change, low energy and low-cost food, ensuring quality, traceability and green sustainability of Galician gastronomy. Therefore, the objective of this chapter is to determine the environmental, economic and energy sustainability of 60 Galician gastronomic recipes, following a farm-to-fork strategy that takes into account the production, processing and consumption stages. For this purpose, multivariate analysis was used as a mathematical tool to define hierarchical dietary clusters based on the GHG emissions, costs and EROI indicator of the recipes.

## 8.2 MATERIALS AND METHODS

### 8.2.1 Meal recipes

Meal recipes were obtained from the recipe book Platos y Menus Atlánticos (Atlantic Dishes and Menus), based on the use of typical Galician food products. This book was published as part of the GALIAT project, the first clinical trial to study the effects of the Atlantic dietary pattern on metabolic and cardiovascular health and adiposity (Calvo-Malvar et al., 2016). It includes recipes nutritionally balanced by a team of nutritionists and information to guide weekly menu planning. Meal recipes and ingredients are detailed in **Tables 8.1- 8.5**.

The book is divided into five sections with different dishes: first course, divided into two subgroups (high-calorie and low-calorie), main course, also classified into two subgroups (high-calorie and low-calorie) and desserts. According to the book's recommendations, the daily menu should offer a first course (high-calorie), a main course (low-calorie) and a dessert. Another option is to have a low-calorie starter followed by a high-calorie main course and dessert. The dessert should preferably be fruit and, one or two days a week, a dairy product. Processed desserts should be eaten only occasionally because of their high caloric value.

**Table 8.1. Composition of the first courses (high energy) considered in this study based on the Atlantic diet.**

| Recipe | Ingredients (g) |
|---|---|
| Turnip greens and rice soup | |
| Turnip greens | 100 |
| Rice | 40 |
| Onion | 50 |
| Tomato | 50 |
| Garlic | 10 |
| Meat broth | 600 |
| Paprika | 0.5 |
| Olive oil | 10 |
| Laurel | 0.25 |
| Saffron | 0.002 |
| Mashed turnip greens and potatoes | |
| Turnip greens | 20 |
| Potatoes | 160 |
| Ham | 5 |
| Garlic | 5 |
| Leek | 10 |
| Cheese | 25 |
| Walnuts | 0.5 |
| Olive oil | 10 |
| Flour | 15 |
| Eggs | 15 |
| Bread | 15 |
| Cannelloni with vegetables and cream cheese | |
| Cheese | 85 |
| Turnip greens | 75 |
| Onion | 25 |
| Pinions | 10 |
| Garlics | 3 |
| Olive oil | 10 |
| Pasta | 30 |
| Tomato sauce | 20 |
| Potato and turnip greens salad | |
| Turnip greens | 125 |
| Potatoes | 70 |
| Garlics | 5 |
| Olive Oil | 40 |
| Pepper | 5 |
| Vinegar | 5 |

**Table 8.1. (cont.) Composition of the first courses (high energy) considered in this study based on the Atlantic diet.**

| Recipe | Ingredients (g) |
|---|---|
| Lentils with turnip greens | |
| Turnip greens | 80 |
| Lentils | 60 |
| Onion | 30 |
| Garlic | 2.5 |
| Carrot | 40 |
| Leek | 20 |
| Meat broth | 450 |
| Bacon | 30 |
| Olive oil | 10 |
| Laurel | 0.25 |
| Potatoes | 35 |
| Turnip soufflé | |
| Turnip greens | 25 |
| Margarine | 15 |
| Flour | 20 |
| Milk | 90 |
| Eggs | 65 |
| Olive Oil | 15 |
| Pepper | 1 |
| Salt | 0.5 |
| Garlic | 10 |
| Fideuá with spinach and tomato sauce, topped with cheese gratin | |
| Pasta | 60 |
| Spinach | 100 |
| Tomato sauce | 40 |
| Cheese | 20 |
| Olive Oil | 5 |
| Garlic | 2 |
| Onion | 20 |
| Meat broth | 120 |

**Table 8.2. Composition of the first courses (low energy) considered in this study based on the Atlantic Diet**

| Recipe | Ingredients (g) |
|---|---|
| Beans with turnip greens | |
| Turnip greens | 40 |
| Beans | 70 |
| Onion | 25 |
| Potatoes | 25 |
| Meat broth | 160 |
| Tomato | 25 |
| Olive oil | 5 |
| Pepper | 0.5 |
| Salt | 0.5 |
| Laurel | 0.25 |
| Tuna salad | |
| Tuna | 100 |
| Lettuce | 60 |
| Onion | 10 |
| Tomate | 70 |
| Olive oil | 10 |
| Vinegar | 2 |
| Garlic | 2 |
| Grilled tuna with Galician "zaragallada"sauce | |
| Tuna | 100 |
| Zaragallada | 120 |
| Olive oil | 10 |
| Vinegar | 2 |
| Garlic | 8 |
| Lettuce | 70 |
| Grilled squids with boiled potato | |
| Squids | 100 |
| Potatoes | 100 |
| Garlic | 2 |
| Lemon juice | 5 |
| Parsley | 1 |
| Olive oil | 15 |
| Beans with mussels and prawns | |
| Beans | 85 |
| Mussels | 60 |
| Prawns | 30 |
| Garlic | 10 |
| Onion | 30 |
| Olive oil | 15 |
| Fish soup | 180 |
| Parsley | 1 |
| Saffron | 0.003 |

**Table 8.2. (cont.) Composition of the first courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Mussel fideuá | |
| Pasta | 50 |
| Mussels | 75 |
| Zaragallada | 125 |
| Fish soup | 260 |
| Saffron | 0.005 |
| Atlantic horse mackerel fillet | |
| Mackerel | 100 |
| Potatoes | 125 |
| Olive oil | 10 |
| Garlic | 5 |
| Vinegar | 2 |
| Parsley | 0.5 |
| Onion | 50 |
| Bonito and vegetable salad | |
| Turnip greens | 60 |
| Potatoes | 60 |
| Onion | 20 |
| Eggs | 65 |
| Tuna | 50 |
| Garlic | 5 |
| Olive oil | 30 |
| Vinegar | 8 |
| Salt | 0.5 |
| Lentil salad with turnip greens | |
| Lentils | 50 |
| Turnip greens | 20 |
| Onion | 20 |
| Pepper | 20 |
| Carrot | 10 |
| Tuna | 30 |
| Olive oil | 15 |
| Vinegar | 5 |
| Salt | 1 |
| Pork tenderloin with salad | |
| Pork | 150 |
| Endive | 30 |
| Pepper | 40 |
| Olive oil | 10 |
| Garlic | 2 |
| Vinegar | 2 |
| Salt | 1 |

**Table 8.2. (cont.) Composition of the first courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Mussels marinara | |
| Mussels | 80 |
| Onion | 50 |
| Fish soup | 75 |
| Garlic | 10 |
| Olive oil | 8 |
| Flour | 8 |
| Wine | 15 |
| Parsley | 1 |
| Pepper | 1 |
| Potatoes | 30 |
| Laurel | 0.5 |
| Mussels in garlic sauce | |
| Mussels | 75 |
| Garlic | 20 |
| Olive oil | 25 |
| Brandy | 10 |
| Chilli | 5 |
| Mussels with onion | |
| Mussels | 100 |
| Onion | 150 |
| Potatoes | 75 |
| Garlic | 5 |
| Olive oil | 10 |
| Wine | 15 |
| Salt | 0.5 |
| Parley | 1 |
| Spanish Tuna Stew | |
| Tuna | 100 |
| Zaragallada | 70 |
| Potatoes | 125 |
| Olive oil | 5 |
| Garlic | 2 |
| Fish soup | 250 |
| Saffron | 0.002 |
| Wine | 10 |
| Pepper | 3 |
| Mussel pie | |
| Mussels | 70 |
| Zaragallada | 70 |
| Eggs | 65 |
| Milk | 25 |
| Garlic | 10 |
| Olive oil | 4.5 |
| Oregano | 0.5 |

**Table 8.2. (cont.) Composition of the first courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Scrambled eggs with mussels | |
| Mussels | 60 |
| Eggs | 65 |
| Olive oil | 4 |
| Garlic | 2 |
| Zaragallada | 40 |
| Mussels Vinaigrette | |
| Mussels | 75 |
| Onion | 25 |
| Tomato | 50 |
| Garlic | 5 |
| Pepper | 65 |
| Olive oil | 25 |
| Vinegar | 15 |
| Parsley | 0.5 |
| Laurel | 0.25 |
| Noodles with mussels | |
| Pasta | 60 |
| Mussels | 30 |
| Wine | 15 |
| Fish soup | 45 |
| Flour | 4 |
| Salt | 0.5 |
| Pepper | 1 |
| Brandy | 15 |
| Oregano | 0.5 |
| Parsley | 0.5 |
| Garlic | 5 |
| Olive oil | 5 |
| Omelet with turnip greens | |
| Turnip greens | 25 |
| Garlic | 2 |
| Ham | 10 |
| Olive oil | 10 |
| Eggs | 65 |
| Galician "zaragallada" sauce with poached egg | |
| Eggs | 65 |
| Zaragallada | 63 |
| Water | 2000 |
| Vinegar | 5 |
| Salt | 3 |

**Table 8.3. Composition of the main courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Rice and turnip greens with tomato sauce and bechamel | |
| Turnip greens | 100 |
| Rice | 40 |
| Milk | 50 |
| Cheese | 5 |
| Flour | 5 |
| Olive oil | 5 |
| Onion | 10 |
| Garlic | 2 |
| Tomato sauce | 15 |
| Water | 80 |
| Rice with carrots and tomato sauce | |
| Carrot | 40 |
| Rice | 50 |
| Tomato sauce | 15 |
| Olive oil | 5 |
| Onion | 10 |
| Garlic | 2 |
| Water | 100 |
| Turnip greens cream | |
| Turnip greens | 125 |
| Potatoes | 35 |
| Onion | 35 |
| Meat broth | 333 |
| Cheese | 10 |
| Olive oil | 5 |
| Pepper | 0.5 |
| Carrot, leek and potato cream | |
| Potatoes | 85 |
| Leek | 35 |
| Carrot | 50 |
| Garlic | 15 |
| Onion | 30 |
| Wine | 15 |
| Meat broth | 150 |
| Olive Oil | 5 |
| Salt | 15 |

**Table 8.3. (cont.) Composition of the main courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Pickled mussels with vegetables | |
| Mussels | 70 |
| Olive oil | 20 |
| Vinegar | 25 |
| Wine | 25 |
| Garlic | 10 |
| Pepper | 2 |
| Carrot | 25 |
| Onion | 25 |
| Laurel | 0.5 |
| Spanish Vegetable Stew | |
| Potatoes | 100 |
| Pumpkin | 70 |
| Olive Oil | 10 |
| Zaragallada | 140 |
| Onion | 50 |
| Garlic | 2 |
| Tomato sauce | 20 |
| Oregano | 0.5 |
| Pumpkin Ratatouille | |
| Pumpkin | 150 |
| Tomato sauce | 50 |
| Pepper | 140 |
| Onion | 50 |
| Olive oil | 10 |
| Scrambled Eggs with turnip greens | |
| Turnip greens | 25 |
| Garlic | 2.5 |
| Ham | 10 |
| Olive oil | 10 |
| Eggs | 65 |
| Sautéed turnip greens with ham | |
| Turnip greens | 100 |
| Garlic | 5 |
| Ham | 20 |
| Olive Oil | 20 |

**Table 8.3. (cont.) Composition of the main courses (low energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Chicken noodle soup | |
| Chicken | 33 |
| Pasta | 20 |
| Meat broth | 375 |
| Salt | 0.5 |
| Saffron | 2 |
| Julianne soup | |
| Potatoes | 30 |
| Carrot | 30 |
| Green peas | 20 |
| Broccoli | 20 |
| Leek | 20 |
| Onion | 20 |
| Olive oil | 10 |
| Garlic | 2 |
| Meat broth | 250 |
| Saffron | 0.002 |
| Turnip greens | 20 |
| Garlic soup | |
| Ham | 25 |
| Garlic | 10 |
| Bread | 50 |
| Meat broth | 420 |
| Pepper | 9.5 |
| Olive oil | 9 |
| Stuffed tomatoes with turnip greens | |
| Tomato | 100 |
| Garlic | 2 |
| Ham | 5 |
| Olives | 6 |
| Cheese | 25 |
| Turnip greens | 20 |
| Olive oil | 10 |
| Tuna and tomato toasts | |
| Bread | 60 |
| Tomato | 40 |
| Tuna | 40 |
| Oregano | 1 |

**Table 8.4. Composition of the main courses (high energy) considered in this study based on the Atlantic Diet**

| Recipe | Ingredients (g) |
|---|---|
| Tuna with white rice | |
| Tuna | 100 |
| Rice | 40 |
| Onion | 10 |
| Garlic | 2 |
| Fish soup | 80 |
| Tomato sauce | 25 |
| Mackerel with turnip greens and potatoes | |
| Mackerel | 100 |
| Potatoes | 75 |
| Turnip greens | 50 |
| Garlic | 7 |
| Onion | 50 |
| Olive oil | 15 |
| Pepper | 1 |
| Beans and rice | |
| Beans | 80 |
| Tomato | 90 |
| Pepper | 30 |
| Sausage | 10 |
| Rice | 40 |
| Carrot | 40 |
| Onion | 20 |
| Olive Oil | 5 |
| Saffron | 0.002 |
| Meat broth | 300 |
| Pan-fried hake with lemon, potatoes and salad | |
| Hake | 100 |
| Potatoes | 100 |
| Tomato | 90 |
| Olive | 15 |
| Lemon | 15 |
| Vinegar | 3 |
| Olive oil | 5 |
| Garlic | 2 |
| Salt | 7.5 |
| Pepper | 7.5 |
| Laurel | 0.5 |
| Onion | 50 |

**Table 8.4. (cont.) Composition of the main courses (high energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Chickpeas with mussels | |
| Chickpeas | 70 |
| Mussels | 40 |
| Tomato | 30 |
| Olive oil | 10 |
| Leek | 40 |
| Onion | 25 |
| Cod and Potato Stew | |
| Cod | 150 |
| Carrot | 20 |
| Onion | 10 |
| Garlic | 2 |
| Parsley | 1 |
| Potatoes | 200 |
| Olive oil | 15 |
| Pepper | 15 |
| Water | 250 |
| Saffron | 15 |
| Beef stew with potatoes and vegetables | |
| Beef | 100 |
| Potatoes | 75 |
| Olive oil | 10 |
| Pepper | 40 |
| Green peas | 20 |
| Carrot | 50 |
| Onion | 25 |
| Tomatoes | 60 |
| Meat broth | 200 |
| Wine | 25 |
| Garlic | 15 |
| Salt | 15 |
| Saffron | 15 |

**Table 8.4. (cont.) Composition of the main courses (high energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Mussels and turnip greens lasagna | |
| Mussels | 75 |
| Turnip greens | 75 |
| Onion | 25 |
| Garlic | 10 |
| Olive oil | 10 |
| Milk | 60 |
| Margarine | 5 |
| Flour | 5 |
| Cheese | 15 |
| Pasta | 35 |
| Tomato | 20 |
| Pepper | 5 |
| Walnut | 5 |
| Salt | 5 |
| Lentils with turnip greens and rice | |
| Lentils | 60 |
| Turnip greens | 30 |
| Carrot | 20 |
| Onion | 10 |
| Tomato | 20 |
| Rice | 30 |
| Olive oil | 5 |
| Garlic | 2 |
| Meat broth | 500 |
| Saffron | 0.002 |
| Hake in green sauce with potatoes | |
| Hake | 100 |
| Wheat flour | 15 |
| Olive oil | 10 |
| Parsley | 2 |
| Garlic | 3 |
| Wine | 15 |
| Potatoes | 125 |
| Fish soup | 100 |
| Onion | 30 |

**Table 8.4. (cont.) Composition of the main courses (high energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Chickpea stew with turnip greens | |
| Turnip greens | 80 |
| Chickpeas | 40 |
| Onion | 30 |
| Sausage | 10 |
| Bacon | 10 |
| Meat broth | 300 |
| Tomato | 30 |
| Olive oil | 10 |
| Pepper | 0.5 |
| Potatoes | 35 |
| Laurel | 0.25 |
| Galician-style octopus with potatoes | |
| Octopus | 150 |
| Potatoes | 200 |
| Olive Oil | 15 |
| Pepper | 1 |
| Turnip greens and ham quiche with cream cheese | |
| Ham | 15 |
| Cheese | 50 |
| Milk | 25 |
| Garlic | 5 |
| Eggs | 65 |
| Olive oil | 5 |
| Pepper | 0.5 |
| Puff pastry | 20 |
| Turnip greens | 40 |
| Creamy mussel risotto | |
| Mussels | 80 |
| Rice | 50 |
| Fish soup | 300 |
| Zaragallada | 60 |
| Cheese | 15 |
| Olive oil | 13 |
| Wine | 13 |
| Garlic | 10 |
| Saffron | 4 |

**Table 8.4. (cont.) Composition of the main courses (high energy) considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Fish stew with turnip greens | |
| Turnip greens | 50 |
| Fish | 50 |
| Potatoes | 50 |
| Mussels | 50 |
| Prawns | 30 |
| Garlic | 5 |
| Onion | 30 |
| Fish soup | 250 |
| Tomato | 30 |
| Olive oil | 20 |
| Bread | 10 |
| Almond | 9 |
| Parsley | 0.5 |

**Table 8.5. Composition of the desserts considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Rice pudding and mirabelle plum | |
| Mirabelle plum | 15 |
| Rice | 15 |
| Milk | 125 |
| Sugar | 9 |
| Cinnamon | 7.5 |
| Lemon | 7.5 |
| Mirabelle plum cake | |
| Mirabelle plum | 10 |
| Sugar | 6 |
| Flour | 6 |
| Almon | 6 |
| Milk | 75 |
| Eggs | 15 |
| Mirabelle plum brownie | |
| Mirabelle plum | 15 |
| Eggs | 17 |
| Flour | 7 |
| Cocoa | 15 |
| Sweetener | 2 |
| Olive oil | 3 |
| Vanilla | 1 |
| Salt | 15 |
| Mirabelle plum fritters | |
| Mirabelle plum | 10 |
| Flour | 25 |
| Milk | 25 |
| Yeast | 1 |
| Eggs | 8 |
| Olive oil | 5 |
| Sugar | 5 |
| Salt | 15 |
| Mirabelle plum fried milk | |
| Milk | 35 |
| Mirabelle plum | 35 |
| Sugar | 7 |
| Cornstarch | 5 |
| Flour | 5 |
| Eggs | 15 |

**Table 8.5. (cont.) Composition of the desserts considered in this study based on the Atlantic Diet.**

| Recipe | Ingredients (g) |
|---|---|
| Mirabelle plum soufflé | |
| Mirabelle plum | 18 |
| Flour | 8 |
| Sugar | 18 |
| Butter | 8 |
| Milk | 43 |
| Eggs | 55 |
| Cream cheese soufflé | |
| Cheese | 20 |
| Flour | 8 |
| Sugar | 20 |
| Butter | 8 |
| Milk | 43 |
| Eggs | 55 |

### 8.2.2 Calculation of impact indicators

8.2.2.1 Carbon footprint

The functional unit in this study is one serving of a Galician meal, calculated from a cradle-to-fork approach, which includes three life cycle stages within the system boundaries: production of ingredients (S1), transportation (S2) and meal preparation (S3).

Ingredient production (S1): Production of the various food ingredients that make up each recipe. Depending on the specific foodstuff, a cradle to farm or industry gate approach was followed at this stage.

Transport (S2): Transport activities involved in the distribution of the different foodstuffs from the factory or farm gate to retailers, as well as, from the retailers to households. Special attention was paid in this stage to the origin of the different ingredients that constitute the recipes. Food waste in the wholesale and retail distribution was considered.

Meal preparation (S3): This stage includes the main cooking methods used to prepare the recipes (boiling, frying, baking), and refrigerator storage. Food waste in households was taken into account.

**Fig. 8.1** gives an overview of the system boundaries considered in the LCA. Food waste and losses along the supply chain were included in the system boundaries. As a result, quantities greater than those specified in the recipes are produced for each ingredient. To calculate the net amount of food needed to prepare the meal, the percentages of waste at the wholesale and retail distribution stages (Gustavsson et al., 2013) and the average ratios of food waste in households (Garcia-Herrero et al., 2018) were taken into account.

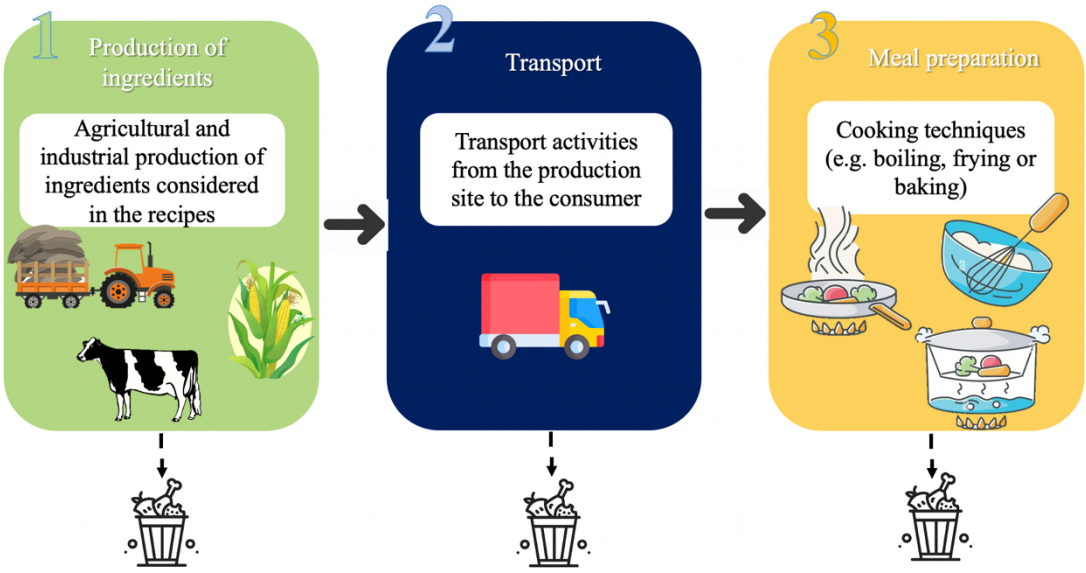


**Fig. 8.1. System boundaries considered in the life cycle assessment**

The CF associated with the production of the different ingredients considered in the recipes was collected from LCA studies related to 1 kg of edible product. A compilation of the different LCAs used to estimate the GHG emissions from the ingredients of each meal preparation is presented in **Table 8.6**. Priority was given to cradle-to-farm, cradle-to-industry or cradle-to-port gate LCA studies. If additional life cycle stages were identified (cradle-to-grave, cradle-to-retailer or cradle-to-consumer), these were excluded from the CF calculation. On the other hand, local Spanish LCA studies on food production were selected when available. If no LCA from peer-reviewed journal articles were available in the Spanish or European context, an average global result based on systematic literature reviews and meta-analyses was used.

For each ingredient, the GHG emissions associated with transport activities from the production site to the consumer were calculated according to the following assumptions. For food ingredients produced in Galicia, road transport was considered for an average distance of 60 km. For all food products imported from outside Galicia but within Spain, an average distribution distance of 400 km was assumed (Esteve-Llorens et al., 2019b). The fieldwork in the analysis of product labels was fundamental to determine the origin of the food. The transport vehicle selected was a Euro 5 diesel freight truck (>32 tons) (Castañé and Antón, 2017). Its associated GHG emissions, 92.10 $mgCO_2eq \cdot kg^{-1} \cdot km^{-1}$, were obtained from the Ecoinvent ® v3.2 database and the IPCC characterisation factors.

Food preparation also contributes to the total GHG emissions due to the energy requirements for the different cooking techniques (e.g., boiling, frying or baking), calculated according to the methodology reported by Sonesson et al. (2003). The energy values were converted into kg $CO_2$ equivalent using the emission coefficient 0.45 $kgCO_2eq \cdot kWh$ provided by the Ecoinvent® database.

**Table 8.6. Life cycle assessment considered for the estimation of the carbon footprint values of the ingredients of each meal preparation.**

| Foodstuff | CF ($kgCO_2eq \cdot kg^{-1}$) | Source | Location of origin (Source) | Geography |
|---|---|---|---|---|
| Saffron | 0.01 | (Khanali et al., 2017) | Iran | National |
| Lemon | 0.15 | (Aguilera et al., 2015a) | Spain | Local |
| Pumpkin | 0.2 | (Aguilera et al., 2015b) | Spain | Local |
| Carrot | 0.2 | (Nemecek et al., 2012) | Global | Local |
| Tomato | 0.22 | (Aguilera et al., 2015b) | Spain | Local |
| Pepper | 0.22 | (Aguilera et al., 2015b) | Spain | Local |
| Lettuce | 0.22 | (Aguilera et al., 2015b) | Spain | Local |
| Potato | 0.24 | (Aguilera et al., 2015b) | Spain | Local |
| Onion | 0.24 | (Aguilera et al., 2015b) | Spain | Local |
| Endive | 0.24 | (Aguilera et al., 2015b) | Spain | National |
| Cauliflower | 0.24 | (Aguilera et al., 2015b) | Spain | Local |
| Leek | 0.39 | (Clune et al., 2017) | Global | National |
| Turnip greens | 0.46 | (Audsley et al., 2009) | United Kingdom | Local |
| Mirabelle plum | 0.43 | (Audsley et al., 2009) | United Kingdom | Local |
| Cornstarch | 0.45 | (Audsley et al., 2009) | United Kingdom | National |
| Wheat flour | 0.45 | (Lantmännen, 2010) | Global | National |
| Spinach | 0.54 | (Clune et al., 2017) | Global | Local |
| Garlic | 0.39 | (Khoshnevisan and Rafiee, 2013) | Iran | Local |
| White bean | 0.51 | (Clune et al., 2017) | Global | National |
| Sugar | 0.61 | (Klenk et al., 2012) | Europe | National |
| Pea | 0.6 | (Aguilera et al., 2015b) | Spain | Local |
| Chickpeas | 0.67 | (Clune et al., 2017) | Global | National |
| Orange juice | 0.67 | (Doublet et al., 2013) | Europe | National |
| Bread | 0.88 | (Barilla Center for Food Nutrition, 2015) | Global | Local |
| Pinion | 0.95 | (West Africa Fair Fruit, 2011) | Ghana for export to Europe | National |
| Lentil | 1.03 | (Clune et al., 2017) | Global | National |
| Milk | 1.23 | (González-García et al., 2013b) | Portugal | Local |
| Cod | 1.2 | (Ziegler and Valentinsson, 2008) | Norway | Local |
| Pasta | 1.28 | (Hess et al., 2016) | United Kingdom | National |
| Margarine | 1.36 | (Nilsson et al., 2010) | United Kindgom, Germany and France | National |
| Chilli pepper | 1.3 | (Audsley et al., 2009) | United Kingdom | National |
| Yoghurt | 1.5 | (González-García et al., 2013a) | Portugal | National |
| Mussels | 1.59 | (Iribarren et al., 2010a) | Galicia (Spain) | Local |
| Mackerel | 1.54 | (Vázquez-Rowe et al., 2010a) | Galicia (Spain) | Local |
| Tomato sauce | 1.6 | (Berners-Lee et al., 2012; Hospido and Tyedmers, 2005) | United Kingdom | National |

**Table 8.6. (cont.) Life cycle assessment considered for the estimation of the carbon footprint values of the ingredients of each meal preparation.**

| Foodstuff | CF ($kgCO_2eq \cdot kg^{-1}$) | Source | Location of origin (Source) | Geography |
|---|---|---|---|---|
| Tuna | 1.6 | (Hospido and Tyedmers, 2005) | Spain | Local |
| Walnut | 1.62 | (Clune et al., 2017) | Global | National |
| Egg | 1.8 | (Nielsen et al., 2013) | Denmark | Local |
| Almond | 1.74 | (Clune et al., 2017) | Global | National |
| White wine | 2.2 | (Werner et al., 2014) | Denmark | Local |
| Vinegar | 2.24 | (Bartocci et al., 2017) | Italy | National |
| Broccoli | 1.94 | (Audsley et al., 2009) | United Kingdom | Local |
| Rice | 2.31 | (Hess et al., 2016) | United Kingdom | National |
| Chicken | 2.5 | (González-García et al., 2014) | Portugal | Local |
| Vanilla | 1.5 | (Lantmännen Unibake Denmark A/S, 2010) | Denmark | International |
| Cocoa | 3.6 | (Miah et al., 2018) | Global | International |
| Olive oil | 3.7 | (Monini, 2014) | Mediterranean countries | Local |
| Olive | 3.73 | (Audsley et al., 2009) | United Kingdom | Local |
| Octopus | 4.11 | (Iribarren et al., 2010b) | Mauritania and landed in Galicia (NW Spain) | Local |
| Alcoholic beverages | 4.55 | (Saxe, 2010) | Denmark | Local |
| Pork meat | 4.96 | (Noya et al., 2017) | Spain | Local |
| Hake | 5.98 | (Iribarren et al., 2010b) | Northern Stock | Local |
| Prawn | 6.2 | (Blonk et al., 2008) | Netherlands | Local |
| Butter | 7.2 | (Vergé et al., 2013) | Canada | National |
| Bacon | 8.5 | (Noya et al., 2017) | Spain | Local |
| Squid | 8.1 | (Iribarren et al., 2010b) | Mauritania and landed in Galicia (NW Spain) | Local |
| Cheese | 10.4 | (González-García et al., 2013c) | Spain | Local |
| Canned tuna | 10.2 | (Roibás et al., 2018) | Galicia (NW Spain) | Local |
| Sausauges (ham, chorizo) | 11.3 | (Noya et al., 2016) | Spain | Local |
| Beef meat | 24.69 | (van Oort and Andrew, 2016) | Norway | Local |

Note: Carbon footprint of species and condiments was not considered (laurel, parsley, oregano, paprika, cinnamon).
Meat broth. Ingredients: Onion (4%), carrot (3%), leek (3%), chorizo (2%), beef (32%), water (56%). CF: 8 ($kgCO_2eq \cdot kg^{-1}$)
Fish soup. Ingredients: leek (8%), hake (24%), carrot (3%), pepper (5%), onion (11%), water (48%). CF: 1.7 ($kgCO_2eq \cdot kg^{-1}$)
Puff pastry. Ingredients: Flour (42%), water (21%), butter (35%), sugar (1%). CF: 2.8 ($kgCO_2eq \cdot kg^{-1}$)
Zaragallada: Ingredients: Onion (72%), pepper (15%), olive oil (13%). CF: 0.73 ($kgCO_2eq \cdot kg^{-1}$)

8.2.2.2 EROI

EROI expressed as a percentage can be defined as the ratio of the total energy produced to the amount of energy consumed in a production process (Bajan et al., 2021) as shown in **Eq. 8.1**.

$$EROI = \frac{Meal\ energy\ provided}{Cumulative\ Energy\ Demand} \cdot 100 \qquad (8.1)$$

The CED was estimated for each recipe. The CED data for each food were collected from a number of existing LCA publications and SimaPro v9.0 software (**Table 8.7**). The functional unit and system boundaries considered were those of the CF assessment. The energy provided by each recipe was calculated using DIAL (Ortega et al., 2016), a software tool for dietary assessment and nutritional analysis.

8.2.2.3 Cost

The assessment of the economic dimension of the recipes is fundamental to ensure food safety. The theoretical cost of each recipe was estimated by multiplying the gram quantities by the cost per quantity of each ingredient used in the recipe formula. National unit prices for each food ingredient were obtained from the Household Consumption Database Program (MAPA, 2019). For more details, see **Table 8.8**.

**Table 8.7. Cumulative energy demand (CED) per food ingredient (Functional Unit: 1 kg)**

| Foodstuff | CED (MJ) | Source |
|---|---|---|
| Condiments | 0 | Assumption |
| Lemon | 5.73 | SimaPro v9.0 software - Lemon market for lemon GLO), Cut-off U |
| Pumpkin | 4.1 | SimaPro v9.0 software - Zucchini {GLO}\| market for\| Cut-off, U |
| Carrot | 4.30 | SimaPro v9.0 software - Carrot {GLO}\| market for\| Cut-off, U |
| Tomato | 5.23 | SimaPro v9.0 software - Tomato, fresh grade {GLO}\| market for\| Cut-off, U |
| Pepper | 19.76 | SimaPro v9.0 software - Bell pepper {GLO}\| market for\| Cut-off, U |
| Lettuce | 34.88 | SimaPro v9.0 software - Lettuce {GLO}\| market for\| Cut-off, U |
| Potato | 7.39 | SimaPro v9.0 software - Potato {GLO}\| market for\| Cut-off, U |
| Onion | 4.88 | SimaPro v9.0 software - Onion {GLO}\| market for\| Cut-off, U |
| Endive | 34.88 | Assimilated to lettuce |
| Cauliflower | 6.16 | SimaPro v9.0 software - Cauliflower {GLO}\| market for\| Cut-off, U |
| Leek | 2.4 | Assimilated to garlic |
| Turnip greens | 6.79 | Assimilated to broccoli |
| Mirabelle plum | 13.9 | (Svanes and Johnsen, 2019) |
| Cornstarch | 27.16 | SimaPro v9.0 software -Maize flour (Row) \| market for\| Cut-off, U |
| Wheat flour | 22.44 | SimaPro v9.0 software -Wheat flour (GLO) \| market for\| Cut-off, U |
| Spinach | 3.62 | Spinach (GLO) market for, cut-off U |
| Garlic | 2.4 | (Samavatean et al., 2011) |
| White bean | 19.56 | SimaPro v9.0 software -Fava bean {GLO}\| market for\| Cut-off, U |
| Sugar | 57.69 | SimaPro v9.0 software - Sugar, from sugarcane {GLO}\| market for\| Cut-off, U |
| Pea | 2.61 | SimaPro v9.0 software - Peas, green at fam/NL Mass |
| Chickpea | 6.54 | SimaPro v9.0 software - Chickpeas, market mix, at regional storage/NL Mass |
| Orange juice | 5.01 | SimaPro v9.0 software - Orange, processing grade {GLO}\| market for\| Cut-off, U |

**Table 8.7. (cont.) Cumulative energy demand (CED) per food ingredient (Functional Unit: 1 kg)**

| Foodstuff | CED (MJ) | Source |
|---|---|---|
| Bread | 6.88 | (Caputo et al., 2014) |
| Pinion | 4.85 | SimaPro v9.0 software -Pineapple {GLO}\| market for\| Cut-off, U |
| Lentil | 1.92 | Assimilated to chickpeas |
| Milk | 20.69 | SimaPro v9.0 software -Cow milk {GLO}\| market for\| Cut-off, U |
| Skimmed milk | 13.48 | SimaPro v9.0 software -Skimmed milk from cow milk {GLO}\| market for\| Cut-off, U |
| Cod | 28.12 | (Vázquez-Rowe et al., 2014) |
| Pasta | 22.8 | (Caputo et al., 2014) |
| Margarine | 93.49 | SimaPro v9.0 software - Butter, from cow milk {GLO}\| market for\| Cut-off, U |
| Chili pepper | 5.06 | SimaPro v9.0 software - Chili market for {GLO}\| market for\| Cut-off, U |
| Yoghurt | 25.66 | SimaPro v9.0 software - Yogurt, from cow milk {GLO} market for\| Cut-off, U |
| Mussels | 31.03 | (Vázquez-Rowe et al., 2014) |
| Mackerel | 11.53 | (Vázquez-Rowe et al., 2014) |
| Tomato sauce | 5.23 | SimaPro v9.0 software -Tomato, fresh grade {GLO} market for tomato, fresh grade \| Cut-off, U |
| Tuna | 19.23 | (Vázquez-Rowe et al., 2014) |
| Walnut | 41 | Assimilated to peanut and almond |
| Egg | 20.49 | SimaPro v9.0 software -Egg, at farm/NL Mass |
| Almond | 49.85 | SimaPro v9.0 software - Almond {GLO}\| market for\| Cut-off, U |
| White wine | 0 | Assumption |
| Vinegar | 0 | Assumption |
| Broccoli | 6.79 | SimaPro v9.0 software -Broccoli {GLO}\| market for\| Cut-off, U |
| Rice | 9.31 | SimaPro v9.0 software -White rice (raw), at processing /CN Mass |
| Chicken | 22.88 | SimaPro v9.0 software -Chicken meat, at slaughterhouse/NL mas |
| Vanilla | 17.31 | SimaPro v9.0 software -Vanilla {GLO}\| market for\| Cut-off, U |
| Cocoa | 194.8 | SimaPro v9.0 software - Cocoa bean {GLO}\| market for\| Cut-off, U |
| Olive oil | 12.43 | Assimilated to olive |
| Olive | 12.43 | SimaPro v9.0 software - Olive {GLO}\| market for\| Cut-off, U |
| Octopus | 95.93 | (Vázquez-Rowe et al., 2014) |
| Brandy | 0 | Assumption |
| Anise | 0 | Assumption |
| Pork meat | 44.97 | SimaPro v9.0 software - Red, meat, live weight {GLO}\| market for\| Cut-off, U |
| Hake | 28.12 | (Vázquez-Rowe et al., 2014) |
| Prawn | 95.93 | (Vázquez-Rowe et al., 2014) |
| Butter | 93.49 | SimaPro v9.0 software - Butter, from cow milk {GLO}\| market for\| Cut-off, U |
| Bacon | 44.97 | SimaPro v9.0 software - Red, meat, live weight {GLO}\| market for\| Cut-off, U |
| Squid | 99.93 | (Vázquez-Rowe et al., 2014) |
| Cheese | 164.36 | SimaPro v9.0 software - Cheese, from cow milk, fresh, unripened {GLO}\| market for\| Cut-off, U |
| Chorizo | 44.97 | SimaPro v9.0 software - Red, meat, live weight {GLO}\| market for\| Cut-off, U |
| Ham | 44.97 | SimaPro v9.0 software - Red, meat, live weight {GLO}\| market for\| Cut-off, U |
| Beef meat | 44.97 | SimaPro v9.0 software - Red, meat, live weight {GLO}\| market for\| Cut-off, U |
| Sweetener | 61.30 | SimaPro v9.0 software - Sugar, from sugarcane {GLO}\| market for\| Cut-off, U |

**Table 8.8. Average market prices per food ingredient (MAPA, 2020a).**

| Food ingredient | Average Spain (€/kg) |
|---|---|
| Lemon | 1.8 |
| Pumpkin | 1.53 |
| Carrot | 0.96 |
| Tomato | 1.75 |
| Pepper | 2.03 |
| Lettuce | 2.74 |
| Potato | 0.9 |
| Onion | 1.27 |
| Endive | 2.74 |
| Cauliflower | 1.75 |
| Leek | 2.78 |
| Turnip greens | 1.96 |
| Mirabelle plum | 2.1 |
| Cornstarch | 1 |
| Wheat flour | 1 |
| Spinach | 1.65 |
| Garlic | 4.42 |
| White bean | 2.08 |
| Sugar | 0.99 |
| Pea | 2.32 |
| Chickpea | 1.85 |
| Orange juice | 0.81 |
| Bread | 2.38 |
| Pinion | 6.33 |
| Lentil | 1.81 |
| Milk | 0.69 |
| Cod | 9.76 |
| Pasta | 1.95 |
| Margarine | 3.26 |
| Chili pepper | 2.03 |
| Yoghurt | 1.84 |
| Mussels | 3 |
| Mackerel | 4.37 |
| Tomato sauce | 2.49 |
| Tuna | 8.09 |
| Walnut | 5.63 |
| Egg | 2.35 |
| Almond | 14.08 |
| White wine | 1.2 |
| Vinegar | 1.35 |
| Broccoli | 1.96 |
| Rice | 1.66 |
| Chicken | 4.38 |
| Vanilla | 2.4 |

**Table 8.8. (cont.) Average market prices per food ingredient (MAPA, 2020a).**

| Food ingredient | Average Spain (€/kg) |
|---|---|
| Cocoa | 4.81 |
| Puff pastry | 4.6 |
| Olive oil | 3.5 |
| Olive | 2.98 |
| Octopus | 11.72 |
| Brandy | 9.45 |
| Anise | 7.97 |
| Pork meat | 6.31 |
| Hake | 7.26 |
| Prawn | 11.34 |
| Butter | 7.48 |
| Bacon | 6.31 |
| Squid | 8.01 |
| Cheese | 7.62 |
| Chorizo | 9.25 |
| Ham | 11.73 |
| Beef meat | 9.81 |
| Broths | 10.05 |

Note: Prize of species and condiments was not considered (laurel, parsley, oregano, paprika, cinnamon)

### 8.2.3 Statistical Analysis. Cluster Analysis

An useful integration of the three indicators in a comprehensive comparison between recipes can be achieved by an agglomerative hierarchical clustering analysis. The algorithm starts by declaring each of the n recipes as a single cluster. In the first step, the two most similar recipes are merged into a single cluster, giving all n-1 clusters. In the second step, the two most similar clusters are merged into one cluster, giving all n-2 clusters. The iterative process is repeated until all recipes are merged into the same cluster, which occurs in step n-1 (Bergman and Magnusson, 2001).

To calculate the dissimilarity between two recipe clusters, Ward's minimum variance method was chosen because it was found to be the most suitable as it produces a small number of homogeneous and interpretable clusters with relatively more recipes. In addition, Ward's minimum variance method was found to generally outperform other hierarchical methods (Punj and Steward, 1983). The data pretreatment method used in this work was autoscaling, which used the mean and standard deviation for standardization (Moreda-Piñeiro et al., 2001).

The result was presented in a dendrogram, a plot graphically shows the organisation of the recipes and their relationship in the form of a tree (Granato et al., 2018). A constant height cut-off method was used to identify three main clusters and eight secondary clusters, known as subgroups. The R statistical software package was used to perform the clustering analysis and generate the dendrogram.

## 8.3 Results and discussion

### 8.3.1 Estimated carbon footprint, EROI and cost of Galician recipes and comparison with the literature

This study reports the CF of more than 60 recipes of Galician gastronomy using LCA data. The CF associated with the different recipes is shown in **Table 8.9**. The production of raw materials was the main hotspot for global warming for all the recipes. The effect of distribution activities remained insignificant regardless of the recipe (between 1% and 2% of the total GHG). The

reason for this finding was the consumption of proximity food ingredients and the short delivery distances associated with them. GHG emissions related to cooking appliances were remarkable for some recipes with different cooking methods (frying, boiling, baking), although on average cooking activities were not the main factor in the ranking of recipes in terms of CF, which is consistent with the results of other studies based on the Atlantic Dietary Recommendations (Esteve-Llorens et al., 2019a; González-García et al., 2020a). The large differences in GHG emissions of the different recipes could be explained as a function of the composition of animal-derived ingredients, mainly meat ingredients. The fact that meat-containing recipes resulted in higher emissions mirrors the results of other researchers, such as Ernstoff et al. (2019) and Rivera and Azapagic (2019).

**Table 8.9. Carbon Footprint (CF) (kg $CO_2$ eq), energy return on investment ratio EROI (%) and cost (€) of Galician recipes.**

| Meal | CF | EROI | Cost |
|---|---|---|---|
| First courses (high energy) | | | |
| Turnip greens and rice soup | 5.23 | 4.8 | 5.92 |
| Mashed turnip greens and potatoes | 0.67 | 20.7 | 0.66 |
| Cannelloni with vegetables and cream cheese | 1.48 | 10.9 | 1.12 |
| Potato and turnip greens salad | 0.44 | 90.5 | 0.53 |
| Lentils with turnip greens | 4.25 | 9.6 | 5.27 |
| Turnip soufflé | 0.68 | 38.1 | 0.48 |
| Fideuá with spinach and tomato sauce, topped with cheese gratin | 1.63 | 14.0 | 1.85 |
| First courses (low energy) | | | |
| Beans with turnip greens | 1.65 | 12.8 | 2.00 |
| Tuna salad | 0.36 | 20.3 | 1.33 |
| Grilled tuna with Galician "zaragallada"sauce | 0.55 | 27.9 | 1.47 |
| Grilled squids with boiled potato | 1.15 | 9.0 | 1.07 |
| Beans with mussels and prawns | 1.27 | 20.2 | 1.41 |
| Mussel fideuá | 0.94 | 23.1 | 1.24 |
| Atlantic horse mackerel fillet | 0.39 | 23.6 | 1.21 |
| Bonito and vegetable salad | 1.03 | 51.4 | 0.97 |
| Lentil salad with turnip greens | 0.36 | 72.4 | 0.58 |
| Pork tenderloin with salad | 0.96 | 25.0 | 1.24 |
| Mussels marinara | 0.44 | 17.1 | 0.69 |
| Mussels in garlic sauce | 0.39 | 38.6 | 0.59 |
| Mussels with onion | 0.48 | 17.3 | 0.72 |
| Spanish Tuna Stew | 1.05 | 26.4 | 1.86 |
| Mussel pie | 0.82 | 22.5 | 0.63 |
| Scrambled eggs with mussels | 0.50 | 21.1 | 0.47 |
| Mussels Vinaigrette | 0.36 | 24.8 | 0.69 |
| Noodles with mussels | 0.52 | 40.0 | 0.56 |
| Omelet with turnip greens | 0.41 | 39.4 | 0.39 |
| Galician "zaragallada" sauce with poached egg | 0.37 | 38.59 | 0.26 |

**Table 8.9. (cont.) Carbon Footprint (CF) (kg $CO_2$ eq), energy return on investment ratio EROI (%) and cost (€) of Galician recipes.**

| Meal | CF | EROI | Cost |
|---|---|---|---|
| Main courses (high energy) | | | |
| Tuna with white rice | 0.65 | 38.4 | 1.30 |
| Mackerel with turnip greens and potatoes | 0.51 | 50.3 | 0.87 |
| Beans and rice | 2.97 | 12.4 | 3.72 |
| Pan-fried hake with lemon, potatoes and salad | 0.95 | 19.5 | 1.28 |
| Chickpeas with mussels | 0.41 | 61.0 | 0.56 |
| Cod and Potato Stew | 0.49 | 25.4 | 1.98 |
| Beef stew with potatoes and vegetables | 4.69 | 11.0 | 3.66 |
| Mussels and turnip greens lasagna | 1.12 | 20.9 | 0.89 |
| Lentils with turnip greens and rice | 4.44 | 7.0 | 5.38 |
| Hake in green sauce with potatoes | 1.11 | 22.1 | 1.32 |
| Chickpea stew with turnip greens | 3.12 | 10.2 | 3.62 |
| Galician-style octopus with potatoes | 1.69 | 8.6 | 2.19 |
| Turnip greens and ham quiche with cream cheese | 1.25 | 13.0 | 0.96 |
| Creamy mussel risotto | 1.17 | 16.3 | 1.48 |
| Fish stew with turnip greens | 1.43 | 17.9 | 2.16 |
| Main courses (low energy) | | | |
| Rice and turnip greens with tomato sauce and bechamel | 0.67 | 38.9 | 0.46 |
| Rice with carrots and tomato sauce | 0.26 | 118.6 | 0.22 |
| Turnip greens cream | 2.99 | 3.1 | 3.81 |
| Carrot, leek and potato cream | 1.60 | 8.4 | 1.95 |
| Pickled mussels with vegetables | 0.40 | 33.9 | 0.51 |
| Spanish Vegetable Stew | 0.46 | 57.5 | 0.66 |
| Pumpkin Ratatouille | 0.31 | 20.0 | 0.84 |
| Scrambled Eggs with turnip greens | 0.39 | 39.4 | 0.40 |
| Sautéed turnip greens with ham | 0.46 | 51.2 | 0.58 |
| Chicken noodle soup | 3.19 | 3.4 | 3.96 |
| Julianne soup | 2.40 | 5.4 | 2.91 |
| Garlic soup | 4.00 | 6.2 | 4.76 |
| Stuffed tomatoes with turnip greens | 0.70 | 13.4 | 0.57 |
| Tuna and tomato toasts | 0.71 | 81.0 | 0.59 |
| Desserts | | | |
| Rice pudding and mirabelle plum | 0.58 | 31.1 | 0.18 |
| Mirabelle plum cake | 0.40 | 28.0 | 0.22 |
| Mirabelle plum brownie | 0.38 | 19.5 | 0.18 |
| Mirabelle plum fritters | 0.18 | 50.5 | 0.11 |
| Mirabelle plum fried milk | 0.19 | 39.8 | 0.17 |
| Mirabelle plum soufflé | 0.51 | 31.8 | 0.30 |
| Cream cheese soufflé | 0.72 | 17.1 | 0.42 |

Recipes containing meat were associated with higher costs compared to other recipes (**Table 8.9**). In line with this, Kolbe (2020) found that meat-containing recipes were on average more expensive than ovo-lactovegetarian and vegan recipes in Germany. The price of milk-derived ingredients, such as cheese or butter, could be the reason for the high costs of other Galician recipes (MAPA, 2019). Moreover, favouring plant-based diets over resource-intensive animal-based diets not only reduces menu costs, but also represents a significant opportunity, as reported by Shepon et al. (2018), who estimated that replacing animal products with plant-based foods in the US diet could feed 350 million more people.

The EROI results allow us to delve deeper into the energy efficiency of the Galician gastronomic sector, showing that recipes of animal origin, mainly meat-based, had the lowest EROI values (see **Table 8.9)**. Our results are in agreement with previous studies available in the literature. Therefore, Pelletier and Tyedmers (2011) showed an eightfold difference between animal- and plant-based food products in terms of energy efficiency. Following the same line of research, Laso et al. (2018) found that the minimum EROI was observed for animal-based products such as eggs, meat, fish and seafood products.

### 8.3.2 Recipe classification by cluster analysis

The present research applied Ward's minimum variance cluster using the environmental, economic and energy indicators identified in the previous section as input variables. As a result, a classification of recipes was identified. **Tables 8.10 - 8.12** show the results and allow to study in detail the similarities and dissimilarities among the recipes. The results showed a very wide range in CF, EROI and cost among the three main clusters. The segment with the highest CF and cost was cluster 1. The segment with the highest EROI was cluster 3. Each cluster was further subdivided into more subtypes as described below. The dendrogram generated by the R statistical software package is shown in **Fig. 8.2**.

**Table 8.10. Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) - Cluster 1**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Turnip greens and rice soup | Cluster 1 | S2 | 5.9 | 5.2 | 4.8 |
| Turnip greens cream | Cluster 1 | S1 | 3.8 | 3.0 | 3.1 |
| Chicken noodle soup | Cluster 1 | S1 | 4.0 | 3.2 | 3.4 |
| Beans and rice | Cluster 1 | S1 | 3.7 | 3.0 | 12.4 |
| Chickpea stew with turnip greens | Cluster 1 | S1 | 3.6 | 3.1 | 10.2 |
| Beef stew with potatoes and vegetables | Cluster 1 | S2 | 3.7 | 4.7 | 11.0 |
| Lentils with turnip greens | Cluster 1 | S2 | 5.3 | 4.2 | 9.6 |
| Garlic soup | Cluster 1 | S2 | 4.8 | 4.0 | 6.2 |
| Lentils with turnip greens and rice | Cluster 1 | S2 | 5.4 | 4.4 | 7.0 |
| Julianne soup | Cluster 1 | S1 | 2.9 | 2.4 | 5.4 |

**Table 8.11. Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) - Cluster 2**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Fideuá with spinach and tomato sauce, topped with cheese gratin | Cluster 2 | S1 | 1.8 | 1.6 | 14.0 |
| Carrot, leek and potato cream | Cluster 2 | S1 | 1.9 | 1.6 | 8.4 |
| Galician-style octopus with potatoes | Cluster 2 | S1 | 2.2 | 1.7 | 8.6 |
| Fish stew with turnip greens | Cluster 2 | S1 | 2.2 | 1.4 | 17.9 |
| Beans with turnip greens | Cluster 2 | S1 | 2.0 | 1.6 | 12.8 |
| Cannelloni with vegetables and cream cheese | Cluster 2 | S2 | 1.1 | 1.5 | 10.9 |
| Cod and Potato Stew | Cluster 2 | S2 | 2.0 | 0.5 | 25.4 |
| Mussels and turnip greens lasagna | Cluster 2 | S2 | 0.9 | 1.1 | 20.9 |
| Hake in green sauce with potatoes | Cluster 2 | S2 | 1.3 | 1.1 | 22.1 |
| Turnip greens and ham quiche with cream cheese | Cluster 2 | S2 | 1.0 | 1.2 | 13.0 |
| Creamy mussel risotto | Cluster 2 | S2 | 1.5 | 1.2 | 16.3 |
| Tuna salad | Cluster 2 | S2 | 1.3 | 0.4 | 20.3 |
| Grilled tuna with Galician “zaragallada” sauce | Cluster 2 | S2 | 1.5 | 0.6 | 27.9 |
| Grilled squids with boiled potato | Cluster 2 | S2 | 1.1 | 1.1 | 9.0 |
| Beans with mussels and prawns | Cluster 2 | S2 | 1.4 | 1.3 | 20.2 |

**Table 8.11. (cont.) Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) – Cluster 2**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Mussel fideuá | Cluster 2 | S2 | 1.2 | 0.9 | 23.1 |
| Atlantic horse mackerel fillet | Cluster 2 | S2 | 1.2 | 0.4 | 23.6 |
| Pork tenderloin with salad | Cluster 2 | S2 | 1.2 | 1.0 | 25.0 |
| Spanish Tuna Stew | Cluster 2 | S2 | 1.9 | 1.1 | 26.4 |
| Tune with white rice | Cluster 2 | S2 | 1.3 | 0.7 | 38.4 |
| Pan-fried hake with lemon, potatoes and salad | Cluster 2 | S2 | 1.3 | 1.0 | 19.5 |
| Mashed turnip greens and potatoes | Cluster 2 | S3 | 0.7 | 0.7 | 20.7 |
| Pumpkin Ratatouille | Cluster 2 | S3 | 0.8 | 0.3 | 20.0 |
| Stuffed tomatoes with turnip greens | Cluster 2 | S3 | 0.6 | 0.7 | 13.4 |
| Mussels marinara | Cluster 2 | S3 | 0.7 | 0.4 | 17.1 |

**Table 8.11. (cont.) Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) - Cluster 2**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Mussels with onion | Cluster 2 | S3 | 0.7 | 0.5 | 17.3 |
| Mussel pie | Cluster 2 | S3 | 0.6 | 0.8 | 22.5 |
| Scrambled eggs with mussels | Cluster 2 | S3 | 0.5 | 0.5 | 21.1 |
| Mussels Vinaigrette | Cluster 2 | S3 | 0.7 | 0.4 | 24.8 |
| Mirabelle plum brownie | Cluster 2 | S3 | 0.2 | 0.4 | 19.5 |
| Cream cheese soufflé | Cluster 2 | S3 | 0.4 | 0.7 | 17.1 |

**Table 8.12. Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) - Cluster 3**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Turnip soufflé | Cluster 3 | S1 | 0.5 | 0.7 | 38.1 |
| Rice and turnip greens with tomato sauce and bechamel | Cluster 3 | S1 | 0.5 | 0.7 | 38.9 |
| Pickled mussels with vegetables | Cluster 3 | S1 | 0.5 | 0.4 | 33.9 |
| Scrambled Eggs with turnip greens | Cluster 3 | S1 | 0.4 | 0.4 | 39.4 |
| Mussels in garlic sauce | Cluster 3 | S1 | 0.6 | 0.4 | 38.6 |
| Noodles with mussels | Cluster 3 | S1 | 0.6 | 0.5 | 40.0 |
| Omelet with turnip greens | Cluster 3 | S1 | 0.4 | 0.4 | 39.4 |
| Galician “zaragallada” sauce with poached egg | Cluster 3 | S1 | 0.3 | 0.4 | 38.6 |
| Rice pudding and mirabelle plum | Cluster 3 | S1 | 0.2 | 0.6 | 31.1 |
| Mirabelle plum cake | Cluster 3 | S1 | 0.2 | 0.4 | 28.0 |
| Mirabelle plum fried milk | Cluster 3 | S1 | 0.2 | 0.2 | 39.8 |
| Mirabelle plum soufflé | Cluster 3 | S1 | 0.3 | 0.5 | 31.8 |
| Spanish Vegetable Stew | Cluster 3 | S2 | 0.7 | 0.5 | 57.5 |
| Sautéed turnip greens with ham | Cluster 3 | S2 | 0.6 | 0.5 | 51.2 |

**Table 8.12. (cont.) Recipe classification based on carbon footprint (kg $CO_2$ eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) - Cluster 3**

| Meal | Cluster | Subgroup | Cost | CF | EROI |
|---|---|---|---|---|---|
| Mackerel with turnip greens and potatoes | Cluster 3 | S2 | 0.9 | 0.5 | 50.3 |
| Chickpeas with mussels | Cluster 3 | S2 | 0.6 | 0.4 | 61.0 |
| Bonito and vegetable salad | Cluster 3 | S2 | 1.0 | 1.0 | 51.4 |
| Mirabelle plum fritters | Cluster 3 | S2 | 0.1 | 0.2 | 50.5 |
| Potato and turnip greens salad | Cluster 3 | S3 | 0.5 | 0.4 | 90.5 |
| Tuna and tomato toasts | Cluster 3 | S3 | 0.6 | 0.7 | 81.0 |
| Lentil salad with turnip greens | Cluster 3 | S3 | 0.6 | 0.4 | 72.4 |
| Rice with carrots and tomato sauce | Cluster 3 | S3 | 0.2 | 0.3 | 118.6 |

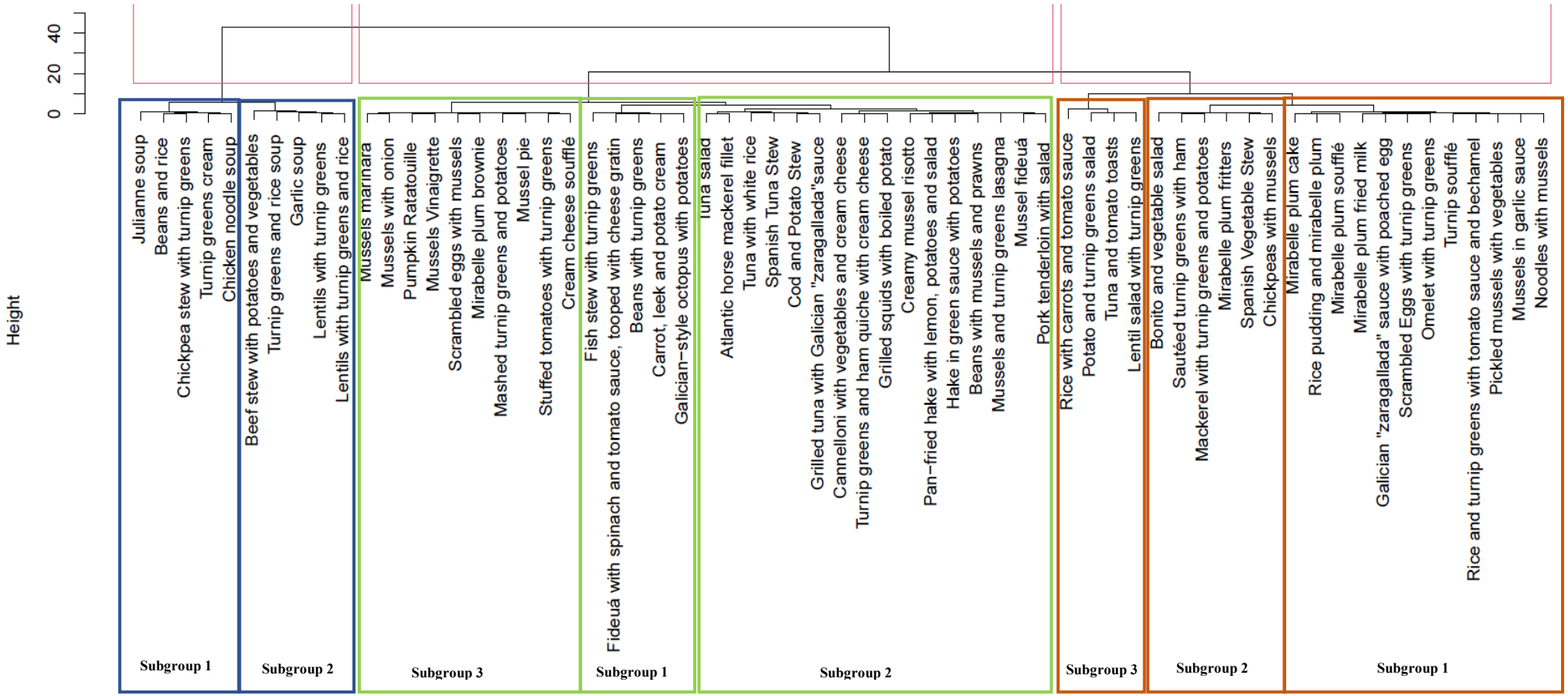


**Fig. 8.2. Cluster dendrogram**

8.3.2.1 Cluster 1

Of the total 63 meal recipes, this cluster included 10 recipes (**Table 8.10)** that have the characteristics of very low EROI (mean [SD], 7.3 [3.3]), combined with very high carbon intensity (mean [SD], 3.7 [0.9] kg $CO_2$ eq) and economic cost (mean [SD], 4.3 [0.9] €). These recipes tended to have characteristics of high carbon lifestyle factors, such as meat-rich ingredients. Meals in this cluster contain high amounts of beef broth. Some recipes also include other types of red meat (pork, sausage, ham) as well as white meat (chicken). This close association between meat and CF is consistent with the findings reported by González-García et al. (2021), who showed a wide variation in GHG emissions in menus for young children based on the Atlantic Dietary Guidelines in relation to the presence of animal-based foods, especially beef.

The dendrogram allows us to identify a major division of this cluster into two subgroups according to the contribution of meat to the recipe. The first subgroup consists of six main course recipes: Julienne soup, turnip green cream, chicken noddle soup, chickpea stew with turnips. It contains preparations with a meat content of more than 85 g.

The second subgroup, consisting of three main courses (Beef stew with potatoes and vegetables, garlic soup and lentils with turnip greens and rice), and two first courses (Lentils with turnip greens and turnip greens and rice soup), is prepared with meat portions ranging from 161 to 204 g.

8.3.2.2 Cluster 2

There are 31 meal recipes in cluster 2 (see **Table 8.11)**. Fewer high-carbohydrate lifestyle characteristics are observed in this cluster compared to cluster 1. Recipes rich in fish with some vegetables and moderate consumption of red meat and dairy products were included in this second cluster, which can be divided into three subgroups.

Subgroup 1 consists of meals with little meat, octopus and meals with plenty of fish. The CF, EROI and cost for this subgroup were (mean [SD], 1.6 [0.1] kg $CO_2$ eq, 12.4 [4.0] and 2.0 [0.1] €), respectively. This subgroup includes three main courses (Galician-style octopus with potatoes, fish stew with turnip greens, carrot, leek and potato cream) and two first courses (beans with turnip greens and fideuá with spinach and tomato sauce topped with cheese grain).

Subgroup 2 consists mainly of moderate fish and seafood recipes, including different types of fish species (hake, cod, tuna, mussels, prawns, squids, mackerel and fish soup). The fish-based dishes included in this subgroup are cod stew with potatoes; lasagna of mussels and turnip greens; hake in green sauce with potatoes; creamy mussel risotto; tuna salad; grilled tuna with Galician "zaragallada" sauce; grilled squid with boiled potatoes; beans with mussels and prawn; mussel fideuá; Atlantic horse mackerel fillet; tuna stew; tuna with white rice; fried hake with lemon, potatoes and salad. Some dishes are rich in dairy products, especially cheese, such as turnip and ham quiche with cream cheese or cannelloni with vegetables and cream cheese. Subgroup 2 contains nine first courses and five main courses. The recipes in this subgroup have a CF of 0.9 [0.3] kg $CO_2$ eq, an EROI of 21.4 [7.1], and a cost of 1.3 [0.3] €.

First course recipes for mussels constitute a large part of the recipes in subgroup 3 (mussels in marinara style, mussels with onions, mussel cake, scrambled eggs with mussels, mussels in vinaigrette). Cheese is used as an ingredient in moderate amounts (about 20-25 g) in some recipes included in this subgroup 3, such as turnip and potato puree, fresh cheese soufflé and tomatoes stuffed with turnips. The brownie dessert Mirabelle was also classified within this subgroup due to the high CED of cocoa (194.8 MJ) and sweetener (61.3 MJ). Although the average CF (mean [SD], 0.5 [0.2] kg $CO_2$ eq) and the EROI (mean [SD], 19.4 [3.2]) were

slightly lower than for subgroup 2, the main difference with subgroup 2 was the monetary cost, which was 0.6 [0.2] € for subgroup 3.

8.3.2.3 Cluster 3

The third cluster comprises 22 recipes (see **Table 8.12)**, mainly of vegetable origin. Some products of animal origin with a relatively high CED (milk, tuna, mackerel, eggs, mussels) were less frequent ingredients, but were also part of some recipes in this group. The food preparations in cluster 3 contain the most low-cost (mean [SD], 0.46 [0.22] €) and low-carbon (mean [SD], 0.7 [0.18] kg $CO_2$ eq) recipes. Furthermore, this cluster could be divided into three subgroups, mainly based on the EROI values.

The first subgroup includes dishes with milk, eggs and fish (mussels and tuna) with EROI values ranging from 28 to 40. Dishes made with milk comprise four mirabelle dessert recipes (mirabelle plum rice pudding, mirabelle plum cake, mirabelle plum fried milk and mirabelle plum soufflé) and three turnip recipes (rice and turnips with tomato sauce and béchamel, turnip soufflé and scrambled eggs with turnips). The list of dishes with eggs contains two first courses (omelette with turnip greens and Galician "zaragallada" sauce with poached egg). Two first courses with mussels in small quantities (less than 75 g) were also included in this subgroup (mussels with garlic and pickled mussels with vegetables).

The second subgroup was based on vegetable dishes (vegetable stew, mirabelle plum fritters, sautéed turnip greens with ham) and three fish dishes with low CED (chickpeas with mussels, bonito and vegetable salad, and mackerel with turnip greens and potatoes). The EROI values ranged from 50.3 to 61.0.

The third subgroup consists of recipes based on vegetables, starch products (rice and bread), lentils and tuna. This subgroup consists of two first courses (potato and turnip salad and lentil salad with turnip) and two main dishes (tuna and tomato toast, rice with carrots and tomato sauce). This subgroup has the highest EROI values, ranging from 72.4 to 118.6.

### 8.3.3 Comparison with the literature: sustainable diets and recipes, and development of ecolabels

The trend of promoting sustainable diets is growing in the literature and is reflected in the restaurant industry, which offers interesting perspectives on the role of restaurants in promoting gastronomic heritage and sustainability. Therefore, environmental, nutritional and economic aspects have been analysed for different complete daily traditional dietary recommendations around the world.

Recent results have been published for traditional diets, defined as seasonal and local food consumption. Therefore, Ulaszewska et al. (2017) used an environmental hourglass approach for the analysis of the GHG emissions of the NND. Other authors, such as González-García et al. (2020b) quantified the CF of the Atlantic Diet and the MD considering a cradle-to-consumer gate approach and a functional unit based on daily food consumption. Kovacs et al. (2021) examined the global warming impacts of FBDGs in Italy, Germany, India, the Netherlands, Oman, Thailand, Uruguay and United States. At global level, Kesse-Guyot et al. (2021) explored the environmental impacts (GHG emissions, CED and land occupation) associated with the EAT Lancet diet.

In the same line, very few studies have evaluated the nutritional, health and environmental sustainability of recipes. Hence, González-García et al. (2021) analysed the menus served at a Spanish nursery canteen considering two environmental indicators: CF and WF. Both indicators for the menus varied considerably between 619-1359 $L \cdot menu^{-1}$ for the WF and 0.75-2.95 $kgCO_2eq \cdot menu^{-1}$ for the CF.

On the other hand, some studies jointly assessed environmental dimensions with nutritional ones. Batlle-Bayer et al. (2020b) analysed the global warming potential, blue WF and LU of 15 tapas meals eaten in a Spanish restaurant. The novelty of the study carried out by Batlle-Bayer et al. (2020b) was the choice of a functional unit based on the caloric energy intake and the nutritional quality of the meals. Ribal et al. (2016) developed a model to construct diets that are nutritious, sustainable, and economical. They chose a menu for school children in Spain as a case study. Rossi et al. (2021) used a mathematical model to design a four-week menu characterised by a large vegetable component. This menu combined nutritional adequacy and acceptability criteria while minimising GHG emissions.

In line with these few multi-criteria sustainability studies, our research not only analysed the characteristics of the Atlantic Diet and its environmental, energy, and economic sustainability, but also made its benefits visible to consumers and restaurants, providing a basis for the introduction of ecolabels in restaurants, enabling consumers to make informed purchasing decisions. In addition, diets around the world could adopt some of the positive aspects of the Atlantic Diet to improve their sustainability profile.

### 8.3.4 Policy implications

This work builds on the proposition that meals and menus with low environmental impact, low cost, and high EROI can help enable sustainable food transitions, contribute to the achievement of green food services, and create positive experiences for all stakeholders (eg, local businesses, restaurants, consumers, tour operators) (Kumar, 2019).

Tourism activities make a relevant contribution to GHG emissions (standing at about 8% of the world's carbon emissions) (Lenzen et al. 2018). By 2035, it is estimated that emissions from tourism will increase more than double (UNWTO, 2020). The CF of tourism includes the GHG emissions associated with tourism activities (food purchase, accommodation, transport, fuel, and shopping). Due to the important role of tourism in Spain, the CF associated to it was estimated on 47,825 $ktCO_2e$ (14.2% of total Spanish CF) (Osorio et al., 2023). This study addressed the need to reduce $CO_2$ emissions associated with tourism in Spain by promoting sustainable recipes.

We showed public health benefits as well as potential positive environmental and economic impacts of reducing animal products in recipes, especially red meat. These conclusions are useful to improve the healthy Atlantic dietary pattern in terms of its environmental sustainability. However, we need potential pathways for realizing these transitions to more plant-based diets, advances in policy-making, and stakeholder engagement.

Governments should formulate national policies that contribute not only to personal health and nutrition, but also to local and global environmental sustainability. Out of 215 countries, only 83 have FBDGs, with 20 including limited meat consumption. Their absence is more pronounced in low-income countries (Fischer and Garnett, 2016).

Public health nutrition strategies should also promote global reference diets, such as the WHO global dietary recommendations or the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems (Willett et al., 2019b). These diets will ensure compliance with the SDGs and the Paris Agreement. They should form the basis of education programs and nutrition policies.

On the other hand, school meals can also help students, their families, and the wider community by providing nutrition education experiences. The recommendations for sustainability in school food policies and sustainability practices in schools have been widely addressed in the scientific literature (Dos Santos et al., 2022; Eustachio-Colombo et al., 2020). In addition, food provides an useful vehicle for teaching cultural issues to school children.

Incorporating some of the sustainable Atlantic recipes analysed in this study into school meals would help promote an Atlantic diet based on fresh, seasonal, and local foods and reduce food-related GHG emissions. School garden programs are an excellent platform for experiential learning and nutrition education. School gardens are ideal for encouraging the consumption of seasonal foods and for promoting environmental attitudes, traditional knowledge and experience. These aspects help to realize the potential of food in achieving SDGs. Therefore, government funds should be invested in these initiatives.

Finally, the development of alternative nutritious and healthy hybrid meat substitutes can potentially contribute to climate change mitigation and the achievement of SDGs. Due to the lower levels of amino acids, vitamins, and n-3 PUFA in plant-based protein meat substitutes, more scientific research is needed in this area.

### 8.3.5 Assumptions and limitations

The constraints, limitations, and assumptions are relevant to address the potential shortcomings of the research. Carbon emissions and their impact on climate change is one of the main challenges in achieving environmental sustainability. Although other indicators to measure biodiversity loss and water issues may be of interest, the CF was chosen because it is a good proxy for the rest of the impacts (Kalbar et al., 2017), and it is the most used indicator in the environmental analysis of recipes and diets (Batlle-Bayer et al., 2020b; Kovacs et al., 2021).

The wide range of LCA studies used to quantify the potential CF of each recipe and the lack of uncertainty measurement results for each CF collected in the literature for each food ingredient did not allow a sensitive and reliable uncertainty analysis. In addition, the CFs of spices and seasonings (bay leaf, parsley, oregano, paprika, cinnamon) were not included in the evaluation of the CFs, mainly because of the small amounts they are present in the recipes. For the same reason, the economic costs of spices and seasonings were not included in the economic study.

In addition, we assumed a distance of 400 km for all food products imported from outside Galicia but within Spain, following Esteve-Llorens et al. (2019a). Although this assumption is very restrictive and favours some ingredients and disfavours others, it does not significantly change the CF results. The reason for this is that distribution activities were not the main CF hotspot for any recipe. This fact had already been addressed in previous studies in the scientific literature (Esteve-Llorens et al., 2019a; González-García et al., 2020a).

On the other hand, due to the lack of information on the EROI values of some food ingredients, some assumptions were made. Therefore, spices, condiments and beverages were excluded from the energy assessment. In addition, some food ingredients were assimilated to others in the same family. These include leek (assimilated to garlic), endive (assimilated to lettuce), turnip greens (assimilated to broccoli), and lentils (assimilated to chickpeas). A detailed description of these assumptions and limitations can be found in **Table 8.7**.

As for hierarchical cluster analysis, the main limitation is that there is no objective way to determine the clusters found when cutting the branches of the dendrogram. We used the most common method of constant height cutoff. However, there is controversy about the optimal cutoff parameter or how to estimate the number of clusters in the dataset (Langfelder et al., 2008).

Regarding the database, a book has been considered as a reference that includes dishes that are part of the Atlantic Diet, although it is not an accurate representation of it. Despite this fact, and in the context of this study, the use of this recipe book is useful to respond to the main

objective of this research, which is to make a general classification of recipes consumed in Galicia based on sustainability factors.

## 8.4 CONCLUDING REMARKS

This chapter contributed to a better understanding of the environmental, economic and energy sustainability of food recipes belonging to the Galician gastronomy. The findings from this study revealed the classification of recipes into three meaningful clusters with significant differences in CF, EROI and costs. This classification was shown to be related to the presence or absence of animal products in the recipes.

The study highlights that reducing animal-based ingredients in recipes not only leads to a significant reduction in GHG emissions, but also to low costs and high energy efficiency. In addition, replacing red meat with white meat, fish and seafood, and dairy products is associated with a lower CF and higher cost-effectiveness. Although a team of nutritionists confirmed the nutritional quality of all recipes, it would be interesting to include the nutritional dimension in the selection criteria for future research to facilitate comparison of the nutritional quality of the recipes.

To sum up, the findings from this study could be used as an educational tool for customers and restaurants to gain a more complete understanding of the environmental, economic and energy impacts of recipes. On the other hand, they could also be used as a reference for the improvement of FBDGs in Spain. Galician restaurants can benefit from this study to create environmentally friendly menus.

# SECTION IV

## IMPACTS OF SOCIO-CULTURAL, HEALTH, POLITICAL AND ECONOMIC FACTORS ON FOOD CONSUMPTION PATTERNS

# 9. EXAMINING THE SYNCHRONY BETWEEN SUSTAINABLE DEVELOPMENT GOALS AND THE COVID-19 PANDEMIC[67]

The unprecedented crisis associated with the COVID-19 pandemic has had a planetary impact on the socio-economic development of society. COVID-19 has jeopardized the achievement of the Sustainable Development Goals. In particular, productive activities for food provision must address the degree of compliance with SDGs 6 (Clean Water), 12 (Responsible Consumption and Production) closely related to 2 (Zero Hunger), and 13 (Climate Action).

Spain is probably one of the European countries where consumer behaviour has been most affected by the COVID-19 pandemic. Within this framework, the main objective of this chapter is to address the impact of the COVID-19 pandemic on Spanish food consumption patterns through the evaluation of carbon footprint and water footprint indicators.

The results showed significant fluctuations in the carbon footprint and water footprint between 2019 and 2021. The analysis showed a significant peak between March 2020 and April 2020. Higher household food consumption during the months of confinement could be behind these results. An upward trend was also observed in the last months of 2019 and 2020, corresponding to the Christmas holidays. On the other hand, a downward trend was observed in 2021, as the vaccination campaign in Spain progressed.

These results suggest that COVID-19 had a negative impact on the implementation of the SDGs related to the maintenance of a healthy planetary diet, jeopardizing the achievement of the 2030 Agenda for Sustainable Development.

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## 9.1 INTRODUCTION

The food and agriculture sector faces daunting and complex challenges driven by population growth, sustainability concerns, and income and wealth inequalities. Current challenges include: i) ensuring food security and availability, ii) increasing the diversity of products in the food basket, iii) ensuring social standards for food safety, food quality, environmental protection and animal welfare, and iv) promoting equitable food systems (European Commission, 2019b). Indeed, the link between agriculture and food and human and planetary health is enshrined in many of the 17 SDGs adopted by 193 countries, which set targets for 2030. In particular, the link is clear for SDG 6 (Clean water and sanitation), SDG 12 (Responsible production and consumption) closely linked to SDG 2 (Zero Hunger), and SDG 13 (Climate action) (United Nations, 2018).

### 9.1.1 Goal 6 on Clean Water and Sanitation

Access to clean water is essential to achieving food security for all, now and in the future (Young et al., 2021). High-quality water is essential for most food production (cereals, livestock, fish and oils), processing, transformation and preparation (Jackson et al., 2015). However, the increasing depletion of freshwater resources is linked to overpopulation, high living standards, dietary changes and the effects of climate change (FAO, 2021a).

The WF was developed as a consumption-based indicator to address policy issues of water security and sustainable water use. The WF represents the total amount of water used (externally or internally) relative to human consumption (Jackson et al., 2015).

### 9.1.2 Goal 12 on Responsible production and consumption and its link to Goal 2 on Zero Hunger

There is a broad consensus that we need to rethink the way we produce and consume. The level of overexploitation of natural resources and waste production is too high for ecosystems to have the capacity to absorb disturbances and remain largely unchanged (Cunha and Custódio, 2021). In the food sector, food loss and waste are estimated at 30-40% of the food supply, which represents an unsustainable use of land, water, soil, and energy (Blakeney, 2019). The fact that food for human consumption is wasted hinders the achievement of SDG 2 (Zero Hunger), which aims to ensure access to safe, healthy and sufficient food for all.

Catalysing a sustainable transformation of food systems is critical to address the foundations for successful, responsible consumption and production. Actions to be implemented include: i) shifting to healthier and more sustainable diets, ii) reducing food loss and waste through a circular economy approach, and iii) preventing overnutrition.

### 9.1.3 Goal 13 on Climate Action

Agricultural and food systems are heavily impacted and contribute significantly to climate change, natural resource degradation, ecosystem stress or biodiversity loss (Braun and Ghosh, 2020). Agriculture and land-use change account for a quarter of global GHG emissions (Laborde et al., 2021), of which up to 80% are associated with livestock production (Springmann et al., 2016).

Nitrous oxide ($NO_2$) emissions from agricultural soils and methane ($CH_4$) released from livestock manure are the two main agricultural GHG emissions with significant global warming potential. Both, together with the other four GHG emissions identified in the Kyoto Protocol, carbon dioxide ($CO_2$), sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), are quantified by characterisation factors in the CF indicator for

agricultural activities and result in the focus of many sustainability policies among companies and authorities (Laurent et al., 2012).

### 9.1.4 Impact of the COVID-19 pandemic on Sustainable Development Goals

Although achieving the full set of SDGs was already elusive for many countries before COVID-19, the pandemic was a setback, putting countries on an even slower path toward implementing the 2030 Agenda (Abidoye et al., 2021). On December 31, 2019, the WHO reported that several cases of pneumonia of unknown aetiology associated with a new coronavirus, later named "COVID-19 virus", had been detected in Wuhan, China (WHO, 2020b). On January 30, 2020, the outbreak of the new coronavirus was declared a public health emergency of international concern, and shortly thereafter, in March 2020, COVID-19 was officially declared a global pandemic due to the rapid increase in cases outside of China, with more than 100,000 cases and 4,000 deaths reported in 114 countries (WHO, 2020b).

To contain the spread of COVID-19, countries around the world imposed various measures. Initially, quarantine and self-isolation helped to mitigate the health crisis. However, support for those who had to isolate was not the same in all countries. The United Kingdom and Finland provided financial support through the welfare system. Sweden provided supported accommodation. Denmark and other non-European countries also provided hotel facilities. Second, some European countries strongly recommended the use of face masks (e.g., Belgium, Poland, Switzerland, Finland). Other countries were initially more cautious, reserving the use of facemasks for health and social care workers (e.g. United Kingdom and France). Third, universal testing was recommended to complete COVID-19. Although this was not a problem for countries with testing capacity, such as Germany, other smaller countries sent samples abroad (e.g., Ireland) (Rajan et al., 2022).

In the case of Spain, the government announced the implementation of the State of Emergency on March 14, 2020 (Gobierno de España, 2020c), which initially required the population to stay indoors, only going out to buy food, medicine or to work in jobs deemed essential. There were also temporary closures of businesses and restrictions on restaurants and takeaways.

Uncertainty about the health effects of the coronavirus and the restrictions associated with the containment measures influenced physical and mental illness, anxiety, anger and depression (Brooks et al., 2020; Fawaz and Samaha, 2020) and dietary behaviours (Fawaz and Samaha, 2020). Not only did food consumption increase during the lockdown period, but access to fresh food was limited, leading to high consumption of processed foods (Eftimov et al., 2020; Navarro-Pérez et al., 2022). The ability to consume a healthy and varied diet was compromised at a time when it was particularly necessary to strengthen our immune systems. In this framework, the WHO issued a series of dietary and nutritional recommendations during self-quarantine to address the problem of overweight and obesity that intensified with the pandemic (WHO, 2019).

Despite the volume of research published to date on health guidelines during lockdowns (WHO, 2020c) and the impact on personal health of changes in dietary patterns (Ammar et al., 2020; A. Brown et al., 2021), few studies have assessed the impact on planetary health. The temporary suspension of industrial activity and reduced demand for public and private transport led to an overall reduction in emissions to the environment (European Commission, 2020d), but how did the temporary change in food consumption patterns affect environmental sustainability? This study provides a unique and valuable insight into the potential impact of the shutdown periods on dietary habits and lifestyles in Spain through the evaluation of environmental impacts. This study not only analyses the changes in food consumption patterns

due to the COVID-19 pandemic, but also demonstrates the link between COVID-19, food consumption patterns, and planetary health. This issue is particularly challenging because it has been largely unaddressed in the literature, despite the fact that food change scenarios have implications for achieving the SDGs (United Nations, 2021).

Therefore, the aim of this chapter is to explore the link between COVID-19 and SDGs 2, 6, 12, and 13. To this end, the impact of the COVID-19 pandemic on food expenditure in Spain and on the environmental pressure associated with food consumption was analysed using CF and WF indicators within the framework of LCA. This assessment was carried out before and during/after COVID-19 (period between 2019 and 2021). While each goal is expected to have been affected by changes brought about by the pandemic, understanding the impact of the COVID-19 pandemic on the SDGs is important for post-pandemic recovery and resilience to future challenges.

## 9.2 MATERIALS AND METHODS

### 9.2.1 Food consumption data

The Household Consumption Survey of the Ministry of Agriculture, Fisheries and Food provided information on the consumption expenditure of household's resident in Spain by Autonomous Community, food category and year. Food consumption away from home was not included in the survey. This represented 14% of total food consumption in 2019, 8% of total food consumption in 2020, and 10% of total food consumption in 2021 (MAPA, 2021).

Based on the database, a set of 36 dietary scenarios was designed to characterise the food consumption of Spaniards every month for 36 months, from January 2019 (pre-COVID-19) to December 2021 (post-COVID recovery). In addition, three annual scenarios were designed, corresponding to total food consumption in 2019 (pre-COVID-19 pandemic), 2020 (during the COVID-19 pandemic) and 2021 (post-COVID-19 pandemic).

In each scenario, the 86 most consumed foods in Spain were included. Individual foods with similar characteristics were then grouped into whole food categories based on the classification of González-García et al. (2020a) (see **Fig. 9.1**).

Due to the lack of reliable data, beverages and spices were excluded from dietary scenarios in agreement with other studies available in the literature (Cambeses-Franco et al., 2021a; Kovacs et al., 2021). The average intake per food category for each scenario for the years 2019, 2020 and 2021 were summarized in **Tables 9.1 - 9.3**. Microsoft Excel was used as a tool to calculate, analyse and visualize the large amount of data used for the study.

Fruits: Oranges, mandarin, apple, pear, melon, watermelon, lemon, peaches, apricot, strawberry, plum, grapes, kiwi, pineapple, mango.

Vegetables: Tomatoes, onions, peppers, lettuce, carrot, courgette, cucumber, cabbage, garlic, mushrooom, asparagus, aubergines, artichokes, leek, green peas.

Pulses: chickpeas, beans, lentils.

Starch-based products: bread, rice, pasta, potatoes.

Nuts: olives, almonds, walnut, peanut, hazelnut, pistachio, chestnut.

Dairy products: milk, yogurt, cheese, butter.

Eggs.

Meat: beef, chicken, pork, rabbit, sheep, turkey, processed meat.

Fish and seafood: Hake, mackerel, salmon, pilchard, cod, tuna, trout, sole, bass, gilt-head bream, turbot, angler, prawns, squids, mussels, clams.

Sweets: honey, sugar, ice cream, chocolate, pastry, biscuits, cereals.

Oils and fats: sunflower oil, olive oil, margarine.

Ready meals: pizza, soups and creams, sauces.

**Fig. 9.1. Most frequently foodstuffs consumed in Spain grouped into comprehensive food categories according with the classification.**

**Table 9.1. Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern in 2019.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Fruits | | | | | | | | | | | |
| Oranges | 71.2 | 66.6 | 73.8 | 66.8 | 64.7 | 47.9 | 33.6 | 23.2 | 22.8 | 29.4 | 47.4 | 54.6 |
| Mandarin | 38.7 | 28.9 | 21.5 | 16.1 | 11.0 | 4.1 | 1.0 | 0.8 | 3.2 | 20.7 | 36.0 | 33.9 |
| Banana | 38.7 | 37.3 | 41.9 | 40.9 | 43.9 | 39.0 | 33.1 | 29.7 | 34.9 | 40.4 | 42.1 | 37.7 |
| Apple | 31.9 | 31.0 | 35.7 | 33.1 | 32.2 | 24.8 | 20.8 | 18.4 | 26.4 | 36.9 | 34.3 | 29.7 |
| Pear | 15.8 | 14.7 | 16.8 | 14.9 | 14.4 | 10.4 | 8.6 | 11.0 | 14.6 | 19.5 | 19.6 | 14.8 |
| Melon | 4.3 | 3.6 | 4.3 | 4.1 | 12.7 | 33.6 | 65.0 | 69.4 | 59.7 | 27.2 | 8.3 | 6.6 |
| Watermelon | 0.2 | 0.2 | 2.0 | 5.5 | 34.3 | 70.2 | 87.1 | 67.7 | 36.4 | 7.4 | 0.8 | 0.3 |
| Lemon | 6.7 | 5.8 | 6.4 | 6.4 | 7.4 | 7.5 | 8.3 | 7.2 | 7.2 | 7.1 | 8.2 | 8.0 |
| Peaches | 0.1 | 0.1 | 0.1 | 0.2 | 4.3 | 16.0 | 25.7 | 25.4 | 25.1 | 16.0 | 2.6 | 0.2 |
| Apricot | 0.1 | 0.2 | 0.1 | 0.2 | 8.8 | 14.5 | 6.9 | 1.8 | 0.6 | 0.2 | 0.1 | 0.1 |
| Strawberry | 5.5 | 15.1 | 26.8 | 29.4 | 19.0 | 4.1 | 1.5 | 1.1 | 1.1 | 1.0 | 0.8 | 1.0 |
| Plum | 0.4 | 0.7 | 1.0 | 1.1 | 0.9 | 3.0 | 9.4 | 12.7 | 10.1 | 7.6 | 2.8 | 1.2 |
| Grapes | 4.2 | 2.6 | 2.5 | 2.1 | 2.1 | 1.4 | 1.8 | 4.5 | 13.8 | 16.3 | 11.6 | 9.3 |
| Kiwi | 9.1 | 8.4 | 9.3 | 8.4 | 8.6 | 7.8 | 6.9 | 6.0 | 6.9 | 9.1 | 10.4 | 9.3 |
| Pineapple | 7.5 | 5.4 | 6.0 | 5.6 | 6.3 | 4.9 | 4.5 | 3.2 | 4.3 | 5.0 | 5.4 | 12.9 |
| Mango | 1.8 | 1.9 | 1.8 | 1.5 | 1.9 | 1.6 | 1.5 | 2.0 | 3.3 | 5.8 | 3.6 | 2.9 |
| | Vegetables | | | | | | | | | | | |
| Tomatoes | 53.1 | 51.4 | 57.4 | 51.0 | 61.9 | 65.6 | 71.8 | 66.5 | 71.2 | 63.5 | 53.7 | 47.6 |
| Onions | 37.0 | 34.3 | 35.7 | 33.0 | 32.0 | 29.3 | 30.4 | 31.5 | 27.5 | 31.3 | 32.7 | 33.0 |
| Peppers | 21.8 | 20.7 | 21.9 | 21.0 | 20.1 | 20.0 | 19.5 | 20.6 | 26.7 | 26.7 | 23.5 | 19.4 |
| Lettuce | 18.0 | 16.9 | 19.5 | 16.9 | 20.6 | 19.2 | 19.1 | 15.5 | 16.2 | 18.6 | 16.6 | 18.3 |
| Carrot | 18.9 | 16.9 | 16.4 | 15.9 | 15.2 | 13.4 | 13.0 | 11.8 | 15.0 | 15.7 | 17.1 | 15.5 |
| Courgette | 18.0 | 19.7 | 20.8 | 18.7 | 19.4 | 16.7 | 16.5 | 15.2 | 17.4 | 19.9 | 17.3 | 16.4 |
| Cucumber | 5.6 | 5.1 | 6.4 | 7.2 | 10.6 | 13.1 | 14.5 | 13.1 | 10.6 | 9.3 | 6.1 | 5.0 |
| Cabbage | 10.7 | 8.9 | 7.6 | 5.6 | 5.2 | 4.4 | 4.3 | 4.1 | 5.2 | 6.8 | 10.7 | 8.5 |
| Garlic | 3.8 | 3.2 | 3.6 | 3.5 | 3.0 | 3.0 | 4.9 | 3.7 | 2.4 | 3.2 | 3.1 | 3.2 |
| Mushroom | 7.8 | 7.1 | 7.7 | 6.7 | 5.6 | 4.9 | 3.5 | 3.6 | 4.6 | 6.3 | 7.2 | 8.1 |
| Asparagus | 1.7 | 2.9 | 6.2 | 7.3 | 7.2 | 3.1 | 1.8 | 1.0 | 1.8 | 1.8 | 2.0 | 1.7 |
| Aubergines | 5.0 | 5.8 | 8.1 | 7.0 | 6.9 | 6.5 | 6.9 | 8.4 | 8.9 | 9.4 | 7.9 | 5.8 |
| Artichokes | 12.9 | 15.7 | 15.9 | 11.1 | 7.8 | 2.6 | 0.9 | 0.4 | 0.6 | 1.4 | 2.9 | 4.8 |
| Leek | 6.3 | 5.7 | 5.5 | 4.9 | 4.0 | 3.7 | 2.8 | 2.9 | 4.4 | 5.0 | 5.8 | 5.0 |
| Green peas | 1.1 | 1.1 | 1.2 | 0.9 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.9 | 0.9 |
| | Pulses | | | | | | | | | | | |
| Chickpeas | 4.9 | 3.9 | 4.4 | 3.9 | 3.7 | 3.2 | 3.2 | 2.9 | 3.7 | 4.6 | 4.5 | 4.0 |
| Beans | 3.1 | 2.8 | 3.0 | 2.7 | 2.2 | 2.4 | 2.0 | 1.8 | 2.6 | 3.3 | 3.2 | 2.4 |
| Lentils | 3.6 | 2.8 | 3.0 | 2.7 | 2.5 | 2.3 | 2.0 | 2.0 | 3.0 | 3.1 | 3.2 | 2.8 |

**Table 9.1. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern in 2019.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Starch-based products | | | | | | | | | | | | |
| Bread | 94.7 | 86.8 | 95.1 | 90.3 | 91.8 | 86.4 | 85.9 | 81.5 | 83.1 | 91.3 | 90.8 | 89.4 |
| Rice | 11.9 | 11.4 | 11.8 | 11.2 | 11.5 | 10.6 | 10.3 | 10.1 | 10.3 | 11.5 | 10.9 | 10.1 |
| Pasta | 13.4 | 11.6 | 12.3 | 11.7 | 11.9 | 11.3 | 10.9 | 10.4 | 11.5 | 12.3 | 13.0 | 12.0 |
| Potatoes | 81.3 | 74.2 | 79.2 | 78.3 | 81.7 | 75.7 | 83.6 | 77.4 | 77.2 | 81.2 | 79.9 | 78.2 |
| Nuts | | | | | | | | | | | | |
| Olives | 9.0 | 8.3 | 9.5 | 10.0 | 10.0 | 9.9 | 10.7 | 10.2 | 9.1 | 9.7 | 10.6 | 10.4 |
| Almonds | 0.8 | 0.8 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 1.5 | 1.1 | 1.1 | 1.9 |
| Walnut | 3.3 | 2.8 | 2.8 | 2.5 | 2.5 | 2.0 | 1.6 | 1.4 | 1.9 | 3.2 | 3.8 | 4.2 |
| Peanut | 1.1 | 1.2 | 1.3 | 1.4 | 1.2 | 1.0 | 1.0 | 0.9 | 1.0 | 1.2 | 1.2 | 1.5 |
| Hazelnut | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.3 | 0.3 | 0.5 |
| Pistachio | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.8 | 0.7 | 1.1 |
| Chestnut | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dairy products | | | | | | | | | | | | |
| Milk | 265.1 | 237.2 | 254.2 | 250.5 | 257.3 | 238.8 | 238.3 | 232.2 | 234.4 | 250.3 | 246.3 | 240.4 |
| Yogurt | 32.6 | 32.2 | 36.4 | 33.9 | 36.4 | 33.5 | 33.0 | 31.9 | 33.4 | 36.5 | 33.0 | 29.4 |
| Cheese | 24.5 | 24.7 | 27.5 | 27.1 | 27.6 | 26.3 | 26.5 | 25.9 | 25.8 | 27.5 | 27.6 | 29.4 |
| Butter | 1.2 | 1.1 | 1.2 | 1.2 | 1.1 | 1.0 | 1.0 | 1.1 | 1.1 | 1.3 | 1.3 | 1.6 |
| Eggs | | | | | | | | | | | | |
| Total | 23.2 | 21.6 | 24.3 | 21.6 | 23.4 | 23.4 | 22.9 | 22.9 | 22.9 | 22.9 | 22.9 | 22.9 |
| Meat | | | | | | | | | | | | |
| Beef | 15.8 | 14.3 | 15.0 | 14.4 | 15.1 | 12.8 | 13.1 | 12.1 | 13.6 | 15.6 | 15.7 | 16.6 |
| Chicken | 40.8 | 36.5 | 40.3 | 37.1 | 37.8 | 35.0 | 33.7 | 33.9 | 35.4 | 37.9 | 39.1 | 36.2 |
| Pork | 32.4 | 28.6 | 30.7 | 28.0 | 27.9 | 27.3 | 25.2 | 24.9 | 26.6 | 29.9 | 30.8 | 33.4 |
| Rabbit | 2.8 | 2.7 | 3.3 | 2.7 | 3.0 | 2.8 | 2.5 | 2.5 | 2.4 | 2.6 | 2.6 | 2.6 |
| Sheep | 5.1 | 3.5 | 3.9 | 4.5 | 3.2 | 3.0 | 2.8 | 3.1 | 3.0 | 2.9 | 3.5 | 9.5 |
| Turkey | 4.9 | 4.4 | 4.8 | 4.6 | 4.7 | 4.5 | 4.4 | 3.7 | 4.3 | 4.7 | 4.4 | 5.4 |
| Processed meat | 33.6 | 32.1 | 35.0 | 33.5 | 34.1 | 31.5 | 30.7 | 29.8 | 32.3 | 37.0 | 37.1 | 42.7 |

**Table 9.1. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern in 2019.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Fish and seafood | | | | | | | | | | | |
| Hake | 16.7 | 15.7 | 16.8 | 15.5 | 15.4 | 15.1 | 14.4 | 12.9 | 13.6 | 14.0 | 13.6 | 14.0 |
| Mackerel | 0.8 | 1.1 | 3.7 | 4.1 | 3.0 | 1.8 | 1.4 | 1.2 | 1.3 | 1.2 | 0.8 | 0.6 |
| Salmon | 6.8 | 6.2 | 6.7 | 5.9 | 8.1 | 7.4 | 6.4 | 6.4 | 8.6 | 9.9 | 8.4 | 6.8 |
| Pilchard | 1.2 | 1.2 | 1.4 | 1.4 | 1.5 | 1.8 | 1.7 | 1.3 | 1.4 | 1.4 | 1.2 | 1.0 |
| Cod | 4.9 | 6.8 | 8.1 | 8.4 | 5.2 | 4.5 | 4.2 | 3.8 | 4.0 | 4.5 | 4.3 | 3.8 |
| Tuna | 1.8 | 1.9 | 1.8 | 2.1 | 2.4 | 3.8 | 6.6 | 5.5 | 3.7 | 2.5 | 1.7 | 1.2 |
| Trout | 1.6 | 1.5 | 1.6 | 1.4 | 1.8 | 1.6 | 1.5 | 1.2 | 1.1 | 1.4 | 1.4 | 1.0 |
| Sole | 3.6 | 3.4 | 4.2 | 4.6 | 4.6 | 4.3 | 4.1 | 3.2 | 4.0 | 3.7 | 3.3 | 2.6 |
| Bass | 3.9 | 3.5 | 3.6 | 3.4 | 3.8 | 3.7 | 3.4 | 2.8 | 3.2 | 3.2 | 3.9 | 3.4 |
| Gilt-head bream | 3.8 | 3.2 | 3.9 | 3.8 | 3.9 | 3.7 | 3.6 | 3.8 | 3.6 | 4.2 | 4.2 | 4.1 |
| Turbot | 0.7 | 0.6 | 0.4 | 0.6 | 0.8 | 0.5 | 0.3 | 0.4 | 0.4 | 0.6 | 0.5 | 1.0 |
| Angler | 2.4 | 1.6 | 1.5 | 1.7 | 1.7 | 1.9 | 1.7 | 1.6 | 1.2 | 1.5 | 1.5 | 2.9 |
| Prawns | 7.5 | 5.7 | 7.5 | 8.0 | 7.7 | 8.4 | 8.6 | 9.5 | 7.6 | 7.8 | 13.7 | 30.7 |
| Squids | 7.8 | 6.9 | 7.6 | 7.9 | 8.1 | 7.5 | 8.1 | 7.1 | 7.4 | 8.2 | 8.0 | 8.1 |
| Mussels | 6.1 | 5.8 | 5.6 | 4.7 | 3.6 | 5.0 | 6.0 | 6.2 | 6.0 | 6.6 | 6.7 | 8.7 |
| Clams | 2.5 | 2.3 | 2.5 | 2.6 | 2.1 | 2.6 | 2.4 | 2.5 | 2.6 | 2.7 | 2.9 | 5.2 |
| | Sweets | | | | | | | | | | | |
| Honey | 1.9 | 1.3 | 1.3 | 1.4 | 1.3 | 0.9 | 1.1 | 1.2 | 1.1 | 1.4 | 1.4 | 1.9 |
| Sugar | 10.8 | 9.7 | 11.5 | 11.5 | 10.2 | 8.9 | 7.9 | 8.8 | 9.5 | 11.5 | 11.2 | 13.4 |
| Ice cream | 4.0 | 3.5 | 5.0 | 7.1 | 13.6 | 21.4 | 27.2 | 23.5 | 12.0 | 7.1 | 4.1 | 6.2 |
| Chocolate | 12.6 | 11.5 | 12.3 | 11.6 | 10.6 | 9.0 | 8.0 | 7.9 | 8.9 | 12.1 | 16.2 | 22.2 |
| Pastry | 20.1 | 19.5 | 21.2 | 20.5 | 19.7 | 17.0 | 15.7 | 16.2 | 17.0 | 20.5 | 22.1 | 24.3 |
| Biscuits | 18.8 | 18.4 | 19.8 | 18.5 | 17.9 | 15.9 | 14.8 | 14.0 | 16.7 | 18.5 | 18.6 | 19.3 |
| Cereals | 5.6 | 5.2 | 5.8 | 5.4 | 5.5 | 4.8 | 4.7 | 4.3 | 5.1 | 5.6 | 5.5 | 5.5 |
| | Oils and fats | | | | | | | | | | | |
| Sunflower oil | 9.7 | 9.1 | 10.1 | 10.0 | 10.0 | 9.0 | 8.9 | 8.6 | 8.8 | 9.5 | 9.9 | 10.1 |
| Olive oil | 19.8 | 17.3 | 19.6 | 20.6 | 20.6 | 19.9 | 19.5 | 19.1 | 20.5 | 21.8 | 21.0 | 21.5 |
| Margarine | 1.8 | 1.9 | 1.8 | 1.8 | 1.7 | 1.5 | 1.4 | 1.5 | 1.5 | 1.7 | 1.7 | 1.8 |
| | Ready meals | | | | | | | | | | | |
| Pizza | 10.5 | 9.6 | 10.6 | 10.2 | 10.0 | 8.8 | 8.5 | 8.8 | 9.2 | 10.3 | 9.6 | 9.8 |
| Soups and creams | 25.9 | 19.9 | 19.9 | 19.7 | 20.5 | 21.8 | 23.5 | 21.2 | 20.5 | 23.6 | 24.0 | 23.6 |
| Sauces | 10.0 | 9.2 | 10.7 | 10.2 | 11.0 | 10.7 | 10.7 | 10.6 | 10.0 | 10.6 | 9.9 | 12.0 |

**Table 9.2. Daily intake (g·person$^{-1}$·day$^{-1}$) per food item for the Spanish Dietary Pattern in 2020.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Fruits | | | | | | | | | | | |
| Oranges | 66.1 | 66.2 | 81.6 | 95.6 | 74.1 | 42.4 | 27.6 | 18.7 | 20.9 | 32.3 | 50.4 | 64.0 |
| Mandarin | 35.2 | 29.3 | 25.8 | 21.5 | 6.3 | 0.9 | 0.6 | 1.2 | 4.8 | 27.0 | 41.0 | 42.2 |
| Banana | 40.4 | 42.5 | 47.6 | 55.8 | 52.2 | 42.6 | 35.6 | 29.5 | 35.8 | 45.4 | 45.9 | 42.7 |
| Apple | 34.2 | 33.6 | 40.0 | 46.0 | 41.2 | 29.7 | 21.5 | 20.6 | 29.2 | 42.4 | 36.0 | 30.8 |
| Pear | 15.7 | 15.9 | 18.7 | 21.6 | 17.3 | 11.6 | 9.0 | 10.9 | 16.3 | 21.5 | 19.9 | 16.7 |
| Melon | 5.0 | 5.0 | 4.5 | 7.3 | 16.8 | 38.3 | 62.8 | 66.3 | 62.2 | 32.7 | 10.8 | 6.9 |
| Watermelon | 0.0 | 0.4 | 1.5 | 6.1 | 40.2 | 79.5 | 101.8 | 81.2 | 41.6 | 7.7 | 0.5 | 0.4 |
| Lemon | 6.9 | 6.2 | 8.1 | 11.3 | 10.1 | 9.7 | 8.3 | 7.6 | 7.5 | 9.2 | 8.2 | 9.1 |
| Peaches | 0.2 | 0.1 | 0.1 | 0.9 | 6.4 | 19.3 | 28.7 | 26.0 | 20.5 | 10.8 | 1.5 | 0.3 |
| Apricot | 0.1 | 0.1 | 0.1 | 0.6 | 12.2 | 11.7 | 5.3 | 1.3 | 0.2 | 0.1 | 0.1 | 0.2 |
| Strawberry | 6.1 | 16.4 | 22.9 | 27.4 | 20.1 | 4.3 | 1.6 | 1.1 | 1.1 | 1.0 | 0.8 | 1.9 |
| Plum | 0.8 | 0.9 | 1.0 | 1.3 | 1.2 | 4.9 | 8.9 | 9.7 | 10.2 | 5.9 | 1.8 | 0.4 |
| Grapes | 4.8 | 2.4 | 2.4 | 2.9 | 2.8 | 1.7 | 3.0 | 6.4 | 17.0 | 20.8 | 13.3 | 12.2 |
| Kiwi | 9.7 | 10.3 | 10.2 | 11.8 | 10.4 | 8.3 | 7.9 | 6.5 | 7.1 | 10.3 | 10.2 | 11.1 |
| Pineapple | 5.9 | 4.5 | 5.6 | 7.7 | 7.2 | 6.6 | 4.8 | 3.6 | 4.3 | 5.5 | 6.9 | 13.9 |
| Mango | 2.1 | 2.4 | 2.3 | 2.3 | 2.4 | 2.0 | 2.6 | 2.6 | 3.7 | 5.8 | 3.6 | 3.2 |
| | Vegetables | | | | | | | | | | | |
| Tomatoes | 53.3 | 55.8 | 62.6 | 73.2 | 76.9 | 71.7 | 75.5 | 65.7 | 70.7 | 62.5 | 61.0 | 54.8 |
| Onions | 33.9 | 34.6 | 43.1 | 46.5 | 40.4 | 32.7 | 28.8 | 27.0 | 32.3 | 38.7 | 37.0 | 40.7 |
| Peppers | 22.5 | 21.2 | 26.0 | 30.1 | 26.5 | 24.1 | 23.4 | 23.5 | 30.1 | 31.7 | 24.5 | 23.5 |
| Lettuce | 18.8 | 19.2 | 22.6 | 24.8 | 24.4 | 20.2 | 17.5 | 16.1 | 17.3 | 19.1 | 19.5 | 19.5 |
| Carrot | 19.5 | 17.8 | 21.6 | 24.7 | 21.4 | 16.3 | 13.9 | 12.6 | 15.7 | 18.4 | 18.0 | 18.5 |
| Courgette | 18.8 | 21.2 | 24.4 | 27.5 | 25.3 | 19.6 | 17.3 | 15.1 | 18.3 | 19.8 | 21.2 | 18.6 |
| Cucumber | 5.7 | 6.4 | 7.1 | 10.2 | 12.4 | 13.8 | 15.5 | 13.3 | 11.5 | 9.5 | 8.0 | 5.9 |
| Cabbage | 10.6 | 9.7 | 10.1 | 10.8 | 7.0 | 5.0 | 3.4 | 3.5 | 6.0 | 9.6 | 10.3 | 10.6 |
| Garlic | 3.4 | 3.4 | 4.2 | 4.5 | 4.1 | 3.3 | 2.8 | 2.5 | 3.1 | 3.2 | 3.5 | 3.9 |
| Mushroom | 7.2 | 7.5 | 7.3 | 8.7 | 7.6 | 5.7 | 4.5 | 4.3 | 5.4 | 7.7 | 9.3 | 8.3 |
| Asparagus | 2.0 | 2.6 | 5.2 | 5.8 | 6.5 | 2.8 | 1.1 | 1.0 | 1.3 | 2.0 | 1.5 | 2.1 |
| Aubergines | 6.4 | 7.1 | 8.2 | 11.4 | 9.9 | 8.8 | 8.9 | 8.0 | 10.2 | 10.3 | 10.1 | 6.7 |
| Artichokes | 10.4 | 16.3 | 13.7 | 13.2 | 9.4 | 1.9 | 0.6 | 0.2 | 0.3 | 1.0 | 3.8 | 7.4 |
| Leek | 6.8 | 5.6 | 6.6 | 7.0 | 5.5 | 3.6 | 2.7 | 2.8 | 4.1 | 5.9 | 6.2 | 5.8 |
| Green peas | 1.2 | 1.2 | 1.5 | 1.5 | 1.4 | 1.1 | 0.9 | 0.9 | 0.8 | 1.2 | 1.0 | 1.1 |
| | Pulses | | | | | | | | | | | |
| Chickpeas | 4.7 | 4.3 | 6.8 | 5.7 | 4.3 | 3.7 | 3.2 | 3.2 | 3.9 | 5.2 | 5.0 | 3.9 |
| Beans | 3.2 | 2.9 | 4.7 | 3.7 | 3.0 | 2.7 | 2.2 | 2.1 | 2.9 | 3.8 | 3.3 | 2.6 |
| Lentils | 3.6 | 3.2 | 5.3 | 3.5 | 3.2 | 2.8 | 2.4 | 2.2 | 3.2 | 3.8 | 3.5 | 2.8 |

**Table 9.2. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food item for the Spanish Dietary Pattern in 2020.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **Starch-based products** | | | | | | | | | | | | |
| Bread | 93.2 | 91.2 | 103.0 | 13.1 | 103.6 | 90.5 | 84.0 | 79.0 | 85.0 | 95.9 | 91.8 | 95.7 |
| Rice | 12.2 | 11.6 | 17.9 | 13.3 | 12.4 | 11.4 | 11.1 | 10.1 | 10.7 | 13.1 | 11.4 | 11.3 |
| Pasta | 13.4 | 12.6 | 18.5 | 114.2 | 13.1 | 11.8 | 11.7 | 10.8 | 11.3 | 13.8 | 12.5 | 12.8 |
| Potatoes | 75.7 | 79.7 | 107.0 | 13.1 | 102.9 | 88.3 | 90.9 | 77.7 | 84.9 | 98.1 | 90.9 | 93.3 |
| **Nuts** | | | | | | | | | | | | |
| Olives | 8.7 | 9.0 | 11.5 | 15.1 | 14.4 | 12.7 | 12.3 | 10.4 | 9.8 | 11.5 | 12.1 | 13.6 |
| Almonds | 0.9 | 0.8 | 0.9 | 1.6 | 0.9 | 0.8 | 0.6 | 0.5 | 1.7 | 2.6 | 1.1 | 1.5 |
| Walnut | 2.7 | 2.8 | 3.0 | 3.4 | 3.0 | 2.3 | 1.9 | 1.5 | 1.7 | 3.7 | 3.9 | 4.7 |
| Peanut | 1.2 | 1.3 | 1.7 | 2.1 | 1.9 | 1.4 | 1.1 | 1.0 | 1.2 | 1.6 | 1.6 | 1.7 |
| Hazelnut | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.5 | 0.5 |
| Pistachio | 0.8 | 0.8 | 1.0 | 1.3 | 1.1 | 0.8 | 0.6 | 0.6 | 0.6 | 0.9 | 1.1 | 1.3 |
| Chestnut | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Dairy products** | | | | | | | | | | | | |
| Milk | 251.3 | 238.9 | 297.7 | 296.8 | 279.5 | 255.7 | 250.8 | 226.1 | 243.3 | 267.3 | 252.0 | 262.6 |
| Yogurt | 34.1 | 33.9 | 36.8 | 41.9 | 40.4 | 35.2 | 33.2 | 30.2 | 33.3 | 37.2 | 33.3 | 31.1 |
| Cheese | 25.7 | 26.7 | 30.7 | 35.9 | 34.5 | 30.2 | 28.4 | 26.5 | 27.6 | 32.3 | 29.2 | 31.0 |
| Butter | 1.2 | 1.5 | 1.8 | 2.3 | 1.8 | 1.3 | 1.3 | 1.2 | 1.3 | 1.6 | 1.4 | 1.9 |
| **Eggs** | | | | | | | | | | | | |
| Eggs | 24.2 | 23.5 | 29.5 | 23.5 | 31.2 | 31.2 | 25.5 | 25.5 | 25.5 | 25.5 | 25.5 | 25.5 |
| **Meat** | | | | | | | | | | | | |
| Beef | 15.7 | 14.8 | 18.2 | 18.4 | 17.5 | 14.6 | 13.8 | 11.9 | 14.3 | 18.3 | 16.3 | 18.7 |
| Chicken | 38.6 | 36.6 | 47.2 | 50.3 | 46.1 | 41.2 | 36.5 | 33.2 | 37.5 | 42.6 | 40.5 | 40.4 |
| Pork | 32.1 | 31.1 | 36.5 | 39.4 | 35.4 | 31.6 | 28.8 | 26.1 | 28.6 | 34.9 | 32.3 | 36.2 |
| Rabbit | 2.8 | 2.6 | 3.3 | 3.1 | 3.1 | 2.8 | 2.8 | 2.3 | 2.8 | 2.9 | 2.7 | 2.3 |
| Sheep | 3.9 | 3.6 | 3.7 | 4.7 | 4.4 | 3.8 | 3.3 | 3.3 | 2.9 | 3.6 | 3.7 | 10.7 |
| Turkey | 4.7 | 4.8 | 5.0 | 5.2 | 4.8 | 4.2 | 4.4 | 3.5 | 4.2 | 5.0 | 4.4 | 5.0 |
| Processed meat | 33.7 | 32.9 | 40.4 | 41.5 | 38.5 | 35.7 | 32.4 | 30.8 | 34.6 | 41.4 | 38.3 | 45.3 |

**Table 9.2. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food item for the Spanish Dietary Pattern in 2020.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Fish and seafood | | | | | | | | | | | | |
| Hake | 14.6 | 15.5 | 17.6 | 18.0 | 18.2 | 15.1 | 14.1 | 11.2 | 13.8 | 15.4 | 14.7 | 13.0 |
| Mackerel | 0.6 | 1.2 | 4.7 | 5.1 | 3.0 | 1.3 | 1.0 | 1.0 | 1.1 | 1.2 | 1.1 | 0.5 |
| Salmon | 6.6 | 7.2 | 8.5 | 10.2 | 10.4 | 8.8 | 8.8 | 9.0 | 10.6 | 12.1 | 10.6 | 10.0 |
| Pilchard | 1.3 | 1.4 | 2.3 | 1.6 | 1.8 | 1.7 | 1.6 | 1.3 | 1.3 | 1.5 | 1.1 | 1.0 |
| Cod | 4.3 | 7.0 | 8.9 | 9.1 | 6.6 | 5.4 | 5.0 | 4.5 | 4.7 | 5.0 | 4.7 | 5.2 |
| Tuna | 1.4 | 1.5 | 2.0 | 2.5 | 3.5 | 3.9 | 6.9 | 5.3 | 3.2 | 2.3 | 2.3 | 1.2 |
| Trout | 1.5 | 1.4 | 1.6 | 2.0 | 1.8 | 1.7 | 1.2 | 1.2 | 1.4 | 1.3 | 1.4 | 1.2 |
| Sole | 3.3 | 4.0 | 3.8 | 3.7 | 4.7 | 4.5 | 4.6 | 3.4 | 4.3 | 3.7 | 3.2 | 1.9 |
| Bass | 4.4 | 4.1 | 4.6 | 4.5 | 5.1 | 4.8 | 3.3 | 3.2 | 4.1 | 4.7 | 4.5 | 4.5 |
| Gilt-head bream | 3.9 | 3.9 | 4.7 | 5.5 | 5.5 | 4.6 | 4.2 | 3.5 | 4.1 | 5.8 | 4.6 | 5.1 |
| Turbot | 0.7 | 0.4 | 0.5 | 1.1 | 1.2 | 0.9 | 0.8 | 0.8 | 0.7 | 0.9 | 0.8 | 1.7 |
| Angler | 1.6 | 1.5 | 2.0 | 2.0 | 2.3 | 2.1 | 1.8 | 1.4 | 1.8 | 1.7 | 2.3 | 3.9 |
| Prawns | 8.1 | 6.2 | 7.2 | 9.8 | 10.0 | 10.3 | 9.4 | 9.0 | 8.4 | 9.8 | 12.3 | 33.3 |
| Squids | 7.5 | 6.5 | 8.2 | 8.7 | 9.4 | 9.2 | 8.0 | 7.2 | 8.2 | 9.0 | 9.1 | 11.3 |
| Mussels | 5.8 | 5.1 | 3.7 | 4.9 | 5.0 | 4.9 | 7.2 | 6.8 | 6.4 | 6.2 | 7.0 | 9.6 |
| Clams | 2.8 | 2.5 | 2.3 | 3.0 | 3.1 | 2.8 | 2.7 | 2.6 | 2.6 | 3.4 | 2.8 | 5.6 |
| Sweets | | | | | | | | | | | | |
| Honey | 1.4 | 1.4 | 1.6 | 1.9 | 1.5 | 1.2 | 1.0 | 0.7 | 1.3 | 1.8 | 1.5 | 1.6 |
| Sugar | 10.4 | 10.0 | 15.6 | 17.7 | 13.2 | 11.0 | 8.9 | 8.4 | 10.0 | 13.2 | 12.9 | 14.3 |
| Ice cream | 3.1 | 3.7 | 5.0 | 8.9 | 18.0 | 21.4 | 27.6 | 24.8 | 14.4 | 7.8 | 5.1 | 6.6 |
| Chocolate | 12.6 | 11.4 | 14.4 | 17.3 | 13.8 | 10.3 | 8.8 | 8.2 | 9.7 | 14.0 | 17.0 | 25.4 |
| Pastry | 20.4 | 20.4 | 21.7 | 24.5 | 21.0 | 18.1 | 16.2 | 15.5 | 17.6 | 23.0 | 23.8 | 27.2 |
| Biscuits | 18.6 | 18.5 | 22.1 | 22.5 | 19.9 | 16.7 | 14.5 | 13.8 | 16.7 | 19.5 | 19.4 | 19.4 |
| Cereals | 5.6 | 5.4 | 7.0 | 6.9 | 6.4 | 5.6 | 4.9 | 4.4 | 5.4 | 6.2 | 6.0 | 5.9 |
| Oils and fats | | | | | | | | | | | | |
| Sunflower oil | 9.1 | 9,1 | 13.1 | 14.0 | 12.1 | 9.6 | 8.6 | 9.0 | 9.7 | 11.1 | 9.6 | 10.4 |
| Olive oil | 21.1 | 21.1 | 25.6 | 24.0 | 25.7 | 24.8 | 21.5 | 20.7 | 22.0 | 27.2 | 22.8 | 22.4 |
| Margarine | 1.6 | 1.7 | 2.3 | 2.7 | 2.1 | 1.7 | 1.5 | 1.5 | 1.6 | 1.9 | 1.8 | 1.9 |
| Ready meals | | | | | | | | | | | | |
| Pizza | 10.8 | 10.7 | 12.4 | 12.2 | 10.8 | 9.5 | 9.0 | 8.2 | 8.7 | 11.0 | 10.6 | 10.8 |
| Soups and creams | 27.5 | 23.1 | 26.8 | 23.1 | 22.0 | 23.9 | 24.5 | 20.7 | 22.6 | 27.3 | 25.4 | 25.7 |
| Sauces | 10.3 | 10.4 | 12.7 | 14.0 | 13.5 | 12.5 | 11.6 | 10.8 | 11.1 | 12.5 | 11.5 | 13.5 |

**Table 9.3. Daily intake (g·person$^{-1}$·day$^{-1}$) per food item for the Spanish Dietary Pattern in 2021.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Fruits | | | | | | | | | | | |
| Oranges | 68.2 | 68.9 | 71.2 | 65.4 | 60.9 | 35.8 | 26.2 | 19.7 | 19.8 | 27.6 | 44.7 | 53.5 |
| Mandarin | 38.7 | 32.2 | 25.8 | 17.0 | 5.9 | 0.8 | 0.7 | 0.8 | 4.9 | 21.9 | 34.9 | 34.2 |
| Banana | 43.6 | 44.8 | 47.6 | 46.1 | 48.8 | 42.9 | 35.7 | 31.6 | 38.1 | 45.4 | 43.8 | 40.2 |
| Apple | 33.6 | 34.1 | 34.8 | 32.3 | 30.8 | 23.7 | 18.4 | 17.1 | 23.6 | 34.6 | 32.0 | 29.6 |
| Pear | 16.4 | 17.5 | 18.5 | 17.8 | 16.3 | 11.2 | 9.8 | 11.3 | 13.2 | 17.4 | 15.9 | 13.0 |
| Melon | 4.6 | 4.5 | 5.2 | 6.3 | 13.9 | 40.2 | 61.3 | 64.3 | 56.8 | 30.4 | 7.2 | 6.8 |
| Watermelon | 0.2 | 0.2 | 1.3 | 6.7 | 34.9 | 75.0 | 87.2 | 73.9 | 47.7 | 9.1 | 0.5 | 0.1 |
| Lemon | 7.1 | 7.6 | 7.2 | 7.0 | 7.6 | 7.8 | 7.7 | 7.8 | 6.2 | 6.5 | 6.7 | 7.7 |
| Peaches | 0.3 | 0.3 | 0.3 | 0.4 | 4.4 | 14.5 | 23.1 | 23.0 | 19.3 | 9.3 | 1.6 | 0.2 |
| Apricot | 0.1 | 0.1 | 0.2 | 0.5 | 7.7 | 10.1 | 5.4 | 1.2 | 0.4 | 0.2 | 0.1 | 0.1 |
| Strawberry | 4.6 | 11.0 | 21.5 | 27.8 | 16.6 | 5.3 | 2.3 | 1.6 | 1.3 | 1.2 | 0.5 | 0.9 |
| Plum | 0.2 | 0.6 | 1.0 | 1.5 | 1.6 | 4.7 | 10.0 | 11.4 | 9.5 | 6.0 | 1.6 | 0.4 |
| Grapes | 4.6 | 3.5 | 4.1 | 3.5 | 3.0 | 1.9 | 2.7 | 6.3 | 14.8 | 18.5 | 12.0 | 11.4 |
| Kiwi | 10.6 | 10.1 | 10.3 | 9.2 | 8.9 | 7.6 | 7.5 | 6.6 | 7.7 | 10.4 | 10.0 | 12.1 |
| Pineapple | 6.1 | 6.6 | 7.1 | 6.7 | 6.4 | 5.7 | 4.8 | 3.8 | 4.6 | 5.3 | 5.5 | 12.3 |
| Mango | 2.8 | 2.7 | 2.8 | 2.4 | 3.2 | 3.0 | 2.2 | 2.9 | 3.9 | 6.5 | 4.7 | 3.5 |
| | Vegetables | | | | | | | | | | | |
| Tomatoes | 56.5 | 57.4 | 57.1 | 55.7 | 62.7 | 63.1 | 69.0 | 63.9 | 66.1 | 60.1 | 52.3 | 49.1 |
| Onions | 40.6 | 38.2 | 37.6 | 36.3 | 32.4 | 29.1 | 27.8 | 27.6 | 30.8 | 31.1 | 32.7 | 32.7 |
| Peppers | 25.1 | 26.9 | 23.6 | 22.0 | 22.8 | 21.2 | 22.0 | 21.0 | 25.5 | 27.0 | 22.9 | 20.1 |
| Lettuce | 19.9 | 19.9 | 20.3 | 20.4 | 20.3 | 18.9 | 17.5 | 15.8 | 16.6 | 19.9 | 17.7 | 18.1 |
| Carrot | 21.2 | 18.0 | 19.3 | 17.4 | 16.3 | 13.2 | 13.0 | 12.2 | 15.0 | 16.8 | 17.6 | 16.4 |
| Courgette | 19.6 | 22.2 | 22.6 | 22.7 | 20.4 | 16.6 | 16.0 | 15.0 | 18.5 | 20.4 | 17.5 | 13.7 |
| Cucumber | 6.4 | 6.3 | 7.4 | 9.4 | 12.0 | 14.5 | 15.1 | 13.7 | 10.8 | 9.7 | 6.7 | 5.6 |
| Cabbage | 12.1 | 10.0 | 8.3 | 6.4 | 5.2 | 3.5 | 4.1 | 2.9 | 4.6 | 7.0 | 8.2 | 9.1 |
| Garlic | 4.1 | 3.8 | 3.6 | 3.6 | 3.1 | 2.9 | 2.9 | 2.9 | 2.5 | 3.0 | 3.4 | 3.4 |
| Mushroom | 8.2 | 8.2 | 7.2 | 7.3 | 6.3 | 5.0 | 4.2 | 3.5 | 5.0 | 7.4 | 7.0 | 7.0 |
| Asparagus | 1.5 | 3.1 | 4.4 | 6.0 | 6.1 | 3.3 | 1.1 | 0.9 | 1.1 | 1.7 | 1.7 | 1.4 |
| Aubergines | 5.9 | 8.0 | 8.0 | 9.0 | 8.1 | 7.4 | 8.0 | 8.7 | 7.9 | 8.6 | 8.2 | 4.9 |
| Artichokes | 9.7 | 14.3 | 11.4 | 13.0 | 8.2 | 2.2 | 0.5 | 0.3 | 0.3 | 0.9 | 2.9 | 6.0 |
| Leek | 6.8 | 5.7 | 5.0 | 4.8 | 4.4 | 3.2 | 3.0 | 2.8 | 4.2 | 4.7 | 5.7 | 5.4 |
| Green peas | 1.1 | 1.1 | 1.2 | 1.0 | 1.0 | 1.0 | 0.8 | 0.8 | 1.0 | 1.1 | 1.1 | 1.1 |
| | Pulses | | | | | | | | | | | |
| Chickpeas | 5.6 | 4.4 | 4.8 | 4.2 | 4.0 | 3.3 | 3.3 | 2.6 | 3.9 | 4.7 | 5.2 | 3.9 |
| Beans | 3.7 | 3.0 | 3.1 | 2.6 | 2.4 | 2.2 | 2.0 | 1.9 | 2.7 | 3.3 | 3.3 | 2.9 |
| Lentils | 4.1 | 3.1 | 3.0 | 3.0 | 2.8 | 2.2 | 2.2 | 1.8 | 2.7 | 3.2 | 3.6 | 2.8 |

**Table 9.3. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern in 2021.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Starch-based products | | | | | | | | | | | | |
| Bread | 91.4 | 86.0 | 95.1 | 91.7 | 87.0 | 81.6 | 81.8 | 77.8 | 80.6 | 85.8 | 86.3 | 88.1 |
| Rice | 13.6 | 11.5 | 12.1 | 11.8 | 12.0 | 10.4 | 11.0 | 10.2 | 10.8 | 11.9 | 11.5 | 11.2 |
| Pasta | 14.8 | 12.2 | 12.9 | 12.1 | 11.8 | 11.2 | 11.3 | 10.0 | 11.2 | 12.1 | 12.9 | 12.3 |
| Potatoes | 91.9 | 86.1 | 89.1 | 89.1 | 86.0 | 79.3 | 84.5 | 74.9 | 78.6 | 82.5 | 78.3 | 83.8 |
| Nuts | | | | | | | | | | | | |
| Olives | 11.4 | 10.2 | 10.9 | 10.9 | 10.8 | 10.9 | 12.1 | 10.3 | 9.4 | 10.3 | 11.7 | 12.1 |
| Almonds | 0.9 | 0.9 | 1.0 | 1.0 | 0.9 | 0.7 | 0.7 | 0.7 | 1.9 | 1.2 | 1.0 | 1.3 |
| Walnut | 2.9 | 3.2 | 2.9 | 2.9 | 2.7 | 2.2 | 1.8 | 1.4 | 2.2 | 3.6 | 3.3 | 3.6 |
| Peanut | 1.5 | 1.4 | 1.8 | 1.8 | 1.6 | 1.3 | 1.2 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 |
| Hazelnut | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 1.0 | 0.3 | 0.4 |
| Pistachio | 1.0 | 0.9 | 1.0 | 0.9 | 0.8 | 0.7 | 0.8 | 0.6 | 0.7 | 0.9 | 0.9 | 1.2 |
| Total | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dairy products | | | | | | | | | | | | |
| Milk | 274.7 | 247.2 | 262.1 | 261.4 | 248.3 | 239.0 | 242.9 | 222.5 | 236.9 | 246.5 | 245.2 | 254.4 |
| Yogurt | 34.0 | 34.0 | 36.1 | 35.1 | 35.0 | 32.7 | 31.7 | 29.6 | 32.5 | 33.7 | 30.9 | 28.3 |
| Cheese | 26.3 | 26.4 | 28.4 | 27.9 | 28.1 | 26.2 | 26.9 | 24.6 | 25.8 | 26.7 | 25.5 | 28.0 |
| Butter | 1.6 | 1.5 | 1.6 | 1.4 | 1.3 | 1.2 | 1.2 | 1.1 | 1.2 | 1.3 | 1.3 | 1.7 |
| Eggs | | | | | | | | | | | | |
| Total | 26.8 | 25.7 | 27.2 | 25.7 | 23.8 | 23.8 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 |
| Meat | | | | | | | | | | | | |
| Beef | 16.9 | 15.7 | 16.3 | 15.6 | 13.7 | 12.1 | 12.1 | 10.8 | 12.8 | 13.9 | 14.4 | 16.7 |
| Chicken | 45.4 | 37.6 | 38.6 | 37.8 | 36.4 | 33.3 | 33.9 | 31.5 | 34.4 | 36.2 | 35.0 | 34.2 |
| Pork | 35.5 | 30.8 | 30.7 | 29.3 | 27.3 | 25.3 | 25.2 | 23.7 | 26.9 | 29.7 | 30.3 | 32.7 |
| Rabbit | 2.7 | 2.3 | 2.6 | 2.9 | 2.4 | 2.4 | 2.5 | 2.2 | 2.0 | 2.4 | 2.3 | 2.2 |
| Sheep | 4.0 | 3.4 | 3.4 | 3.4 | 2.9 | 3.0 | 2.9 | 2.4 | 2.2 | 2.4 | 3.1 | 7.2 |
| Turkey | 4.6 | 4.4 | 4.5 | 4.7 | 4.2 | 4.1 | 4.2 | 3.3 | 4.0 | 4.6 | 4.2 | 5.3 |
| Processed meat | 36.5 | 34.0 | 35.2 | 35.2 | 33.8 | 31.7 | 32.6 | 29.4 | 32.3 | 36.4 | 37.0 | 42.8 |

**Table 9.3. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern in 2021.**

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Fish and seafood | | | | | | | | | | | |
| Hake | 13.5 | 14.3 | 15.2 | 13.5 | 14.3 | 12.3 | 12.0 | 11.5 | 12.2 | 13.2 | 13.8 | 12.4 |
| Mackerel | 0.6 | 0.6 | 2.9 | 4.4 | 2.4 | 1.2 | 1.0 | 1.0 | 0.9 | 1.0 | 0.5 | 0.3 |
| Salmon | 10.3 | 11.6 | 10.4 | 8.2 | 8.1 | 9.1 | 7.9 | 8.4 | 10.4 | 10.6 | 9.4 | 9.2 |
| Pilchard | 1.3 | 1.1 | 1.3 | 1.3 | 1.4 | 1.5 | 1.4 | 1.2 | 1.3 | 1.4 | 1.5 | 1.0 |
| Cod | 5.9 | 8.4 | 11.0 | 9.3 | 7.1 | 6.9 | 7.4 | 5.6 | 6.9 | 6.1 | 5.3 | 5.6 |
| Tuna | 1.3 | 1.8 | 2.1 | 1.9 | 2.8 | 3.0 | 6.1 | 4.8 | 2.4 | 2.0 | 1.6 | 1.2 |
| Trout | 1.5 | 1.1 | 1.4 | 1.5 | 1.5 | 1.5 | 1.4 | 1.0 | 1.1 | 1.2 | 1.1 | 0.9 |
| Sole | 1.4 | 1.4 | 1.8 | 1.4 | 1.6 | 1.4 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 1.0 |
| Bass | 4.0 | 4.1 | 4.1 | 4.4 | 4.1 | 4.1 | 3.6 | 3.1 | 3.6 | 3.8 | 3.7 | 3.8 |
| Gilt-head bream | 4.9 | 4.3 | 4.4 | 4.6 | 5.2 | 4.6 | 4.2 | 4.4 | 4.5 | 4.7 | 4.7 | 4.9 |
| Turbot | 1.0 | 0.5 | 0.7 | 0.9 | 0.4 | 0.8 | 0.5 | 0.4 | 0.5 | 0.3 | 0.6 | 1.0 |
| Angler | 2.0 | 2.0 | 1.9 | 1.7 | 2.1 | 1.7 | 1.3 | 1.1 | 1.5 | 1.4 | 1.6 | 3.5 |
| Prawns | 9.2 | 7.8 | 9.3 | 9.4 | 8.9 | 9.3 | 9.9 | 9.0 | 7.9 | 9.2 | 14.4 | 29.8 |
| Squids | 7.9 | 7.5 | 8.2 | 8.4 | 7.6 | 7.4 | 8.0 | 6.6 | 6.9 | 7.9 | 7.1 | 8.5 |
| Mussels | 6.1 | 6.1 | 5.4 | 3.6 | 3.4 | 4.1 | 6.3 | 5.5 | 5.0 | 5.7 | 5.6 | 8.5 |
| Clams | 3.0 | 2.5 | 2.8 | 2.9 | 2.4 | 2.4 | 2.7 | 2.4 | 2.4 | 2.9 | 2.7 | 4.9 |
| | Sweets | | | | | | | | | | | |
| Honey | 1.3 | 1.4 | 1.4 | 1.0 | 1.2 | 1.0 | 0.9 | 0.8 | 1.1 | 1.2 | 1.3 | 1.6 |
| Sugar | 11.6 | 11.9 | 12.7 | 10.9 | 9.3 | 8.9 | 8.5 | 7.9 | 9.4 | 10.7 | 11.8 | 12.0 |
| Ice cream | 3.6 | 4.3 | 6.0 | 8.9 | 14.8 | 22.3 | 27.4 | 23.6 | 14.2 | 7.8 | 4.3 | 6.2 |
| Chocolate | 13.8 | 12.2 | 12.8 | 12.0 | 10.6 | 8.9 | 8.1 | 7.6 | 8.8 | 12.5 | 16.9 | 22.9 |
| Pastry | 22.3 | 21.2 | 22.0 | 21.6 | 19.7 | 17.8 | 17.3 | 16.4 | 18.6 | 22.9 | 24.0 | 26.4 |
| Biscuits | 19.0 | 18.8 | 19.3 | 18.1 | 17.7 | 15.6 | 14.6 | 13.3 | 16.1 | 17.4 | 17.7 | 18.2 |
| Cereals | 5.9 | 5.8 | 5.9 | 5.7 | 5.6 | 4.9 | 5.0 | 4.6 | 5.3 | 5.5 | 5.7 | 5.6 |
| | Oils and fats | | | | | | | | | | | |
| Sunflower oil | 10.5 | 8.6 | 9.8 | 10.0 | 8.4 | 7.7 | 8.5 | 8.2 | 8.0 | 8.8 | 9.0 | 9.3 |
| Olive oil | 24.9 | 21.1 | 22.7 | 19.8 | 19.0 | 17.7 | 18.1 | 17.8 | 19.9 | 20.2 | 22.1 | 20.6 |
| Margarine | 1.7 | 1.8 | 1.8 | 1.7 | 1.6 | 1.4 | 1.4 | 1.3 | 1.5 | 1.6 | 1.6 | 1.6 |
| | Ready meals | | | | | | | | | | | |
| Pizza | 11.8 | 10.2 | 10.5 | 10.6 | 9.9 | 9.1 | 9.2 | 8.6 | 9.8 | 10.4 | 9.5 | 10.5 |
| Soups and creams | 31.1 | 22.3 | 22.9 | 21.8 | 23.3 | 23.5 | 24.5 | 23.2 | 23.5 | 26.0 | 29.4 | 26.7 |
| Sauces | 12.3 | 11.6 | 12.3 | 12.0 | 11.9 | 11.5 | 12.0 | 10.9 | 11.3 | 11.3 | 10.5 | 13.2 |

### 9.2.2 Theoretical bases of the environmental assessment

LCA and the WF methodologies were followed to determine the CF and WF of the average Spanish food consumption before and after COVID-19. The choice of these two impact indicators provides a complete and comprehensive picture of the environmental impacts related to the dietary pattern under assessment (Petersson et al., 2021).

#### 9.2.2.1 Carbon footprint

The CF was used as an indicator of the impact of GHG emissions associated with each monthly dietary scenario. The average amount of food consumed (grams) per person per day provides the basis for calculating the CF. A cradle-to-consumer LCA approach was taken, considering the food supply chain from the agricultural production to final household consumption. The system was therefore divided into three stages (**Fig. 9.2**):

i) Agriculture and industrial food production (S1): This first stage encompasses the production of the foods that make up each dietary scenario.

ii) Whole-sale and retail distribution stage (S2): This second stage comprises the flow of food items from manufacturer to wholesaler and retailer.

iii) Household consumption stage (S3): This last part of the value chain includes the distribution of food items from retailers to households.

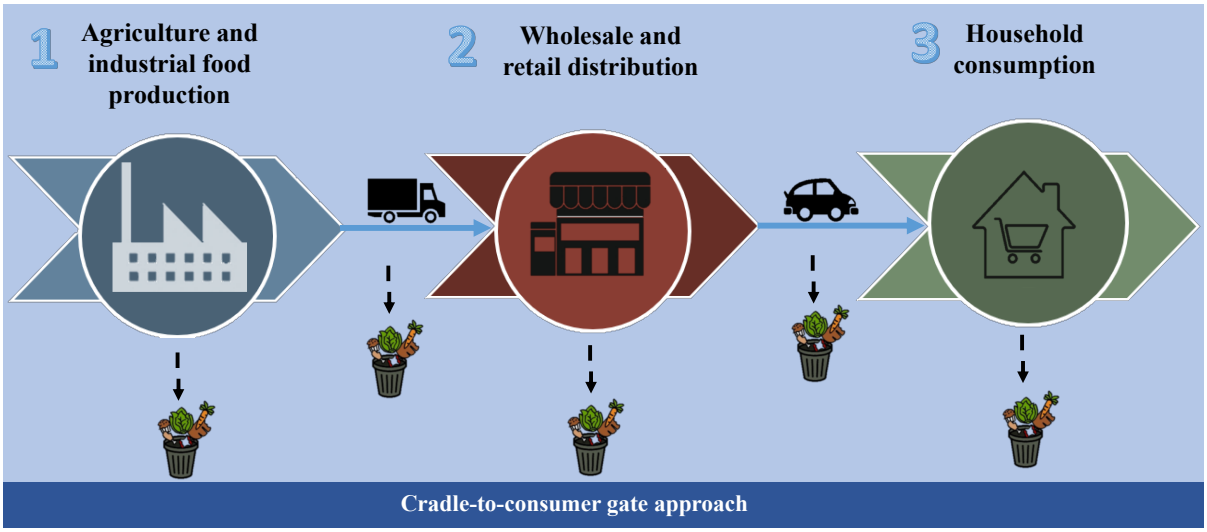


**Fig. 9.2. System boundaries for the carbon footprint analysis.**

CF for each foodstuff from the Spanish shopping basket was collected from LCA literature, as shown in **Table 9.4**. The analysis of 40 LCA studies that covered either primary agricultural production or industrial production stage, was conducted.

**Table 9.4. LCA studies which covered the carbon footprint (CF) of each foodstuff in the Spanish dietary pattern**

| Foodstuff | Source | CF ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|
| | Fruits | |
| Oranges | (Aguilera et al., 2015a) | 0.15 |
| Mandarin | (Aguilera et al., 2015a) | 0.15 |
| Banana | (Aguilera et al., 2015a) | 0.64 |
| Apple | (Aguilera et al., 2015a) | 0.12 |
| Pear | (Aguilera et al., 2015a) | 0.12 |
| Melon | (Clune et al., 2017) | 0.51 |
| Watermelon | (Clune et al., 2017) | 0.32 |
| Lemon | (Aguilera et al., 2015a) | 0.15 |
| Peaches | (Aguilera et al., 2015a) | 0.12 |
| Apricot | (Aguilera et al., 2015a) | 0.12 |
| Strawberry | (Gunady et al., 2012) | 0.33 |
| Plum | (Audsley et al., 2009) | 0.43 |
| Grape | (Aguilera et al., 2015a) | 0.06 |
| Kiwi | (Zeus, 2012) | 0.83 |
| Pineapple | (West Africa Fair Fruit, 2011) | 0.95 |
| Mango | (Frankowska et al., 2019a) | 0.88 |
| | Vegetables | |
| Tomato | (Aguilera et al., 2015b) | 0.22 |
| Onion | (Aguilera et al., 2015b) | 0.24 |
| Peppers | (Aguilera et al., 2015b) | 0.22 |
| Lettuce | (Aguilera et al., 2015b) | 0.23 |
| Carrots | (Nemecek et al., 2012) | 0.20 |
| Courgette | (Aguilera et al., 2015a) | 0.20 |
| Cucumber | (Audsley et al., 2009) | 1.30 |
| Cabbage | (Aguilera et al., 2015b) | 0.24 |
| Garlic | (Khoshnevisan and Rafiee, 2013) | 0.39 |
| Mushroom | (Leiva et al., 2015) | 1.82 |
| Asparagus | (Audsley et al., 2009) | 2.22 |
| Aubergines | (Audsley et al., 2009) | 1.30 |
| Artichoke | (Audsley et al., 2009) | 0.48 |
| Leek | (Clune et al., 2017) | 0.39 |
| Green peas | (Aguilera et al., 2015b) | 0.60 |
| | Pulses | |
| Chickpeas | (Clune et al., 2017) | 0.67 |
| Beans | (Clune et al., 2017) | 0.51 |
| Lentils | (Clune et al., 2017) | 1.03 |

**Table 9.4. (cont.) LCA studies which covered the carbon footprint (CF) of each foodstuff in the Spanish dietary pattern**

| Foodstuff | Source | CF ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|
| | Starch-based products | |
| Bread | (Espinoza-Orias et al., 2011; Kulak et al., 2015; Notarnicola et al., 2017) | 1.15 |
| Rice | (Hess et al., 2016) | 2.31 |
| Pasta | (Hess et al., 2016) | 1.28 |
| Potatoes | (Aguilera et al., 2015b) | 0.24 |
| | Nuts | |
| Olives | (Clune et al., 2017) | 0.63 |
| Almond | (Clune et al., 2017) | 1.74 |
| Walnut | (Clune et al., 2017) | 1.62 |
| Peanut | (Volpe et al., 2015) | 0.62 |
| Hazelnut | (Clune et al., 2017) | 0.97 |
| Pistachio | (Volpe et al., 2015) | 0.53 |
| Chestnut | (Clune et al., 2017) | 0.43 |
| | Dairy products | |
| Milk | (Iribarren et al., 2011a) | 0.77 |
| Yogurt | (González-García et al., 2013a) | 1.50 |
| Cheese | (González-García et al., 2013c) | 10.44 |
| Butter | (Vergé et al., 2013) | 7.20 |
| | Eggs | |
| Eggs | (Nielsen et al., 2013) | 1.80 |
| | Meat | |
| Beef | (van Oort and Andrew, 2016) | 24.69 |
| Pig | (Noya et al., 2017) | 2.50 |
| Chicken | (González-García et al., 2014) | 4.96 |
| Rabbit | (Clune et al., 2017) | 5.72 |
| Sheep | (Clune et al., 2017) | 26.61 |
| Turkey | (Clune et al., 2017) | 3.71 |
| Processed meat | (Noya et al., 2017) | 14.55 |

**Table 9.4. (cont.) LCA studies which covered the carbon footprint (CF) of each foodstuff in the Spanish dietary pattern**

| Foodstuff | Source | CF ($kgCO_2eq \cdot kg^{-1}$) |
|---|---|---|
| | Fish and seafood | |
| Hake | (Iribarren et al., 2010b) | 5.98 |
| Mackerel | (Vázquez-Rowe et al., 2010a) | 1.54 |
| Salmon | (Sherry and Koester, 2020) | 2.26 |
| Pilchard | (González-García et al., 2015a) | 0.43 |
| Cod | (Ziegler et al., 2013) | 1.20 |
| Tuna | (Hospido and Tyedmers, 2005) | 1.64 |
| Trout | (Clune et al., 2017) | 4.20 |
| Sole | (Clune et al., 2017) | 20.86 |
| Bass | (Clune et al., 2017) | 3.27 |
| Gilt-head bream | (Clune et al., 2017) | 3.49 |
| Turbot | (Clune et al., 2017) | 14.50 |
| Angler | (Clune et al., 2017) | 3.49 |
| Prawns | (Clune et al., 2017) | 14.85 |
| Squids | (Iribarren et al., 2010b) | 3.86 |
| Mussels | (Iribarren et al., 2010a) | 1.42 |
| Clams | (Iribarren et al., 2010a) | 1.42 |
| | Sweets | |
| Honey | (Scarborough et al., 2014) | 1.00 |
| Sugar | (Klenk et al., 2012) | 0.23 |
| Ice-cream | (Werner et al., 2014) | 2.80 |
| Chocolate | (Miah et al., 2018) | 3.60 |
| Pastry | (Clune et al., 2017) | 0.52 |
| Biscuits | (Konstantas et al., 2019) | 1.03 |
| Breakfast cereals | (Jeswani et al., 2015) | 2.64 |
| | Oils and fats | |
| Olive oil | (Monini, 2014) | 3.73 |
| Sunflower oil | (Muñoz et al., 2014) | 0.76 |
| Margarine | (Nilsson et al., 2010) | 1.36 |
| | Ready meals | |
| Soups and creams | (Berners-Lee et al., 2012) | 4.00 |
| Pizza | (Werner et al., 2014) | 2.50 |
| Sauces | (Berners-Lee et al., 2012) | 2.10 |

The CF associated with the wholesale and retail distribution stage was calculated based on 2019, 2020 and 2021 import and export data provided by the Ministry of Economy and Competitiveness (multidimensional database DATACOMEX) (Ministerio de Economía, 2019). Based on these data, average import distances were calculated with reference to two modes of transport, transoceanic ships and trucks, and GHG emission factors (Ecoinvent® v3.2 database). For national foodstuffs, an average distance of 400 km per Euro 5 diesel freight lorries (>32 tons) was considered (Ministerio de Economía, 2019) .

For the household consumption stage, the CF was calculated assuming that an average Spanish citizen follows a weekly grocery shopping routine. The average distance between supermarkets and households was estimated to be 3.3 km, and a diesel vehicle with an emission rate of 106 $gCO2eq \cdot km^{-1}$ was considered as a means of transport (Batlle-Bayer et al., 2019). Food losses and food waste from the distribution and consumption stages were taken into consideration (Garcia-Herrero et al., 2018; Gustavsson et al., 2013). A complete description of the CF methodology is described in detail elsewhere (González-García et al., 2020b).

#### 9.2.2.2 Water footprint

Changes in climate and production conditions affect water demand. WF is a geographically explicit indicator that takes into account the location of water use and the type of water consumed (Ruini et al., 2013). Therefore, quantifying the WF requires knowledge of the country of origin of each food item. The collection of import and export trade statistics is fundamental to account for the spatial variable in the WF calculation. The open access database DATACOMEX of the Spanish Ministry of Economy and Competitiveness was used as a source of consultation (Ministerio de Economia, 2019).

Mekonnen and Hoekstra (2010, 2011) were considered as the reference dataset for estimating the three components of the WF for animal products, crops and crop-derived products included in the Spanish food consumption basket. For aquaculture products, the WF was calculated based on that of commercial aquafeed (Pahlow et al., 2015). For non-aquaculture species, the WF was assumed to be zero (Blas et al., 2019).

## 9.3 RESULTS

### 9.3.1 Average composition of the Spanish dietary pattern during the COVID pandemic (2020)

In this section, the average Spanish dietary pattern was described in detail based on data from the Household Consumption Survey of the Ministry of Agriculture, Fisheries and Food (MAPA, 2020a). Only the total expenditure on food in grocery stores and food prepared by the consumer was taken into account. The results did not include food away from home (meals in restaurants and vending machines). When annual data were considered, the average Spanish dietary scenario in terms of food category composition was practically unchanged from 2019 to 2021. Nevertheless, the frequency of intake per food category underwent significant changes when monthly food consumption patterns were analysed.

**Table 9.5** shows the daily intakes per food group for the Spanish dietary pattern throughout 2020. The Spanish dietary pattern is mainly composed of plant-based foods, with about 50% of its content coming from vegetable sources. Plant-based foods were classified into fruits, vegetables, legumes, starchy products, nuts, and oils and fats. Fruits (19%) represented the plant-based food group with the highest contribution to daily consumption, followed by vegetables (16%) and starch-based products (14%).

On the other hand, animal-based foods, which are often the subject of debate due to their greatest climate-related and other environmental impacts, contributed 40% to the total daily

food consumption in Spain. The total per capita consumption of animal products could be used as a proxy indicator for the overall environmental impact of food consumption. Household consumption expenditure on animal products was broken down by food product: dairy products (22% of total daily consumption), meat (9%), fish and seafood (5%) and eggs (2%).

Sweets and convenience foods accounted for about 10% of total daily consumption. Sweets category in the diet of a Spaniard included honey, sugar, ice-cream, chocolate, pastry, cookies and breakfast cereals. The top foodstuffs that contributed to total ready meals intake included pizza, soups and sauces (MAPA, 2020a).

**Table 9.5. Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern (2020).**

| Food item | Spanish dietary pattern (g·person$^{-1}$·day$^{-1}$) | Food item | Spanish dietary pattern (g·person$^{-1}$·day$^{-1}$) |
|---|---|---|---|
| Fruits | | Dairy products | |
| Oranges | 53.2 | Milk | 256.6 |
| Mandarin | 19.5 | Yogurt | 34.6 |
| Banana | 42.6 | Cheese | 29.5 |
| Apple | 33.5 | Butter | 1.5 |
| Pear | 16.1 | Total | 322.2 |
| Melon | 25.8 | Eggs | |
| Watermelon | 29.0 | Total | 26.7 |
| Lemon | 8.4 | Meat | |
| Peaches | 9.2 | Beef | 15.8 |
| Apricot | 2.6 | Chicken | 40.3 |
| Strawberry | 8.9 | Pork | 32.3 |
| Plum | 3.8 | Rabbit | 2.8 |
| Grapes | 7.3 | Sheep | 4.2 |
| Kiwi | 9.4 | Turkey | 4.5 |
| Pineapple | 6.3 | Processed meat | 36.6 |
| Mango | 2.9 | Total | 136.6 |
| Total | 278.4 | Fish and seafood | |
| Vegetables | | Hake | 14.8 |
| Tomatoes | 67.4 | Mackerel | 1.8 |
| Onions | 36.8 | Salmon | 9.2 |
| Peppers | 26.2 | Pilchard | 1.4 |
| Lettuce | 20.3 | Cod | 5.8 |
| Carrot | 18.4 | Tuna | 2.9 |
| Courgette | 21.0 | Trout | 1.4 |
| Cucumber | 10.4 | Sole | 3.7 |
| Cabbage | 8.0 | Bass | 4.3 |
| Garlic | 3.5 | Gilt-head bream | 4.5 |
| Mushroom | 7.0 | Turbot | 0.9 |
| Asparagus | 2.8 | Angler | 2.0 |
| Aubergines | 9.1 | Prawns | 11.2 |
| Artichokes | 6.3 | Squids | 8.4 |
| Leek | 5.2 | Mussels | 6.0 |
| Green peas | 1.2 | Clams | 3.0 |
| Total | 243.7 | Total | 81.3 |

**Table 9.5. (cont.) Daily intake (g·person$^{-1}$·day$^{-1}$) per food group for the Spanish Dietary Pattern (2020).**

| Food item | Spanish dietary pattern (g·person$^{-1}$·day$^{-1}$) | Food item | Spanish dietary pattern (g·person$^{-1}$·day$^{-1}$) |
|---|---|---|---|
| Pulses | | Sweets | |
| Chickpeas | 4.4 | Honey | 1.4 |
| Beans | 3.0 | Sugar | 11.9 |
| Lentils | 3.2 | Ice cream | 12.3 |
| Total | 10.7 | Chocolate | 13.2 |
| Starch-based products | | Pastry | 20.4 |
| Bread | 92.5 | Biscuits | 18.2 |
| Rice | 12.0 | Cereals | 5.7 |
| Pasta | 12.8 | Total | 83.3 |
| Potatoes | 90.7 | Oils and fats | |
| Total | 208.0 | Sunflower oil | 10.3 |
| Nuts | | Olive oil | 22.9 |
| Olives | 11.6 | Margarine | 1.8 |
| Almonds | 1.1 | Total | 35.1 |
| Walnut | 2.8 | Ready meals | |
| Peanut | 1.5 | Pizza | 10.2 |
| Hazelnut | 0.3 | Soups and creams | 24.0 |
| Pistachio | 0.9 | Sauces | 11.9 |
| Chestnut | 0.0 | Total | 46.2 |
| Total | 18.3 | | |

### 9.3.2 Historical per capita food consumption in Spain for the years 2019-2021

**Fig. 9.3** illustrates the change in daily food consumption in Spain from 2019 to 2021 in monthly periods. Overall, there were noticeable shifts in food consumption trends and consumer purchasing habits.

Comparing the pre-quarantine, quarantine, and post-quarantine data, it was observed that while food consumption in Spain remained stable throughout 2019 (pre-COVID-19), it experienced large fluctuations between 2020 (quarantine) and 2021 (post-COVID-19). Food consumption increased sharply and peaked between March 2020 and April 2020 (1632 and 1754 g·person$^{-1}$·day$^{-1}$, respectively). This clear upward trend in total human food consumption coincided with the outbreak of the COVID-19 pandemic in Spain. Strict measures restricting mobility to prevent the spread of the disease radically changed families' consumption patterns. When the lockdown was enforced in March 2020, people stopped buying food away from home (consumed in restaurants, hotels, cafes, and other eating establishments) and consumed food almost exclusively at home. In addition, stress, anxiety, and boredom associated with the COVID-19 pandemic may have played a significant role in this emotional overeating behaviour (Maestre et al., 2021). Household spent on food was 30% higher in April 2020 in comparison with the same period from the previous year, which shows that the health crisis impacted on household consumption patterns (Mean et al., 2020).

Our results also showed increases in consumption of all food categories when comparing April 2020 results to the same time in the immediately preceding reference year (April 2020). However, the percentage increases were lower for high-value perishable products such as fruit (36%), milk (18%), eggs (9%), and fish and seafood (21%). The markets for perishable and short-shelf-life fresh produce were likely to be more affected by quarantine measures than those

for non-perishable foods such as legumes and nuts, which experienced the highest percentage increases (44% and 50%, respectively). In addition, less frequent shopping trips were associated with more shelf-stable foods in the early weeks of the outbreak.

In April 2020, the Council of Ministers approved the Plan for the Transition towards a New Normality. The gradual, flexible and adaptive easing of restrictions led to a dramatic decrease in household food consumption. Food consumption reached a minimum in August 2020 (1328 $g \cdot person^{-1} \cdot day^{-1}$). This decrease in consumption was probably also due to a higher frequency of consumption of meals prepared away from home, as the new normality favoured the hospitality sector with the reopening of restaurants, cafes and bars.

The initial decline in food consumption during the summer was followed by a slight increase at the end of the year. In October, Spain was in the midst of a second wave of COVID-19 and the Spanish government approved another nationwide State of Alert. Among the measures implemented, it is worth mentioning restrictions on nighttime mobility, restrictions on social gatherings and home confinement for certain areas. In November 2020-December 2020, food consumption was 1454 $g \cdot person^{-1} \cdot day^{-1}$ and 1534 $g \cdot person^{-1} \cdot day^{-1}$ respectively, 7% and 12% higher than the same time the previous year.

On the other hand, the excess consumption at Christmas was also responsible that food consumption remained high in December 2020. In fact, there was a sharp increase in consumption of nuts (15% higher), sweets (16%), fish and seafood (33%) and meat (15%) in December 2020 in comparison with November 2020.

When the same comparison was made for the reference year (2019), the findings were similar. Consumption of nuts, sweets, fish and seafood and meat grew by a 11%, 18%, 25% and 10% between November 2019 and December 2019. Nevertheless, food consumption was still unusually high at the end of December 2020 (1534 $g \cdot person^{-1} \cdot day^{-1}$) in comparison with December 2019 (1371 $g \cdot person^{-1} \cdot day^{-1}$).

In December 2020, the European Medicines Agency approved the use of an effective vaccine against COVID, and Spain launched the national vaccination strategy. Based on scientific, ethical and economic criteria, a priority list of population groups to be vaccinated was established (Gobierno de España, 2020a). Vulnerable groups, health and social care workers, frontline workers and dependent people with disabilities were the first in the world to be vaccinated.

After the launch of the vaccine, food consumption decreased until August 2021 (1285 $g \cdot person^{-1} \cdot day^{-1}$). It is noteworthy that a slight increase in food consumption was observed in March 2021 (ranged from 1400 $g \cdot person^{-1} \cdot day^{-1}$ in February 2021 to 1464 $g \cdot person^{-1} \cdot day^{-1}$ in March 2021). The British variant, which was more contagious, accounted for the majority of cases in Spain during this time period. However, although there was a dramatic drop in food consumption in early 2021, it was not until the vaccine was effective and available to all age groups that food consumption reached levels similar to those in 2019.

In June 2019, the average daily consumption was close to 1367 $g \cdot person^{-1} \cdot day^{-1}$. By June 2021 the average daily consumption was similar, at just under 1358 $g \cdot person^{-1} \cdot day^{-1}$. At the end of 2021 a slight increase in consumption associated with Omicron variant of COVID-19 could be observed (1393 $g \cdot person^{-1} \cdot day^{-1}$ in December 2021 compared to 1338 $g \cdot person^{-1} \cdot day^{-1}$ in September 2021).

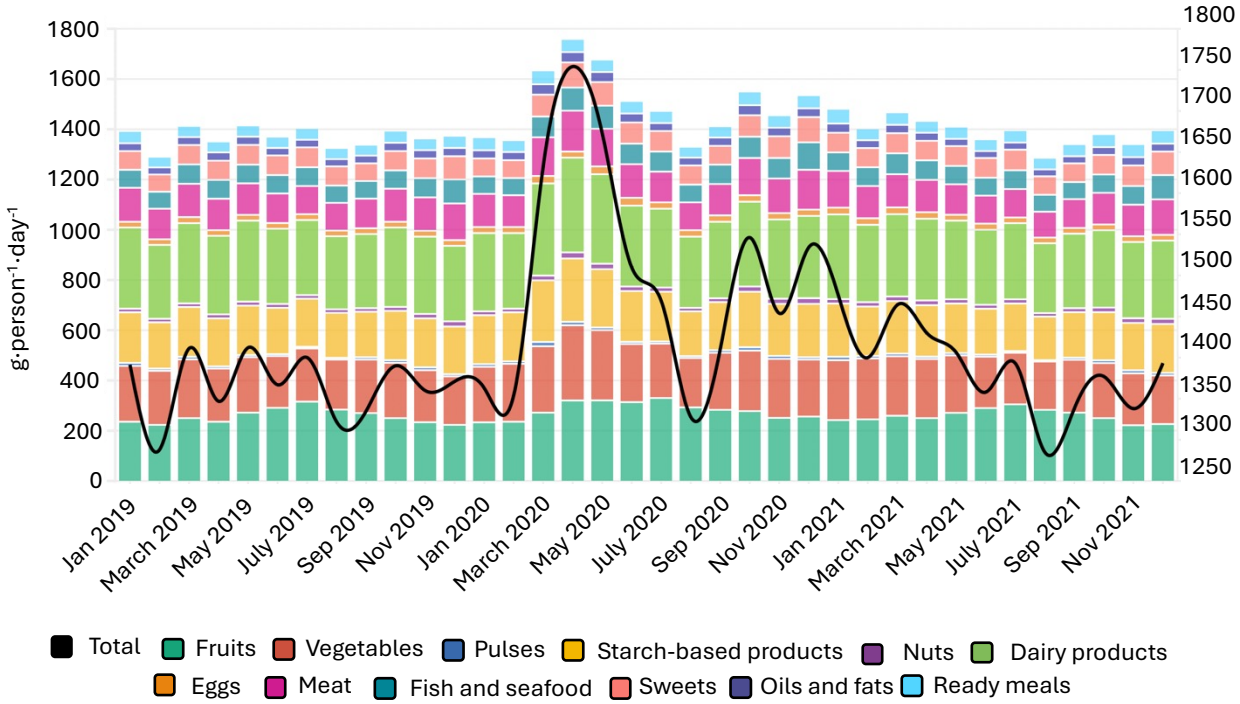


**Fig. 9.3. Evolution of per capita food consumption in Spain for the years 2019, 2020 and 2021.**

### 9.3.3 Impact of COVID-19 on responsible production and consumption (SDG 12)

The results in **Fig. 9.3** show that the pandemic in 2020 has an impact on the achievement of SDG 12 (responsible production and consumption). The key elements of this goal include reducing material consumption and footprint, increasing recycling, preventing food waste, and proposing science-policy solutions for a more sustainable production and consumption system (Keivanpour, 2022).

According to our results, the total daily intake per person was 1356 $g \cdot person^{-1} \cdot day^{-1}$ in 2019. It was increased by 10% in 2020 (1490 $g \cdot person^{-1} \cdot day^{-1}$), but then decreased in 2021 (1377 $g \cdot person^{-1} \cdot day^{-1}$). Panic buying during COVID-19 due to people's concerns about possible food shortages led to overconsumption of food. People felt the need to buy large quantities of food, resulting in large amounts of food waste and threatening the achievement of SDG 12. In addition, the purchase of food with a longer shelf life led to a decrease in the purchase of fresh food, which includes principles of environmental sustainability.

### 9.3.4 Carbon footprint assessment during the COVID pandemic (2020)

The average dietary CF for the Spanish households in the COVID pandemic period (2020) was 3.64 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$. Almost 96% of the total GHG emissions come from the agricultural and industrial food production stage (S1), which is the most critical in terms of environmental impact. GHG emissions related to wholesale and retail trade (S2) and transport of food from supermarkets to households (S3) accounted for 3% and 2% of the total GHG emissions, respectively. Food losses or waste were estimated at 175.1 $g \cdot person^{-1} \cdot day^{-1}$ of the food supply. We found that the most commonly wasted food groups were sweets (mainly refined flour) (23.4 $g \cdot person^{-1} \cdot day^{-1}$), fruits (56.1 $g \cdot person^{-1} \cdot day^{-1}$) and vegetables (45.8 $g \cdot person^{-1} \cdot day^{-1}$). The greater waste of sweets was associated with their increased consumption during the first weeks of the lockdown, triggered by stress, boredom and emotional eating.

**Fig. 9.4** shows the contribution of each food category to climate change, showing the high impact of animal-derived foods on this environmental indicator (59% of total CF). We can observe that there is not a strong relationship between higher consumption of food groups and higher GHG. Although meat alone represents only 9% of total intake, it accounts for 40% of total GHG emissions. Beef and processed meat are the main environmental hotspots. It is also worth noting the impact of dairy products (0.60 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$) and fish and seafood (0.54 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$) on CF. In contrast, although the Spanish dietary pattern is associated with a high intake of fruits (278.4 $g \cdot person^{-1} \cdot day^{-1}$) and vegetables (243.7 $g \cdot person^{-1} \cdot day^{-1}$), the CF values for these food items are of much less relevance.

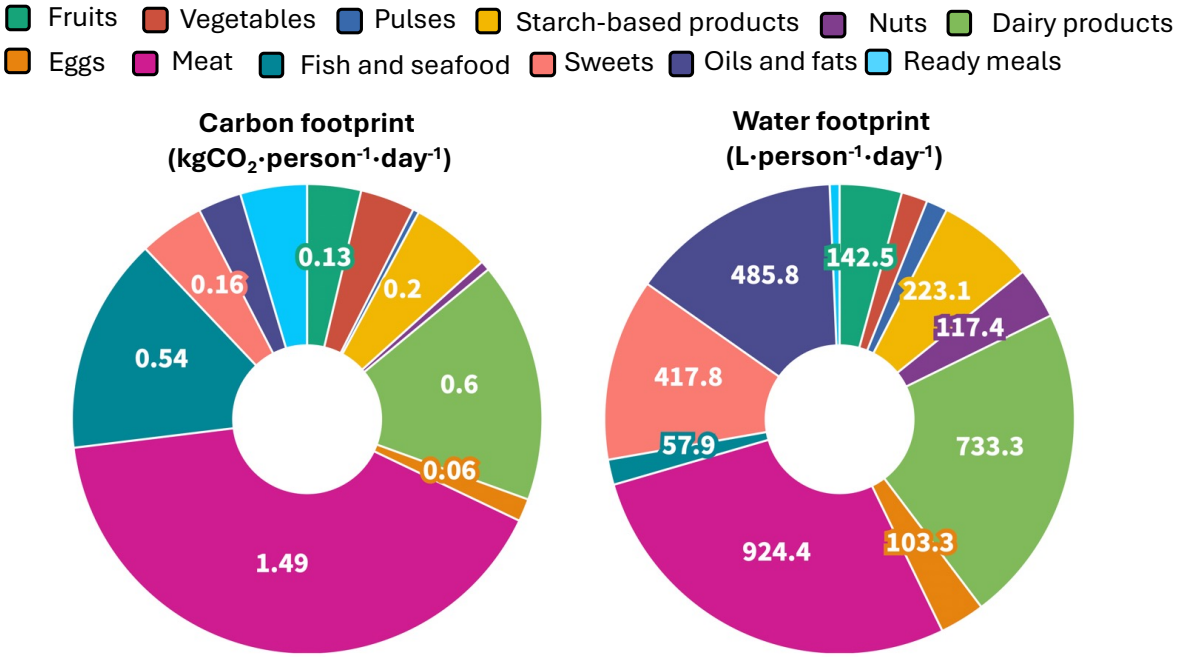


**Fig. 9.4. Distribution of carbon footprint ($kgCO_2 \cdot person^{-1} \cdot day^{-1}$) and water footprint ($L \cdot person^{-1} \cdot day^{-1}$) food categories per 2020 Spanish Dietary Pattern.**

### 9.3.5 Water footprint assessment during the COVID pandemic (2020)

The WF of the Spanish dietary pattern in 2020 was 3337 $L \cdot person^{-1} \cdot day^{-1}$, divided further into green (2612 $L \cdot person^{-1} \cdot day^{-1}$), blue (381 $L \cdot person^{-1} \cdot day^{-1}$) and grey (344 $L \cdot person^{-1} \cdot day^{-1}$) WFs. **Fig. 9.5** shows the WF sorted by food categories for the Spanish dietary pattern in 2020. While animal products represent 55% of the total WF, the contribution of plant products to the total WF is 32%. Meat, dairy products, oils and fats and sweets were the main contributors to dietary WF, accounting for 28%, 22%, 15% and 13% of total WF, respectively. However, there is no strong relationship between higher consumption of food groups and higher WF. In fact, of these four food categories, only dairy products were among the most consumed (322.2 $g \cdot person^{-1} \cdot day^{-1}$). The rationale behind this finding is the high WF of some food items within these food groups, such as beef, cheese, olive oil or chocolate (Mekonnen and Hoekstra, 2010, 2011).

### 9.3.6 Month-to-month analysis of the carbon footprint and water footprint of Spanish food consumption pattern during 2020

**Figs. 9.5 - 9.6** show the monthly variation of daily household food consumption, CF and WF of the Spanish dietary pattern in 2020. We found that the temporal variation of the environmental indicators varied according to the critical response actions for COVID-19.

The first critical fluctuation in environmental parameters occurred between February and March in the values of CF, which increased by 19% and WF by 22%. On March 14, the government declared a nationwide State of Alert. This restriction of movement led people to buy more food than usual, possibly due to stress and boredom caused by the confinement (Maestre et al., 2021). The upward trend in CF and WF continued until April, when both environmental indicators reached their maximum levels (4.15 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ and 3608 $L \cdot person^{-1} \cdot day^{-1}$).

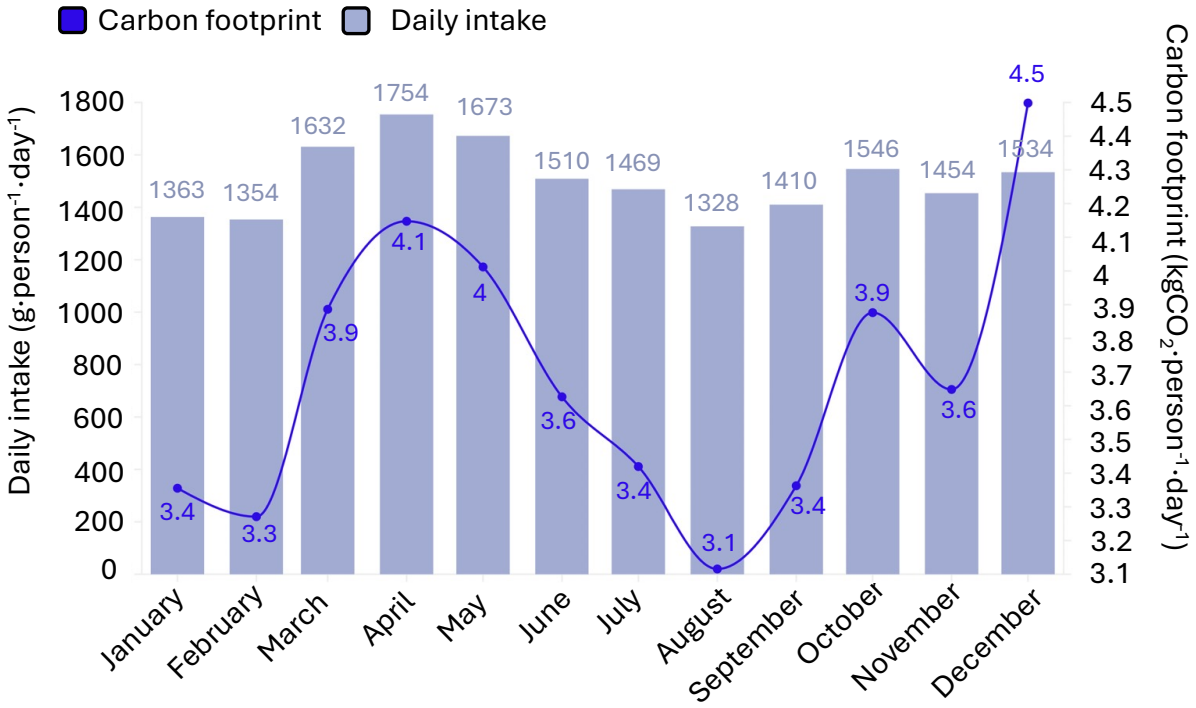


**Fig. 9.5. Monthly variation of the carbon footprint of the Spanish dietary patter throughout the year 2020.**

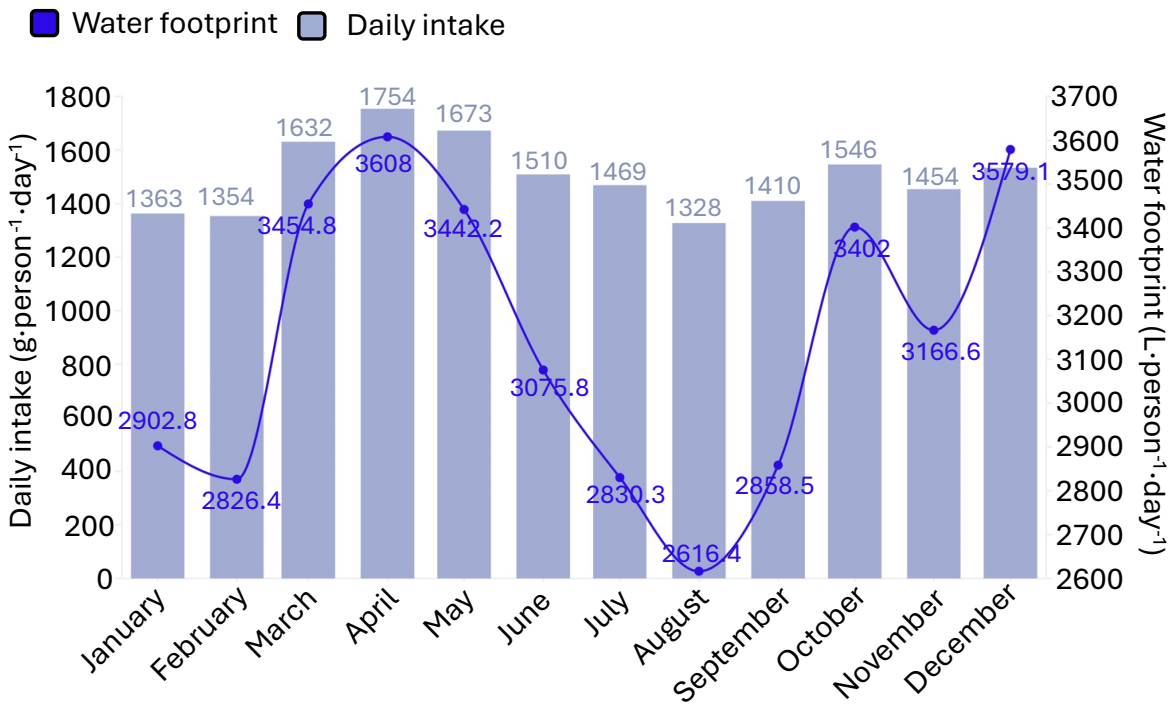


**Fig. 9.6. Monthly variation of the water footprint of the Spanish dietary pattern throughout the year 2020.**

Pulses was the food category, which experienced the highest increase (59%) between February and March. This food group mainly includes the following items, chickpeas, beans and lentils. This increase in pulses consumed was responsible for the highest values of increase in CF (40%) and WF (59%) for this food category. The Spanish dietary pattern also experienced quite marked increases in CF and WF of eggs (23% and 12%, respectively), sweets (22% and 26%, respectively), starch-based products (25% and 24%, respectively) and oils and fats consumption (24% and 22%, respectively).

The lowest percentage increase occurred in the fresh produce categories, fruits (13% in CF and 14% for WF), vegetables (15% and 22%, respectively), and fish and seafood (12% and 18%, respectively) (**Figs. 9.7 - 9.8**). Logistics constraints have contributed to potential shortages of these food groups of a perishable nature (Eftimov et al., 2020). In addition, people tried to reduce the risk of coronavirus infection by buying food with a longer shelf life (thus reducing the consumption of fresh food) and limiting shopping trips to once a week.

The number of new cases and deaths decreased from April 3 to April 11. However, on April 3, the highest number of deaths due to COVID-19 was reported in Spain. This was accompanied by an increase in CF and WF. As mentioned above, both peaked in April. The results for March and April showed a significant decrease in the consumption of the food categories legumes (22.7%) and eggs (20%), as shown in **Fig. 9.7**. In contrast, the consumption of fresh fruits (from 272.3 g·person$^{-1}$·day$^{-1}$ in March to 320.0 g·person$^{-1}$·day$^{-1}$ in April), vegetables (from 264.2 g·person$^{-1}$·day$^{-1}$ to 300.1 g·person$^{-1}$·day$^{-1}$) and fish and seafood (from 82.5 g·person$^{-1}$·day$^{-1}$ to 99.8 g·person$^{-1}$·day$^{-1}$) increased. There was also an increase in the intake of sweets, which ranged from 87.4 g·person$^{-1}$·day$^{-1}$ in March to 99.8 g·person$^{-1}$·day$^{-1}$ in April.

In April, the Government approved the de-escalation plan, which was gradually implemented until 21 June, when Spain entered the “new normality”. On April 13, workers in some non-essential sectors, who cannot telework, return to work. On April 26 and 27, children will be allowed to go out for short walks with their parents, and on April 28, the Government

announced the four-phase plan for the adaptation of the whole society to the new normality. The relaxation of the confinement measures led to an overall decrease in household food consumption expenditure in Spain. For example, if we compare April and June, we can observe a significant decrease in household consumption (from 1754 $g \cdot person^{-1} \cdot day^{-1}$ in April to 1510 $g \cdot person^{-1} \cdot day^{-1}$ in June), CF (from 4.14 kg $CO_2 \cdot person^{-1} \cdot day^{-1}$ in April to 3.63 kg $CO_2 \cdot person^{-1} \cdot day^{-1}$ in June) and WF (from 3608 $L \cdot person^{-1} \cdot day^{-1}$ in April to 3076 $L \cdot person^{-1} \cdot day^{-1}$ in June). CFs and WFs decreased progressively to reach their minimum value in August (3.12 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ and 2616 $L \cdot person^{-1} \cdot day^{-1}$). This lower household food consumption in August for all food categories is also due to the effect of heat and appetite. In addition, spending time outdoors during the summer, as there were few restrictions in August, may have also influenced this decrease in household food consumption.

A peak was observed in October for both environmental indicators (3.88 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ and 3402 $L \cdot person^{-1} \cdot day^{-1}$). The high value in CF and WF coincided with the approval of a new national state of alarm for the country on October 25, in an attempt to combat the coronavirus wave that was being experienced. The state of alarm would last until May 9, 2021. In addition, the Government introduced a national regulation to contain a new coronavirus outbreak.

The third peak on the environmental variables analysed occurred on December (4.50 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ and 3579 $L \cdot person^{-1} \cdot day^{-1}$). This third peak could be associated with the extra calories consumed in all celebrations during Christmas. In fact, if we compare the environmental metrics in December with that of November, a significant increase can be observed in the CF and WF of the most consumed products at Christmas in Spain: meat (28% and 19%, respectively), fish and seafood (63% and 80%, respectively), sweets (25% and 37%, respectively) and nuts (13% and 19%, respectively) food categories.

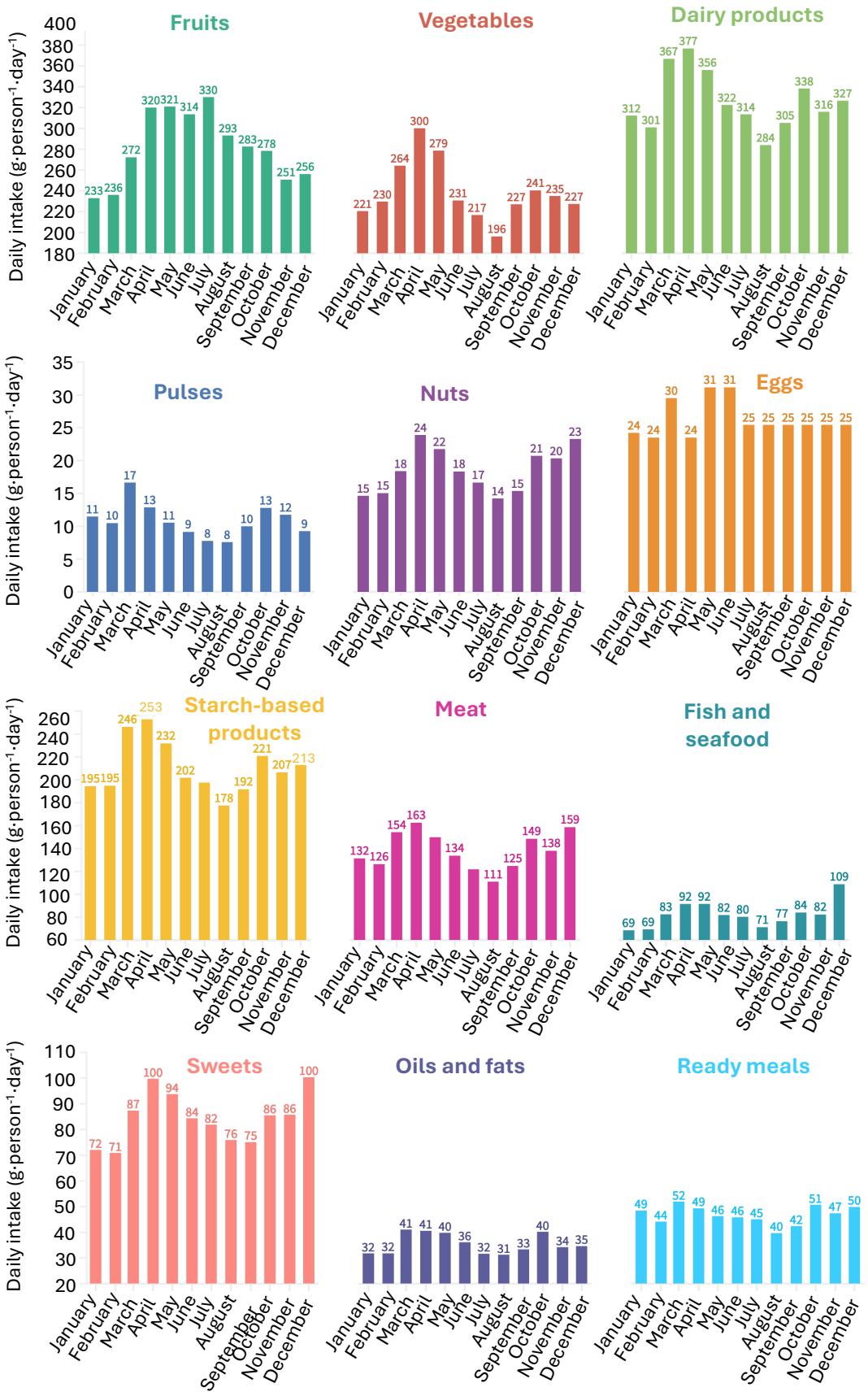


**Fig. 9.7. Monthly variation of the daily intake of the Spanish dietary pattern throughout the year 2020.**

### 9.3.7 Spanish dietary carbon footprint for the years 2019-2021

**Fig. 9.8** shows the variation of the CF associated to the Spanish dietary pattern throughout the years 2019, 2020 and 2021. The CF remained practically constant between January 2019 and November 2019. In December 2019, the CF reached its annual highest level (4.2 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). One reason for this could be that Christmas is an extremely food-focused holiday. An evaluation of environmental data suggested an increase in CF associated to the most popular food groups consumed in Christmas: nuts (11%), sweets (26%), fish and seafood (51%) and meat (22%), in comparison with previous month period.

On the other hand, in 2020 the COVID-19 pandemic led to significant changes in food-related GHG emissions. Hence, CF increased sharply since January 2020 (3.4 kg$CO_2$eq·person$^{-1}$·day$^{-1}$) reaching a peak in April 2020 (4.1 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). This is clearly due to an overall increment in food consumption during the lockdown imposed in Spain on 14 March. Therefore, lockdown had a negative impact on the environment in terms of GHG emissions.

CF suddenly decreased between April 2020 and August 2020, bottomed out in August 2020 (2.9 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). Therefore, this provides evidence about the relationship between the gradual relaxation of the confinement measures and changes in food-related CFs.

From August 2020 to December 2020, CF experienced a sharp increase, reaching 4.0 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ in December 2020. Overall, this highlights the significance of an increase in COVID-19 cumulative number of coronavirus cases in Spain in the last months of the year, as well as the spending and overconsumption of food items in Christmas festivities. It is noteworthy that although overall food consumption was higher in April 2020 than in December 2020, the CF had its highest ever level in December 2020. One reason for this could be the greatest difference between the consumption of fish and seafood (associated with the ancient tradition of Christmas dates) and their related CF, which was much higher in December 2020 (0.90 kg$CO_2$eq·person$^{-1}$·day$^{-1}$) than in April 2020 (0.56 kg$CO_2$eq·person$^{-1}$·day$^{-1}$).

After the launch of the largest vaccine drive in Spain (December 2020), a decline could be seen both in food consumption and in the CF associated with food. It is noticeable that CF remained constant between January 2021 and April 2021, when the fastest-spreading British variant was traversing the planet. In June 2021 CF associated to the Spanish dietary pattern (3.1 kg$CO_2$eq·person$^{-1}$·day$^{-1}$) was in line with the values obtained for the reference year (2019) in the same period of time (3.2 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). In fact, the CF was at their lowest point in three years in August 2021 (2.9 kg$CO_2$eq·person$^{-1}$·day$^{-1}$). The CF increased in last months of 2021 due to Spain tightened restrictions amid concerns over omicron coronavirus variant.

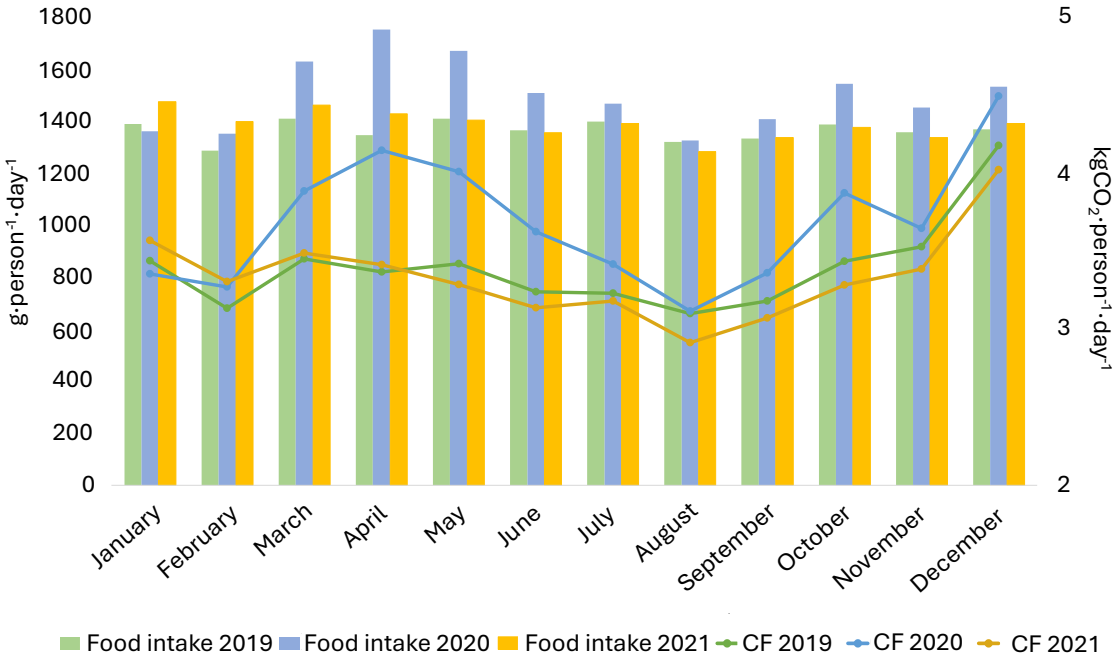


**Fig. 9.8. Evolution of Spanish dietary carbon footprint for the years 2019, 2020 and 2021.**

### 9.3.8 Spanish dietary water footprint for the years 2019-2021

**Fig. 9.9** illustrates the variation of the WF associated to the Spanish dietary pattern between 2019 and 2021. What is striking in this figure is the variability of WFs between 2019 and 2021.

In 2019, the WF reached two peaks, a minimum peak in August 2019 (2489 L·person$^{-1}$·day$^{-1}$) during the summer, and a maximum peak in December 2019 (3166 L·person$^{-1}$·day$^{-1}$) coinciding with overconsumption at Christmas holidays. If the results of December 2019 are compared with those of October 2019, it could be identified a marked increase in meat (16%), fish and seafood (19%), nuts (39%) and sweets (54%) categories. In fact, these are the most traditional and popular food products consumed during Christmas in Spain.

In 2020, the same peaks were observed, one in August 2020 (2616 L·person$^{-1}$·day$^{-1}$) and the other in December 2020 (3579 L·person$^{-1}$·day$^{-1}$). Nevertheless, the WF values were higher on both time periods than for 2019. It is likely that this increase was due to the effects of COVID-19 pandemic on food consumption. As noted above, the COVID-19 pandemic increased the need for consumers to purchase essential and non-essential products, which exacerbated food wastage and had an impact on environmental issues, such as water consumption.

There has been a steady decline in WF values in Spain from November 2020 - December 2020 (3166 L·person$^{-1}$·day$^{-1}$ and 3579 L·person$^{-1}$·day$^{-1}$, respectively) to July 2021 - August 2021 (2653 L·person$^{-1}$·day$^{-1}$ and 2456 L·person$^{-1}$·day$^{-1}$, respectively). What can be clearly seen in this **Fig. 9.9** was that values obtained for the WF associated to the Spanish dietary pattern in May 2021 (2811 L·person$^{-1}$·day$^{-1}$), June 2021 (2634 L·person$^{-1}$·day$^{-1}$), July 2021(2653 L·person$^{-1}$·day$^{-1}$) and August 2021 (2456 L·person$^{-1}$·day$^{-1}$) were similar to those obtained in May 2019 (2805 L·person$^{-1}$·day$^{-1}$), June 2019 (2626 L·person$^{-1}$·day$^{-1}$), July 2019 (2577 L·person$^{-1}$·day$^{-1}$) and August 2019 (2489 L·person$^{-1}$·day$^{-1}$) prior COVID-19. The relaxation of restrictions at the pace of vaccination, increased freedom and guarded against COVID-19 waves. Throughout summer 2021, the largest share of people had already been vaccinated against COVID-19, and only mild contact restrictions were necessary. For the last months of

2021, the impact of the fastest-spreading Omicron variant marked an increase in the WF indicator, which peaked in December 2021 (3260 L·person$^{-1}$·day$^{-1}$).

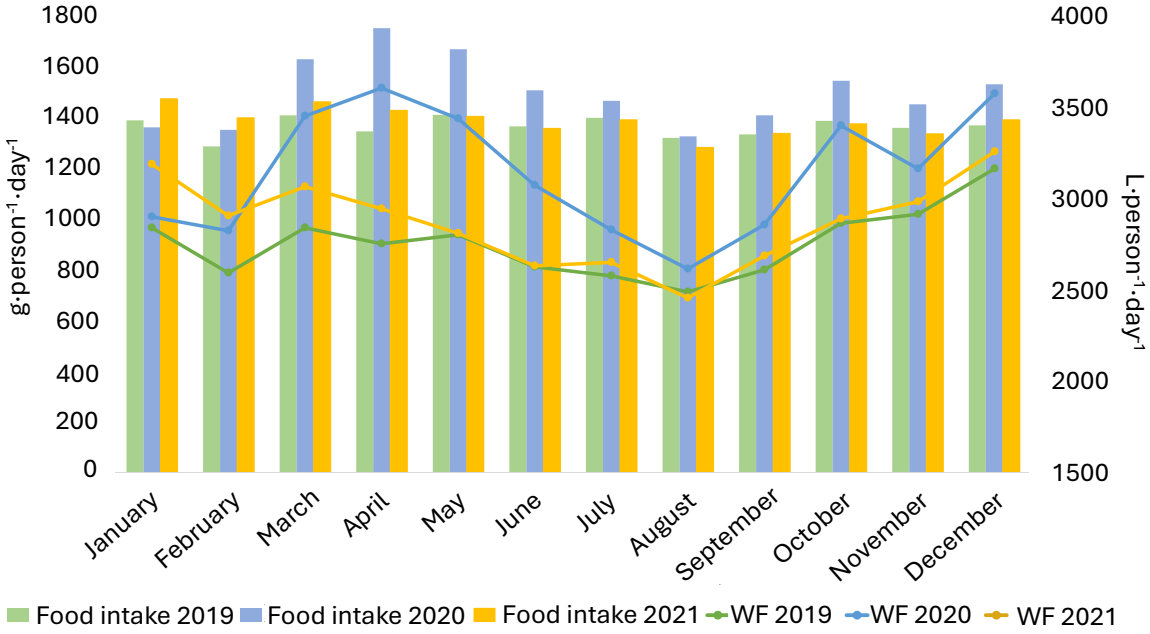


**Fig. 9.9. Evolution of Spanish dietary water footprint for the years 2019, 2020 and 2021.**

### 9.3.9 Impact of COVID-19 on Climate Action (Goal 13)

On the basis of the CF assessment referred in the previous subsection, it could be concluded that COVID-19 was a major obstacle to the achievement of SDG 13 (Climate action). The COVID-19 pandemic has gravely wounded planetary health with serious consequences affecting global warming. In accordance with our results, there was a significant increase in CF associated with the Spanish diet between 2019 and 2020. In 2019, the CF for the Spanish dietary pattern was estimated at 3.32 kg$CO_2$eq·person$^{-1}$·day$^{-1}$. This rose to 3.64 kg$CO_2$eq·person$^{-1}$·day$^{-1}$ in 2021, bringing the CF back down to 3.30 kg$CO_2$eq·person$^{-1}$·day$^{-1}$.

Hence, consumerism played a huge role in climate change. The link between consumer behaviour during the pandemic and global warming was clear. During COVID-19 pandemic, there was a tendency to stock up and to overbuy, which led to more food waste and to an only temporary increment in carbon dioxide emissions, as our results support.

### 9.3.10 Impact of COVID-19 on Clean Water and Sanitation (Goal 6)

The COVID-19 pandemic has interrupted the food-water nexus setting back progress towards the SDG 6. Water consumption levels have increased in the agricultural sector due to the food overconsumption amid coronavirus panic.

According to the findings obtained, water consumption increased during the COVID-19 pandemic. The WF before COVID-19 pandemic (2019) was calculated as 2930 L·person$^{-1}$·day$^{-1}$. This rose to 3337 L·person$^{-1}$·day$^{-1}$ in 2020, during the COVID-19 restrictions. By 2021, water usage dropped somewhat, but it still remained higher than pre-pandemic levels at 3048 L·person$^{-1}$·day$^{-1}$.

Therefore, it was found that there was a significant correlation between the change in the WF at the country level (Spain) before, after and during COVID-19. Excessive consumption jeopardized water availability and access during a critical pandemic period when sanitation and hygiene were essential.

### 9.3.11 Comparison with other international studies

Food is one of the areas of daily life most affected by the global socioeconomic and health crisis. Studies have reported a positive correlation between food concerns and mobility. Despite some differences between countries, there are notable food categories that were consumed more during COVID-19 as a result of spending more time at home. People worldwide were interested in carbohydrates and high-calorie foods, probably due to changes in preferences, accessibility, and prices. Thus, a significant decline in the nutritional quality of diets worldwide was observed during COVID-19 (Gligorić et al., 2022).

Italians increased consumption of flour-based and sugary foods in place of fresh food (Bracale and Vaccaro, 2020) in the same line than Spaniards (Laguna et al., 2020). The level of adherence to the French dietary recommendations also decreased during the lockdown due to a sharp increase in processed meat, sweet-tasting beverages and alcoholic beverages (Marty et al., 2021). The trend in Latin American countries was the same. A higher prevalence of inactivity and a high consumption of ultra- processed was observed in teenagers of Brazil, Chile and Colombia (Ruíz-Roso et al., 2020). The consumption of packaged foods, takeout meals, and packaging from online shopping, as well as the tendency to stock up and overbuy, has led to more food waste that impacts the environment, human systems, and water quality (Raza et al., 2023).

In this line, Batlle-Bayer (2020a) made a comparison from a threefold environmental perspective (Global Warming Potential, Blue WF and LU) between a set of scenarios: a pre-COVID diet, a COVID diet and two alternative diets, based on Spanish dietary recommendations and recommendations of the EAT-Lancet Commission on healthy diets from sustainable food systems, respectively (Batlle-Bayer et al., 2020a). According with their results, COVID diet had larger energy intake, lower nutritional quality and higher environmental impacts than pre-COVID diet which is consistent with our analysis. Moreover, COVID diet showed an increase in environmental impacts in comparison with EAT-Lancet dietary recommendations.

Changes in dietary behaviours at the beginning of the COVID-19 outbreak also impacted on the nutritional quality and environmental impact of French diets. Marty et al. (2022) found temporary decrease in nutritional quality and environmental impact during the first lockdown but no sustained changes in the long run. They found a 1-year trend towards more organic and local food consumption. This long-term trend agrees with the analysis made in Italy (Dangelico et al., 2022). They showed that COVID-19 significantly influenced the behaviour of consumers, who were more willing to pay for sustainable products and pay attention to environmental issues.

### 9.3.12 Strengths and weaknesses of the study

The strengths of our study include the large amount of data used to analyse the impact of COVID-19 on the environmental consequences of changes in Spanish dietary habits. We evaluated dietary scenarios involving more than 80 foods at monthly intervals over three years, which allowed us to obtain a clearer and more detailed picture of CF and WF associated with the dietary habits of a large number of Spaniards.

The main limitation of the study is that it did not take into account regional, climatic and cultural variations in food consumption. This analysis could be of interest since the coexistence of Atlantic and MD in Spain influences the type and quantity of food in the 17 autonomous communities. However, the consideration of an average pattern is very common in the research conducted in this field (Afrouzi et al., 2023).

On the other hand, some limitations related to the methodology have to be addressed. The CF assessment is sensitive to the CF values collected for each food product in meta-analyses, systematic reviews and scientific articles from LCA research. Uncertainty about the total dietary CF content cannot be quantified because the variability of the CF content of each food in the diet is unknown. The limitations of the WF assessment were the paucity of information for estimating the WF of non-aquaculture fishery products.

### 9.3.13 Policy implications

There is ongoing debate over potential long-term changes in environmental sustainability driven by the COVID-19 pandemic. This chapter scrutinized the nexus between the COVID-19 pandemic and their impact on SDGs 6 (Clean water and sanitation), 12 (Responsible production and consumption) closely related to 2 (End Hunger), and 13 (Climate action).

First, it is concluded that societal changes during the COVID-19 pandemic caused environmental damage to food sustainability. However, to ensure that societal and behavioural changes are not permanent and do not jeopardize the future transition to environmental sustainability, it is necessary to formulate a policy framework for food regulation. National governments and global organisations, such as the WHO and the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems, should strengthen their commitment to a sustainable food future by modelling and evaluating dietary guidelines based on personal needs and health and sustainability concerns. Policy action plans for sustainable diets are needed to prevent the environmental consequences of food overconsumption from having an irreparable impact on food sustainability. Yet, only a few countries have incorporated sustainability into their dietary guidelines (Willet et al., 2019a) and to date very few studies have assessed environmental sustainability of dietary guidance (Springmann et al., 2020). Hence, research still needs to explore how effective are these food guidelines for the environment and what type of governance framework is required to materialize them.

Second, during quarantine and isolation, nutrition tips have been published to stay physically and mentally healthy (WHO, 2019). However, to our best knowledge it has not been published tips for sustainable eating during COVID-19 pandemic. In fact, few studies have evaluated the interconnection between COVID-19 pandemic and environmental sustainability. For instance, Lehmann et al. (2021) addressed three questions in their article: (1) *Did the COVID-19 pandemic impact on the transition towards environmental sustainability?*, (2) *Is there a link between COVID-19 crisis and environmental crisis?* and (3) *How can the transition to environmental sustainability help in the management of future pandemics?* In the same line, the OECD analysed the long and short-term environmental implications of COVID-19.

In a nutritional domain, Aldaco et al. (2020) examined the impact of short-term changes in dietary habits on food loss and food waste. They concluded that during the lockdown, the amount of food waste and food losses generated at home and the associated carbon dioxide emissions and economic costs were increased by 12%, 10%, and 11%, respectively. In contrast, the nutritional value of food waste and losses was reduced by 8%. More research is needed to ensure that the actions taken in the aftermath of the coronavirus outbreak promote a shift towards a more sustainable future for all. What is clear is that sustainability will be at the heart of the response to the health crisis, with the aim of advancing climate goals while transforming our economy to create opportunities and jobs.

## 9.4 CONCLUDING REMARKS

The public health measures taken to contain the COVID-19 pandemic, such as lockdowns, quarantines, isolation, and cordons sanitaires, have drastically changed social behaviours and

lifestyles, jeopardizing the ability to address the multiple challenges of the SDGs. In recent years, the COVID-19 pandemic has affected all aspects of society, including the entire food system.

In this chapter, we were able to analyse the lasting effects of the COVID-19 pandemic on the diet of the Spanish population. The changes in food consumption patterns were characterised not only by an increase in total food consumption, but also by a shift in the composition of the Spanish diet towards more nuts and legumes and less perishable products during the lockdown period. The results of this study confirmed that the COVID-19 pandemic disrupted the system of sustainable production and consumption (SDG 12), as food consumption increased by 10% in 2020 compared to 2019 data.

The overconsumption also impacted climate disruption and water management, worsening the environmental indicators of CF and WF and putting further pressure on the achievement of SDGs 6 (clean water) and 13 (climate action). Carbon emissions from food during COVID-19 rose dangerously above pre-pandemic levels, with a 10% increase. Similarly, the WF increased by 14% in 2020 compared to 2019 (pre-COVID-19). The CF and WF returned to pre-pandemic levels in 2021 as the COVID-19 vaccination campaign progressed.

The trend analysis of the CF and WF revealed a significant peak in these environmental indicators in April 2020, which could not be detected in the same period in 2019 and 2021. Thus, the results obtained were indicative of the most severe closure in the spring of 2020 in Spain, which led to an overconsumption of food and an unequal distribution of food. Other peaks in environmental indicators for 2019, 2020 and 2021 were observed during the Christmas season, a period associated with higher than normal spending and overeating. CF and WF values were unusually high at the end of 2020, when compared to the previous year (2019). In fact, carbon emissions and WF did not return to pre-pandemic levels until the summer of 2021, when Spain reached its highest percentage of fully vaccinated people.

Thus, the environmental pillar of food sustainability in the context of human behaviour during the COVID-19 pandemic has been addressed in this chapter. However, future research is needed to focus on the evaluation of the economic, nutritional and social pillars, which could be of great interest to customers, governments, the food industry and the health sector. Analysis of the evolution of a large-scale CF and WF over a longer period of time could also help to guide decision-making during the post-COVID 19 recovery process.

# 10. SOCIO-ECONOMIC STRATA AND DIETARY CHOICES: AN IN-DEPTH ANALYSIS OF NUTRITIONAL AND ENVIRONMENTAL SUSTAINABILITY IN CHILE[8]

The effects of climate change and water scarcity on food security in Latin America and the prevalence of metabolic risk factors that increase the likelihood of non-communicable diseases among Chilean citizens are considered two major challenges. The 2020 Sustainable Development Goals Report shows that an increasing number of people suffer from food insecurity, and the growing stress on the environment associated with food production and resource exploitation. Therefore, the evaluation and monitoring of nutritional habits must be addressed because of their central role in meeting healthy and sustainable food goals. The objective of this study was to assess the environmental impacts (carbon and water footprint), nutritional quality and cost of diets of different socio-economic subgroups in Chile, mapping environmental hotspots and food insecurity. It was observed that higher income was associated with higher environmental burdens related to food choices and higher dietary costs. Carbon and water footprints ranged from 2.42 to 4.74 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and 1683 to 3110 L·person$^{-1}$·day$^{-1}$ for the first and fifth quintile, respectively. Chilean residents in the highest socio-economic quintile consumed more meat and fewer starch-based products than those in the lowest quintile. Meat was the main contributor to carbon (56% - 59%) and water (40% - 43%) footprints and the main determinant of differences between income quintiles. Although current diets in Chile do not meet nutritional recommendations, diet quality also increased with socioeconomic level. These findings could serve as a reference for implementing public policies in Chile to ensure healthy eating and food security in the context of climate change and water scarcity.

[8] Cambeses-Franco, C., Rebolledo-Leiva, R., Gonzalez-Garcia, S., Feijoo, G., Moreira, M. T., 2022. Addressing the food, nutrition and environmental nexus: The role of socio-economic status in the nutritional and environmental sustainability dimensions of dietary patterns in Chile. Journal of Cleaner Production, 379, 134723. https://doi.org/10.1016/j.jclepro.2022.134723

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## 10.1 INTRODUCTION

Chronic NCDs such as CVD, cancer and T2D are the leading cause of death worldwide and an urgent public health priority (PAHO, 2020). While NCDs tend to manifest later in life in high-income countries, in the case of underdeveloped countries, such as Latin American countries, they affect the working-age population, leading to higher health care costs, limited capacity for work and economic instability (CDC, 2020). Addressing NCDs not only encompass UN SDGs but also support global health security and universal health coverage. In this framework, the WHO and the Pan American Health Organisation (PAHO) promote, coordinate and implement technical cooperation activities aimed at preventing of common risk factors such as tobacco or alcohol use, physical inactivity or intake of unhealthy diets (Allen et al., 2021; PAHO, 2014; WHO, 2020d). One of the main scientific concerns is the complex interrelationship between diet, disease and health, as well as the lack of updated information on dietary intake in Latin American countries (Kovalskys et al., 2019).

### 10.1.1 Tackling socioeconomic disparities in Chilean diets

With these needs and challenges in mind, Chile recently published the "Radiography of Food in Chile", a study commissioned by the Chilean government (in the frame of the "*Elige Vivir Sano*" program) and the company EGP Consultants, with the aim of analysing household food consumption by socio-economic levels.

To do this, they considered data from the "VIII Survey of Family Budgets 2017" performed by the National Institute of Statistics of Chile with information from more than three million households. The main objective of this survey was to identify the structure and characteristics of final consumption expenditure of urban households (INE, 2018). Thus, this survey addressed different topics such as expenditures, income and socioeconomic aspects of the household. In addition, this document defines quintiles determined by ordering all the data according to their observed values in the income variable, from the lowest income to the highest income, and then separating the statistical units into five groups of equal size. The study confirms that Chilean households have an unhealthy dietary pattern, with a habitual intake of sugary drinks and sweets, and an insufficient consumption of fruits, vegetables, fish and legumes. Regarding recommended consumption patterns, the first quintile presented the lowest compliance in all food groups, while the fifth quintile obtained the highest compliance in fruits and vegetables. In addition, older adult households presented compliance indicators higher than the national average in all food groups. Food choice criteria prioritise price, freshness, time gaps for preparation and consumption, and taste over nutritional information and environmental aspects (Government of Chile, 2021).

### 10.1.2 A framework for environmentally sustainable and nutritious diets in Chile

Consideration of an integrated health and environmental modelling framework creates opportunities to improve the nutritional quality and dietary health of the Chilean population and reduce the environmental impact of food systems. The LCA approach is one of the most widely used methodologies to assess the environmental impacts of household consumption on the path towards sustainable consumption and production (Castellani et al., 2019). Among the main environmental issues arising from food production are climate change (agriculture and LU are the main sources of GHG emissions) and the large quantities of water consumed (Clark et al., 2019). Therefore, CF and WF could be used to analyse the environmental consequences of Chilean food habits and, to the extent possible, to what extent they approach or exceed the ecological limits established by the SDGs (zero net GHG emissions by mid-century and improved water quality) (United Nations, 2018). In addition, to address the interconnected

problem described above and integrate the two dimensions of sustainability, both environmental indicators were complemented by the nutritional quality score developed by van Dooren et al. (2014). Potential applications of nutritional indicators to environmental studies are highlighted to demonstrate the value this integrated approach would have in preventing worrying trends such as nutritional misinformation, malnutrition and hunger (FAO et al., 2020).

The integration of nutrition into environmental sustainability studies focused on whole diets represents a growing concern in the scientific community (Ridoutt, 2021). Wright et al. (2023) evaluated the environmental and nutritional impacts of transitioning 2-year-old Norwegians to healthier, plant-based diets aligned with national guidelines and EAT-Lancet recommendations. Results showed that these plant-based choices significantly reduced environmental impact while improving the nutritional quality of children's diets compared to their current eating habits. Abejón et al. (2020) applied a systematic optimisation methodology to define sustainable dietary patterns that aligned with nutritional, environmental and economic considerations. The model analysed six dietary patterns, including current Spanish consumption patterns. The research revealed that diets with better nutritional profiles and lower GHG emissions could be achieved at no additional cost. The key to this change is to consume more vegetables, fruits and legumes, while reducing meat and fish consumption. WHO (2023) introduced the Dietary Impact Assessment model. This interactive modelling tool allows governments to explore the multifaceted consequences of dietary changes in their populations. By designing user-defined scenarios, the Dietary Impact Assessment model facilitates the exploration of potential impacts on public health outcomes (e.g., reduced mortality from diet-related diseases), environmental sustainability metrics (e.g., reduced GHG emissions and resource use), nutritional well-being, and even affordability.

Consequently, so far, environmental and nutritional assessments of dietary patterns of Latin American populations have not yet been extensively studied in the literature. Only Vázquez-Rowe et al. (2017b), and Larrea-Gallegos and Vázquez-Rowe (2020) analysed the environmental impacts of Peruvian dietary profiles, including geographic and socioeconomic aspects. These authors stated a positive correlation between GHG emissions and social expenditure, as well as a low range of diet-related emissions compared to developed nations.

Thus, the objective of this study was to address the correlation between household socioeconomic status in Chile and related nutrition (diet quality), environmental pressures (climate change and water scarcity) and economic costs derived from food consumption patterns. In addition, another objective was to analyse the nutritional and environmental sustainability of the average Chilean diet. The results of this study are expected to guide decision making and public health policies in Chile towards new ways of integrating nutrition, environmental sustainability and socioeconomic development.

## 10.2 Materials and methods

### 10.2.1 Data on food consumption

The Chilean dietary pattern was based on the "Radiography of food in Chile" at national level, a study conducted by the Government of Chile with the aim of understanding Chilean food consumption patterns in terms of household expenditure and assessing relevant gaps to enforce healthy eating patterns in accordance with WHO recommendations and Ministry of Health guidelines (Government of Chile, 2021). This research was based on data from the VIII Household Budget Survey 2017 (National Institute of Statistics) with information from 3,365,700 households. This survey includes more than 137 food products, which are divided into 26 food groups according to their nutritional composition, based on the frequency of

expenditure declaration. The information provided by the survey includes in-home and out-of-home consumption.

### 10.2.2 Diet scenarios

Based on the data, a set of 6 dietary scenarios was designed, as shown in **Table 10.1**, taking into consideration the average diet in Chile and the socio-economic quintiles in Chile. The baseline (average) scenario was based on the average daily per capita consumed intake per raw food item for a Chilean average citizen. The first quintile comprises the food consumption of the part of the population with the lowest per capita income and the fifth the food consumption of the segment with the highest income, without imputed income. The design of the scenarios (the baseline) and the other five (based on the per capita income quintile defined by the VIII Household Budget Survey 2017 conducted by the National Institute of Statistics) was made based on the average consumption data and on the most updated data on current food consumption by household disaggregation established by the study "Radiography of food in Chile" (Goverment of Chile, 2021).

In the current study, the six scenarios only cover a wide range of 59 representative foods, grouped into 14 food categories, as can be seen in **Table 10.1**. The products excluded from our specific case study included spices and beverages, in line with previous studies (Cambeses-Franco et al., 2021b; González-García et al., 2020b). The BECDA was used to calculate the caloric intake linked to each dietary scenario (BEDCA, 2017). The average daily per capita intake was 1130 $g \cdot person^{-1} \cdot day^{-1}$ with an estimated energy intake of 2300 $kcal \cdot person^{-1} \cdot day^{-1}$. The energy supply intake for quintiles ranged from 1765 $kcal \cdot person^{-1} \cdot day^{-1}$ (quintile 1) to 2913 $kcal \cdot person^{-1} \cdot day^{-1}$ (quintile 5).

**Table 10.1. Average daily intake per foodstuff for the six dietary scenarios designed based on socioeconomic status and carbon footprint (CF) associated.**

| Foodstuff | Average | Q1 | Q2 | Q3 | Q4 | Q5 | CF | Country | Source |
|---|---|---|---|---|---|---|---|---|---|
| | g·person$^{-1}$·day$^{-1}$ | | | | | | kg$CO_2$eq·kg$^{-1}$ | | |
| Fruits | | | | | | | | | |
| Oranges | 21.3 | 14.5 | 18.8 | 16.6 | 26.2 | 36.9 | 0.11 | Brazil | (Knudsen et al., 2011) |
| Bananas | 29.2 | 21.3 | 28.4 | 27.8 | 34.3 | 38.6 | 0.36 | Ecuador | (Iriarte et al., 2014) |
| Apples | 22.0 | 16.1 | 21.3 | 22.4 | 25.2 | 28.0 | 0.06 | Chile | (Iriarte et al., 2021) |
| Pears | 7.0 | 5.1 | 6.1 | 6.6 | 8.7 | 9.9 | 0.33 | Global | (Clune et al., 2017) |
| Peaches | 11.5 | 8.7 | 9.9 | 13.2 | 12.8 | 14.0 | 0.75 | Peru | (Bartl et al., 2012) |
| Grapes | 4.8 | 3.3 | 4.3 | 5.4 | 5.5 | 6.1 | 0.41 | Global | (Clune et al., 2017) |
| Strawberry | 5.6 | 3.5 | 4.6 | 5.7 | 6.5 | 9.5 | 0.48 | Peru | (Bartl et al., 2012) |
| Kiwis | 3.1 | 2.1 | 2.4 | 3.1 | 3.7 | 5.2 | 0.52 | Global | (Clune et al., 2017) |
| Melon | 5.5 | 4.3 | 5.9 | 5.7 | 6.9 | 5.0 | 0.65 | Brazil | (de Figueirêdo et al., 2013) |
| Watermelon | 2.9 | 2.4 | 3.3 | 2.7 | 3.3 | 2.7 | 0.32 | Global | (Clune et al., 2017) |
| Avocado | 15.3 | 10.7 | 13.7 | 16.3 | 18.3 | 20.0 | 0.66 | Peru | (Bartl et al., 2012) |
| Lemon | 10.9 | 6.9 | 10.3 | 11.6 | 12.1 | 17.2 | 0.22 | Global | (Clune et al., 2017) |
| Total | 139.1 | 98.8 | 128.8 | 137.2 | 163.4 | 193.0 | | | |
| Vegetables | | | | | | | | | |
| Lettuce | 23.0 | 16.7 | 24.2 | 23.2 | 25.5 | 29.6 | 0.81 | Global | (Clune et al., 2017) |
| Pepper | 10.9 | 7.3 | 10.1 | 12.0 | 12.8 | 3.1 | 1.00 | Global | (Clune et al., 2017) |
| Pumpkin | 11.2 | 8.2 | 11.1 | 11.1 | 11.5 | 17.4 | 0.25 | Argentina | (Blanke and Schaefer, 2012) |
| Tomato | 31.0 | 23.8 | 32.2 | 32.5 | 33.1 | 37.8 | 0.02 | Chile | (Lam et al., 2018) |
| Garlic | 9.1 | 6.7 | 9.3 | 10.1 | 10.5 | 9.7 | 0.55 | Global | (Clune et al., 2017) |
| Carrot | 9.9 | 8.7 | 10.0 | 10.1 | 10.0 | 11.6 | 0.22 | Global | (Clune et al., 2017) |
| Onion | 51.5 | 39.5 | 50.5 | 54.6 | 57.8 | 63.0 | 0.18 | Global | (Clune et al., 2017) |
| Total | 146.6 | 111.0 | 147.3 | 153.7 | 161.2 | 172.2 | | | |
| Pulses | | | | | | | | | |
| Beans | 5.9 | 6.1 | 6.2 | 5.9 | 6.3 | 4.2 | 0.51 | Global | (Clune et al., 2017) |
| Lentils | 2.3 | 2.0 | 2.6 | 2.0 | 2.2 | 2.7 | 1.03 | Global | (Clune et al., 2017) |
| Total | 8.1 | 8.1 | 8.9 | 7.9 | 8.5 | 7.0 | | | |

**Table 10.1. (cont.) Average daily intake per foodstuff for the six dietary scenarios designed based on socioeconomic status and carbon footprint (CF) associated.**

| Foodstuff | Average | Q1 | Q2 | Q3 | Q4 | Q5 | CF | Country | Source |
|---|---|---|---|---|---|---|---|---|---|
| | $g \cdot person^{-1} \cdot day^{-1}$ | | | | | | $kgCO_2eq \cdot kg^{-1}$ | | |
| Starch-based products | | | | | | | | | |
| Bread | 177.0 | 183.0 | 197.3 | 192.3 | 176.7 | 119.0 | 1.15 | Europe | (Espinoza-Orias et al., 2011; Kulak et al., 2015; Notarnicola et al., 2017) |
| Wheat Flour | 18.2 | 15.2 | 16.1 | 17.9 | 19.6 | 14.5 | 0.51 | | |
| Oat | 2.3 | 1.2 | 1.2 | 2.2 | 3.3 | 5.6 | 0.44 | Global | (Clune et al., 2017) |
| Maize | 31.4 | 24.5 | 26.2 | 30.9 | 35.2 | 33.0 | 0.48 | Global | (Clune et al., 2017) |
| Breakfast cereals | 4.8 | 1.9 | 3.4 | 4.7 | 6.4 | 13.3 | 2.64 | Europe | (Jeswani et al., 2015) |
| Potatoes | 76.3 | 89.7 | 90.0 | 78.0 | 70.7 | 42.3 | 0.36 | Global | (Clune et al., 2017) |
| Pasta | 20.6 | 14.8 | 18.7 | 20.3 | 24.4 | 25.9 | 1.28 | Europe | (Hess et al., 2016) |
| Rice | 28.0 | 22.4 | 24.5 | 27.5 | 33.2 | 30.2 | 2.66 | Global | |
| Total | 358.6 | 352.7 | 377.3 | 374.0 | 369.5 | 283.8 | | | |
| Nuts | | | | | | | | | |
| Walnuts | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 1.0 | 1.44 | Brazil | (de Figueirêdo et al., 2014) |
| Hazelnuts | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 1.0 | 0.23 | Europe | (Volpe et al., 2015) |
| Almonds | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 1.0 | 1.74 | Global | (Clune et al., 2017) |
| Dried plum | 0.7 | 0.4 | 0.4 | 0.6 | 1.0 | 1.6 | 0.41 | Chile | (Bravo et al., 2017) |
| Raisins | 0.7 | 0.4 | 0.4 | 0.6 | 1.0 | 1.6 | 0.83 | Europe | (Scarborough et al., 2014) |
| Total | 2.2 | 1.1 | 1.1 | 1.8 | 3.1 | 6.2 | | | |
| Dairy products | | | | | | | | | |
| Milk | 65.3 | 40.7 | 51.7 | 59.6 | 80.8 | 117.4 | 1.52 | Mexico | (Hagemann et al., 2011) |
| Yogurt | 25.6 | 15.8 | 22.6 | 24.0 | 31.8 | 42.0 | 1.30 | Global | (Clune et al., 2017) |
| Cheese | 17.9 | 10.0 | 14.0 | 16.7 | 22.1 | 34.1 | 8.73 | Global | (Clune et al., 2017) |
| Total | 108.9 | 66.5 | 88.4 | 100.3 | 134.7 | 193.5 | | | |
| Eggs | | | | | | | | | |
| Eggs | 17.1 | 14.7 | 17.2 | 18.3 | 18.0 | 17.0 | 3.26 | Global | (Clune et al., 2017) |

**Table 10.1. (cont.) Average daily intake per foodstuff for the six dietary scenarios designed based on socioeconomic status and carbon footprint (CF) associated.**

| Foodstuff | Average | Q1 | Q2 | Q3 | Q4 | Q5 | CF | Country | Source |
|---|---|---|---|---|---|---|---|---|---|
| | g·person$^{-1}$·day$^{-1}$ | | | | | | kg$CO_2$eq·kg$^{-1}$ | | |
| Meat | | | | | | | | | |
| Beef | 21.9 | 14.7 | 19.4 | 21.8 | 28.1 | 30.5 | 29.0 | Uruguay | (González et al., 2011) |
| Pork | 33.7 | 22.0 | 31.1 | 32.0 | 44.5 | 46.9 | 5.72 | Global | (Clune et al., 2017) |
| Chicken | 38.7 | 32.3 | 42.0 | 44.3 | 40.3 | 35.3 | 1.88 | Brazil | (Prudêncio da Silva et al., 2014) |
| Processed | 54.5 | 38.1 | 48.1 | 57.0 | 64.4 | 74.9 | 14.55 | Europe | (Noya et al., 2017) |
| Total | 148.8 | 107.1 | 140.7 | 155.2 | 177.4 | 187.6 | | | |
| Fish and seafood | | | | | | | | | |
| Hake | 3.5 | 3.8 | 3.8 | 3.5 | 3.2 | 3.0 | 0.53 | Chile | (Naranjo et al., 2021) |
| Tuna | 3.7 | 1.8 | 3.2 | 3.4 | 4.7 | 6.7 | 1.80 | Pacific Ocean | (Parker et al., 2015) |
| Mackerel | 2.5 | 2.5 | 2.9 | 2.5 | 2.9 | 1.3 | 1.54 | Europe | (Vázquez-Rowe et al., 2010a) |
| Total | 9.7 | 8.1 | 9.9 | 9.4 | 10.8 | 11.1 | | | |
| Sugar | | | | | | | | | |
| Sugar | 20.4 | 18.7 | 23.4 | 22.0 | 19.7 | 16.4 | 0.44 | Global | (Ecoinvent, 2023) |
| Oils and fats | | | | | | | | | |
| Butter | 3.1 | 2.0 | 2.3 | 3.0 | 4.0 | 4.9 | 7.20 | Canada | (Vergé et al., 2013) |
| Margarine | 3.0 | 2.5 | 3.6 | 3.5 | 3.2 | 2.0 | 2.12 | | |
| Vegetable oil | 17.6 | 14.4 | 17.6 | 19.4 | 19.5 | 17.1 | 0.81 | USA | (Heller et al., 2018) |
| Olive oil | 1.0 | 0.2 | 0.4 | 0.8 | 1.6 | 3.0 | 3.73 | Global | (Monini, 2014) |
| Total | 24.7 | 19.1 | 23.9 | 26.7 | 28.3 | 27.0 | | | |
| Confectionery | | | | | | | | | |
| Biscuits | 10.2 | 6.1 | 8.3 | 9.5 | 13.7 | 16.5 | 1.03 | United Kingdom | (Konstantas et al., 2019) |
| Cake | 53.0 | 27.7 | 41.0 | 48.8 | 67.8 | 103.0 | 2.64 | | |
| Marmalade | 2.2 | 1.3 | 1.6 | 2.1 | 2.7 | 4.0 | 1.60 | Europe | (Werner et al., 2014) |
| Chocolate | 2.6 | 1.0 | 1.3 | 1.8 | 3.0 | 8.2 | 3.60 | Global | (Miah et al., 2018) |
| Candy | 1.4 | 0.5 | 0.8 | 1.0 | 2.4 | 3.4 | 1.90 | United Kingdom | (Berners-Lee et al., 2012) |
| Ice-cream | 11.6 | 6.6 | 8.4 | 11.7 | 15.2 | 20.3 | 2.80 | Europe | (Werner et al., 2014) |
| Total | 81.0 | 43.3 | 61.4 | 75.1 | 104.9 | 155.3 | | | |

**Table 10.1. (cont.) Average daily intake per foodstuff for the six dietary scenarios designed based on socioeconomic status and carbon footprint (CF) associated.**

| Foodstuff | Average | Q1 | Q2 | Q3 | Q4 | Q5 | CF | Country | Source |
|---|---|---|---|---|---|---|---|---|---|
| | $g \cdot person^{-1} \cdot day^{-1}$ | | | | | | $kgCO_2eq \cdot kg^{-1}$ | | |
| Soups and broths | | | | | | | | | |
| Soups and broths | 3.7 | 2.5 | 2.8 | 3.2 | 4.3 | 8.2 | 4.00 | United Kingdom | (Berners-Lee et al., 2012) |
| Fast food | | | | | | | | | |
| Pizza | 30.3 | 18.4 | 22.1 | 30.3 | 39.2 | 52.4 | 2.50 | Europe | (Werner et al., 2014) |
| Chips | 30.3 | 18.4 | 22.1 | 30.3 | 39.2 | 52.4 | 1.55 | USA | (Heller et al., 2018) |
| Total | 60.6 | 36.8 | 44.2 | 60.6 | 78.4 | 104.9 | | | |
| Total | 1129.5 | 888.3 | 1075.3 | 1145.5 | 1282.2 | 1383.0 | | | |

Note: The first quintile (Q1) represents the population with the lowest income, and the fifth quintile group (Q5) represents the population with the highest income.

### 10.2.3 Overview of the system

The scope of this study considered a cradle-to-consumer approach. **Fig. 10.1** presents the system boundaries for the environmental assessment.

i) Food production and processing stage (S1): This sub-system includes all operations aimed at transforming raw agricultural products into food products ready for wholesale distribution. The system boundaries considered in this stage included the cradle-to-farm or gate approach.

ii) Wholesale and retail distribution (S2): This subsystem covers the distribution of products from the manufacturer to wholesale and retail buyers. The geographical origin of all foods included in the diet was analysed. Therefore, this study identified percentages of domestically produced and imported food. Food waste emissions to global warming were considered taking into account that large amounts of food losses and food waste are generated at this stage.

iii) Distribution from retailers to households (S3): This stage includes the path that food products travel from the wholesaler and retailer to the end user or final consumer. Consideration has been given to household food waste associated with buying more food than necessary, preparing excessively large portions or not reusing leftovers. The limits of the system used meant that culinary techniques were not taken into account, in agreement with other studies available in the literature (Esteve-Llorens et al., 2019b; González-García et al., 2020b).

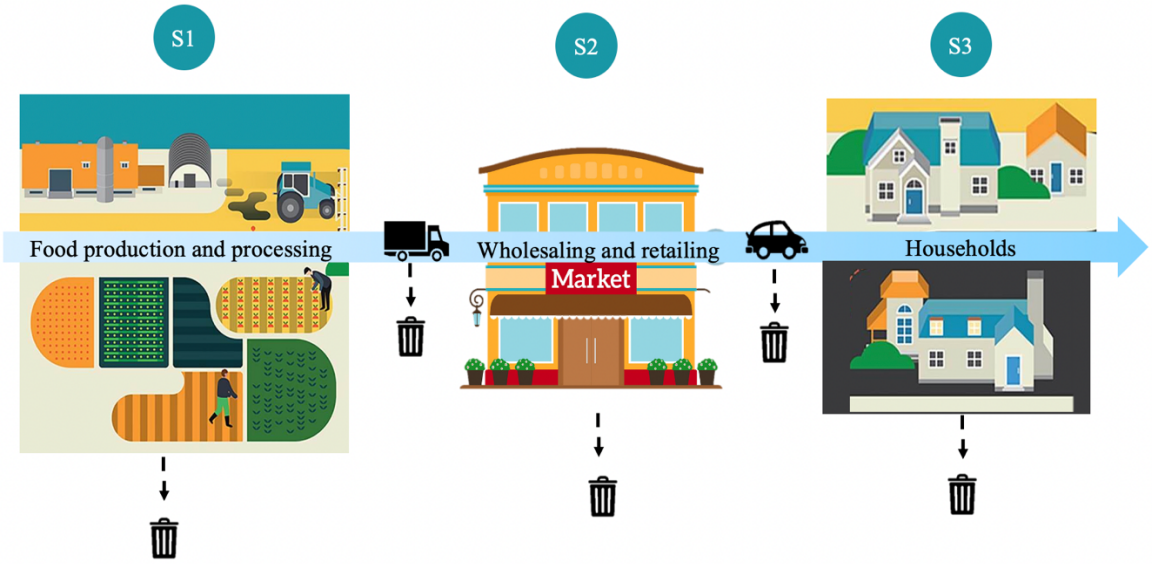


**Fig. 10.1. System boundaries for the carbon footprint calculations**

### 10.2.4 Data acquisition

10.2.4.1 Data acquisition for the distribution of food products

The distance covered by a food product from its production to the wholesaler and retailer was calculated according to the methodology proposed by González-García et al., (2020b). The Observatory of Economic Complexity (OEC) provided freely available information on international trade data and volumes of total imports and exports by food product and country (OEC, 2019). FAOSTAT provided free information on food and agriculture production data for country and year. Therefore, the production volume per foodstuff included in each scenario in tons per year was obtained from this database (FAO, 2019d). The most recent data prior to COVID-19 were used, as confinement could have affected world trade. Therefore, the year 2019 was chosen as the reference year.

It was assumed that food products originated in each production region are transported to wholesalers and retailers by ships and transoceanic trucks for international food products and by Euro 5 diesel freight trucks (>32 tonnes) in the case of domestic food products (González-García et al., 2020b). Considering that most producers do not sell directly to distances greater than 50 km in Chile, this was assumed as an average delivery distance for domestic distribution (Dirven, 2005). On the other hand, the distance to the nearest supermarket for the average household was estimated at 3.3 km (Batlle-Bayer et al., 2019b). The mode of transport to a supermarket was assumed to be a diesel vehicle. An average grocery shopper made one shopping trip per week. The Ecoinvent v3.8. database (Wernet et al., 2016) was used to calculate the $CO_2$eq emissions for lorry and transoceanic vessels. Detailed information on trade data and average distribution distances per food product was compiled in **Table 10.2**.

**Table 10.2. Trade data and average distribution distances per foodstuff**

| Oranges | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 535.2 |
| United States | 99.3 | National distance (km) | 47.1 |
| Belgium | 0.6 | Total distance (km) | 582.2 |
| Turkey | 0.1 | | |
| % Produced abroad | 5.9 | | |
| % Produced at national level | 94.1 | | |
| **Bananas** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3795.4 |
| Ecuador | 99 | National distance (km) | 0.2 |
| Bolivia | 0.7 | Total distance (km) | 3795.6 |
| Peru | 0.3 | | |
| % Produced abroad | 99.6 | | |
| % Produced at national level | 0.4 | | |
| **Apples** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 33.7 |
| United States | 88.2 | National distance (km) | 49.8 |
| China | 10 | Total distance (km) | 83.5 |
| Argentina | 1.9 | | |
| % Produced abroad | 99.6 | | |
| % Produced at national level | 0.4 | | |
| **Pear** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 14.4 |
| Argentina | 79.5 | National distance (km) | 49.8 |
| China | 14.8 | Total distance (km) | 64.3 |
| Colombia | 5.7 | | |
| % Produced abroad | 0.4 | | |
| % Produced at national level | 99.6 | | |
| **Peaches** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 5.8 |
| United States | 100 | National distance (km) | 50 |
| | | Total distance (km) | 55.8 |
| % Produced abroad | 5.9 | | |
| % Produced at national level | 94.1 | | |
| **Strawberries** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 0 |
| Turkey | 100 | National distance (km) | 50 |
| | | Total distance (km) | 50 |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Grapes | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 0 |
| United States | 69,4 | National distance (km) | 52.1 |
| India | 11.9 | Total distance (km) | 52.1 |
| Peru | 8.7 | | |
| Argentina | 6.6 | | |
| Iran | 3.4 | | |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |

| Kiwis | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 42.8 |
| Peru | 61.9 | National distance (km) | 49.4 |
| Ecuador | 28.2 | Total distance (km) | 92.2 |
| Mexico | 6.3 | | |
| Brazil | 3.5 | | |
| % Produced abroad | 1.2 | | |
| % Produced at national level | 98.8 | | |

| Melon | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 9.7 |
| Peru | 94.7 | National distance (km) | 49.8 |
| Brazil | 2.9 | Total distance (km) | 59.5 |
| Argentina | 2.4 | | |
| % Produced abroad | 0.3 | | |
| % Produced at national level | 99.7 | | |

| Watermelon | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 535.2 |
| United States | 99.3 | National distance (km) | 47.1 |
| Belgium | 0.6 | Total distance (km) | 582.2 |
| Turkey | 0.1 | | |
| % Produced abroad | 5.9 | | |
| % Produced at national level | 94.1 | | |

| Avocado | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1884.5 |
| Peru | 87.4 | National distance (km) | 25.7 |
| Mexico | 9.7 | Total distance (km) | 1910.2 |
| Israel | 2.9 | | |
| % Produced abroad | 48.4 | | |
| % Produced at national level | 51.5 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Lemon | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 861.5 |
| Peru | 49.3 | National distance (km) | 42.4 |
| United States | 43.1 | Total distance (km) | 904 |
| Colombia | 7.5 | | |
| % Produced abroad | 15.1 | | |
| % Produced at national level | 84.9 | | |
| **Lettuce** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 0 |
| China | 80.6 | National distance (km) | 50 |
| Brazil | 19.4 | Total distance (km) | 50 |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |
| **Pepper** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 482.6 |
| China | 50.5 | National distance (km) | 48.5 |
| Vietnam | 15.1 | Total distance (km) | 531.2 |
| Brazil | 17.1 | | |
| Spain | 10.5 | | |
| Germany | 6.9 | | |
| % Produced abroad | 2.9 | | |
| % Produced at national level | 97.1 | | |
| **Pumpkin** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 263.5 |
| Peru | 97.7 | National distance (km) | 45.5 |
| Argentina | 2.3 | Total distance (km) | 309 |
| % Produced abroad | 9 | | |
| % Produced at national level | 91 | | |
| **Tomato** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 5.5 |
| Peru | 100 | National distance (km) | 49.9 |
| | | Total distance (km) | 55.4 |
| % Produced abroad | 0.2 | | |
| % Produced at national level | 99.8 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Garlic | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 4223.5 |
| United States | 91 | National distance (km) | 24.7 |
| Argentina | 6.4 | Total distance (km) | 4248.3 |
| Peru | 2.6 | | |
| % Produced abroad | 50.5 | | |
| % Produced at national level | 49.5 | | |
| **Carrot** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 8.9 |
| United States | 94.4 | National distance (km) | 49.9 |
| Argentina | 5.6 | Total distance (km) | 58.9 |
| % Produced abroad | 0.1 | | |
| % Produced at national level | 99.9 | | |
| **Onion** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 788.6 |
| China | 78.5 | National distance (km) | 47.7 |
| Peru | 20 | Total distance (km) | 836.3 |
| United States | 1.5 | | |
| % Produced abroad | 4.6 | | |
| % Produced at national level | 95.4 | | |
| **Beans** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 723.8 |
| Peru | 95.8 | National distance (km) | 38.8 |
| United States | 4.2 | Total distance (km) | 762.5 |
| % Produced abroad | 22.5 | | |
| % Produced at national level | 77.5 | | |
| **Lentils** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 13870.8 |
| Canada | 97.4 | National distance (km) | 2.7 |
| United States | 2.6 | Total distance (km) | 13873.4 |
| % Produced abroad | 94.7 | | |
| % Produced at national level | 5.3 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Bread | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 40.1 |
| Argentina | 71.7 | National distance (km) | 49.4 |
| Mexico | 11.5 | Total distance (km) | 89.5 |
| United States | 7.5 | | |
| Italy | 9.3 | | |
| % Produced abroad | 1.1 | | |
| % Produced at national level | 98.9 | | |
| **Wheat flour** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1621.8 |
| Argentina | 71.7 | National distance (km) | 27.4 |
| Mexico | 11,5 | Total distance (km) | 1649.2 |
| United States | 7.5 | | |
| Italy | 9.3 | | |
| % Produced abroad | 45.2 | | |
| % Produced at national level | 54.8 | | |
| **Oat** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1.3 |
| Germany | 72.6 | National distance (km) | 50 |
| United States | 14.2 | Total distance (km) | 51.3 |
| United Kingdom | 5.1 | | |
| France | 2.6 | | |
| China | 2.0 | | |
| Peru | 1.8 | | |
| Spain | 1.7 | | |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |
| **Maize** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 731.8 |
| Argentina | 89.1 | National distance (km) | 14.1 |
| Paraguay | 9 | Total distance (km) | 745.9 |
| United States | 1.9 | | |
| % Produced abroad | 71.7 | | |
| % Produced at national level | 28.3 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Breakfast cereals | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 2535 |
| Argentina | 66.2 | National distance (km) | 13.8 |
| United States | 13.7 | Total distance (km) | 2548.8 |
| Canada | 9.3 | | |
| % Produced abroad | 72.3 | | |
| % Produced at national level | 27.7 | | |

| Potatoes | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 4.1 |
| Argentina | 36.5 | National distance (km) | 50 |
| United States | 43.4 | Total distance (km) | 54.1 |
| Peru | 8.1 | | |
| Germany | 11.9 | | |
| % Produced abroad | 0.1 | | |
| % Produced at national level | 99.9 | | |

| Pasta | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3840.8 |
| Peru | 35.7 | National distance (km) | 22.5 |
| Argentina | 28.1 | Total distance (km) | 3863.2 |
| Italy | 19.7 | | |
| China | 6.7 | | |
| Turkey | 6 | | |
| Costa Rica | 3.7 | | |
| % Produced abroad | 55.1 | | |
| % Produced at national level | 44.9 | | |

| Rice | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 985 |
| Argentina | 59.6 | National distance (km) | 23.9 |
| Paraguay | 24.7 | Total distance (km) | 1009 |
| Uruguay | 7.5 | | |
| Brazil | 2.6 | | |
| Pakistan | 2.5 | | |
| United States | 3.1 | | |
| % Produced abroad | 52.1 | | |
| % Produced at national level | 47.9 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Walnuts | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 49 |
| United Arab Emirates | 53.1 | National distance (km) | 343.4 |
| Canada | 22.6 | Total distance (km) | 392.4 |
| Switzerland | 24.3 | | |
| % Produced abroad | 2 | | |
| % Produced at national level | 98 | | |
| **Hazelnuts** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 191.5 |
| United States | 72.6 | National distance (km) | 49.1 |
| Spain | 23.2 | Total distance (km) | 240.6 |
| Germany | 4.3 | | |
| % Produced abroad | 1.8 | | |
| % Produced at national level | 98.2 | | |
| **Almonds** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 752.2 |
| United States | 99.4 | National distance (km) | 45.9 |
| Spain | 0.6 | Total distance (km) | 798.1 |
| % Produced abroad | 8.3 | | |
| % Produced at national level | 91.7 | | |
| **Dried plum** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 0.1 |
| Argentina | 98.2 | National distance (km) | 50 |
| Lithuania | 1.8 | Total distance (km) | 50.1 |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |
| **Raisins** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 10671 |
| India | 32.1 | National distance (km) | 0 |
| Peru | 23.7 | Total distance (km) | 10671 |
| Argentina | 17.9 | | |
| United States | 10.3 | | |
| Iran | 9.2 | | |
| Netherlands | 6.8 | | |
| % Produced abroad | 100 | | |
| % Produced at national level | 0 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Milk | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 188.7 |
| Spain | 65.5 | National distance (km) | 49.3 |
| Belgium | 25.1 | Total distance (km) | 238.4 |
| United States | 6 | | |
| Argentina | 3.4 | | |
| % Produced abroad | 1.4 | | |
| % Produced at national level | 98.6 | | |
| **Yogurt** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3.1 |
| United States | 45.2 | National distance (km) | 50 |
| Peru | 33.4 | Total distance (km) | 53.1 |
| Colombia | 10 | | |
| France | 7.2 | | |
| Switzerland | 2.8 | | |
| United Kingdom | 1.4 | | |
| % Produced abroad | 0 | | |
| % Produced at national level | 100 | | |
| **Cheese** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 2776.6 |
| United States | 35 | National distance (km) | 33.8 |
| Argentina | 26.9 | Total distance (km) | 2810.4 |
| Germany | 17.4 | | |
| Netherlands | 10.2 | | |
| New Zealand | 10.5 | | |
| % Produced abroad | 32.4 | | |
| % Produced at national level | 67.6 | | |
| **Eggs** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 24.1 |
| Argentina | 61 | National distance (km) | 49.8 |
| Denmark | 16.4 | Total distance (km) | 73.8 |
| United States | 12.2 | | |
| Brazil | 6.1 | | |
| Italy | 4.2 | | |
| % Produced abroad | 0.5 | | |
| % Produced at national level | 99.5 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Beef | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1228.8 |
| Paraguay | 40.1 | National distance (km) | 21.1 |
| Brazil | 39.9 | Total distance (km) | 1249.9 |
| Argentina | 20 | | |
| % Produced abroad | 57.7 | | |
| % Produced at national level | 42.3 | | |
| **Chicken** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 947.6 |
| Brazil | 48.3 | National distance (km) | 40.4 |
| United States | 37.1 | Total distance (km) | 988 |
| Argentina | 14.6 | | |
| % Produced abroad | 19.1 | | |
| % Produced at national level | 80.9 | | |
| **Pork** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1460.1 |
| United States | 47 | National distance (km) | 39.2 |
| Brazil | 45.3 | Total distance (km) | 1499.4 |
| Canada | 7.7 | | |
| % Produced abroad | 21.5 | | |
| % Produced at national level | 78.5 | | |
| **Processed meat** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 0 |
| United States | 69 | National distance (km) | 33.8 |
| Spain | 28.6 | Total distance (km) | 41.9 |
| Italy | 2.4 | | |
| % Produced abroad | 16.3 | | |
| % Produced at national level | 83.7 | | |
| **Sugar** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3117.7 |
| Italy | 66.8 | National distance (km) | 38.6 |
| United States | 25.3 | Total distance (km) | 3156.2 |
| France | 7.9 | | |
| % Produced abroad | 22.9 | | |
| % Produced at national level | 77.1 | | |

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Biscuits | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3052.9 |
| Argentina | 26.4 | National distance (km) | 27.4 |
| Peru | 23.6 | Total distance (km) | 3080.3 |
| Mexico | 13.5 | | |
| Germany | 13 | | |
| Spain | 12.5 | | |
| United States | 11.2 | | |
| % Produced abroad | 45.2 | | |
| % Produced at national level | 54.8 | | |
| **Cake** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 4500.6 |
| Spain | 28.3 | National distance (km) | 27.4 |
| United States | 23.4 | Total distance (km) | 4528 |
| Argentina | 17 | | |
| Belgium | 10.6 | | |
| Peru | 10.6 | | |
| China | 5.3 | | |
| Italy | 4.9 | | |
| % Produced abroad | 45.2 | | |
| % Produced at national level | 54.8 | | |
| **Marmalade** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 535.9 |
| Ecuador | 43.3 | National distance (km) | 46.5 |
| Spain | 20.1 | Total distance (km) | 582.4 |
| Argentina | 12.5 | | |
| Mexico | 7.3 | | |
| United States | 5.5 | | |
| France | 4.9 | | |
| India | 3.7 | | |
| China | 2.6 | | |
| % Produced abroad | 7 | | |
| % Produced at national level | 93 | | |

Notes: For the calculation of percentages of biscuits produced abroad and at national level, biscuits were assimilated to their main ingredient, wheat flour.

For the calculation of percentages of cakes produced abroad and at national level, cakes were assimilated to their main ingredient, wheat flour.

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Chocolate | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 3339.2 |
| Germany | 17.4 | National distance (km) | 33.2 |
| United States | 23.7 | Total distance (km) | 3372.5 |
| Brazil | 16.7 | | |
| Belgium | 12.8 | | |
| Argentina | 8.8 | | |
| Italy | 9.8 | | |
| Mexico | 5.6 | | |
| Spain | 5.2 | | |
| % Produced abroad | 33.6 | | |
| % Produced at national level | 66.4 | | |
| **Candy** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1692.6 |
| Argentina | 44.5 | National distance (km) | 38.6 |
| China | 24.8 | Total distance (km) | 1731.1 |
| Colombia | 8.7 | | |
| Mexico | 8.5 | | |
| Brazil | 7.5 | | |
| United States | 6.1 | | |
| % Produced abroad | 22.9 | | |
| % Produced at national level | 77.1 | | |
| **Ice-cream** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 188.5 |
| United States | 65.2 | National distance (km) | 48.7 |
| Argentina | 27.2 | Total distance (km) | 237.2 |
| France | 4.1 | | |
| Italy | 3.5 | | |
| % Produced abroad | 2.6 | | |
| % Produced at national level | 97.4 | | |
| **Soups and broths** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 4550 |
| United States | 78.8 | National distance (km) | 25 |
| Peru | 11.9 | Total distance (km) | 4575 |
| Spain | 3.9 | | |
| China | 3.8 | | |
| Poland | 1.7 | | |
| % Produced abroad | 50 | | |
| % Produced at national level | 50 | | |

Note: For the calculation of percentages of candy products produced abroad and at national level, candys were assimilated to their main ingredient, sugar

Due to the lack of information, pizza was assimilated to its main ingredient, wheat flour for the acquisition of trade data and the calculation average distribution distances

**Table 10.2. (cont.) Trade data and average distribution distances per foodstuff**

| Pizza | | | |
|---|---|---|---|
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 1621.8 |
| Argentina | 71.7 | National distance (km) | 27.4 |
| Mexico | 11.5 | Total distance (km) | 1649.2 |
| United States | 7.5 | | |
| Italy | 9.3 | | |
| % Produced abroad | 45.2 | | |
| % Produced at national level | 54.8 | | |
| **Chips** | | | |
| Trade data | | Average distribution distances | |
| Main importing countries | % import | Import distance (km) | 9 |
| Belgium | 57.9 | National distance (km) | 50 |
| Netherlands | 23.3 | Total distance (km) | 59 |
| Argentina | 11.5 | | |
| Germany | 7.2 | | |
| % Produced abroad | 0.1 | | |
| % Produced at national level | 99.9 | | |

Note: Due to the lack of information, pizza was assimilated to its main ingredient, wheat flour, for the acquisition of trade data and the calculation average distribution distances

### 10.2.5 Food loss and waste database

Food loss and waste occurring along the supply chain in wholesale and retail distribution was accounted for in the analysis following the weight percentages of food loss and waste for each product group reported by Gustavsson et al. (2013) for Latin America (see **Table 10.3)**. Food waste occurring downstream related to consumer behaviour was also estimated following the food waste percentages of Gustavsson et al. (2013).

**Table 10.3. Food waste and ratios of food waste in wholesale and retail distribution stage (S2) and distribution from retailers to households' stage (S3)**

| | | | Food waste (g·person$^{-1}$·day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | S2 | S3 | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| Fruits | | | | | | | | |
| Oranges | 0.12 | 0.10 | 5.59 | 3.80 | 4.94 | 4.37 | 6.87 | 9.68 |
| Bananas | 0.12 | 0.10 | 7.67 | 5.60 | 7.47 | 7.30 | 9.00 | 10.15 |
| Apples | 0.12 | 0.10 | 5.79 | 4.23 | 5.59 | 5.87 | 6.62 | 7.35 |
| Pears | 0.12 | 0.10 | 1.83 | 1.34 | 1.59 | 1.74 | 2.30 | 2.59 |
| Peaches | 0.12 | 0.10 | 3.01 | 2.28 | 2.59 | 3.48 | 3.35 | 3.68 |
| Grapes | 0.12 | 0.10 | 1.25 | 0.87 | 1.12 | 1.41 | 1.45 | 1.59 |
| Strawberries | 0.12 | 0.10 | 1.48 | 0.91 | 1.21 | 1.51 | 1.71 | 2.49 |
| Kiwis | 0.12 | 0.10 | 0.81 | 0.54 | 0.63 | 0.81 | 0.96 | 1.37 |
| Melon | 0.12 | 0.10 | 1.45 | 1.13 | 1.54 | 1.50 | 1.80 | 1.30 |
| Watermelon | 0.12 | 0.10 | 0.76 | 0.63 | 0.86 | 0.71 | 0.85 | 0.71 |
| Avocado | 0.12 | 0.10 | 4.03 | 2.80 | 3.59 | 4.29 | 4.81 | 5.25 |
| Lemon | 0.12 | 0.10 | 2.87 | 1.82 | 2.70 | 3.04 | 3.18 | 4.51 |
| Vegetables | | | | | | | | |
| Lettuce | 0.12 | 0.10 | 6.04 | 4.39 | 6.35 | 6.09 | 6.71 | 7.77 |
| Pepper | 0.12 | 0.10 | 2.87 | 1.91 | 2.66 | 3.16 | 3.37 | 0.81 |
| Pumpkin | 0.12 | 0.10 | 2.95 | 2.16 | 2.90 | 2.92 | 3.01 | 4.58 |
| Tomato | 0.12 | 0.10 | 8.15 | 6.26 | 8.46 | 8.55 | 8.69 | 9.92 |
| Garlic | 0.12 | 0.10 | 2.38 | 1.77 | 2.44 | 2.66 | 2.76 | 2.54 |
| Carrot | 0.12 | 0.10 | 2.60 | 2.28 | 2.62 | 2.65 | 2.62 | 3.05 |
| Onion | 0.12 | 0.10 | 13.51 | 10.37 | 13.26 | 14.34 | 15.19 | 16.55 |
| Pulses | | | | | | | | |
| Beans | 0.02 | 0.02 | 0.24 | 0.25 | 0.26 | 0.24 | 0.26 | 0.17 |
| Lentils | 0.02 | 0.02 | 0.09 | 0.08 | 0.11 | 0.08 | 0.09 | 0.11 |
| Starch-based products | | | | | | | | |
| Bread | 0.04 | 0.10 | 27.86 | 28.81 | 31.06 | 30.27 | 27.81 | 18.73 |
| Wheat flour | 0.04 | 0.10 | 2.87 | 2.39 | 2.53 | 2.82 | 3.08 | 2.27 |
| Oat | 0.04 | 0.10 | 0.36 | 0.19 | 0.18 | 0.35 | 0.53 | 0.88 |
| Maize | 0.04 | 0.10 | 4.94 | 3.86 | 4.12 | 4.86 | 5.55 | 5.19 |
| Breakfast cereals | 0.04 | 0.10 | 0.76 | 0.30 | 0.53 | 0.75 | 1.01 | 2.10 |
| Potatoes | 0.03 | 0.04 | 5.64 | 6.62 | 6.65 | 5.76 | 5.22 | 3.13 |
| Pasta | 0.04 | 0.10 | 3.24 | 2.34 | 2.94 | 3.19 | 3.84 | 4.08 |
| Rice | 0.04 | 0.10 | 4.40 | 3.52 | 3.85 | 4.34 | 5.23 | 4.76 |
| Nuts | | | | | | | | |
| Walnuts | 0.04 | 0.10 | 0.04 | 0.02 | 0.02 | 0.03 | 0.06 | 0.15 |
| Hazelnuts | 0.04 | 0.10 | 0.04 | 0.02 | 0.02 | 0.03 | 0.06 | 0.15 |
| Almonds | 0.04 | 0.10 | 0.04 | 0.02 | 0.02 | 0.03 | 0.06 | 0.15 |
| Dried plums | 0.12 | 0.10 | 0.18 | 0.10 | 0.10 | 0.16 | 0.26 | 0.43 |
| Raisins | 0.12 | 0.10 | 0.18 | 0.10 | 0.10 | 0.16 | 0.26 | 0.43 |

**Table 10.3. (cont) Food waste and ratios of food waste in wholesale and retail distribution stage (S2) and distribution from retailers to households' stage (S3)**

| | | | Food waste (g·person$^{-1}$·day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | S2 | S3 | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| Dairy products | | | | | | | | |
| Milk | 0.08 | 0.04 | 8.64 | 5.39 | 6.84 | 7.89 | 10.68 | 15.52 |
| Yogurt | 0.08 | 0.04 | 3.39 | 2.08 | 2.99 | 3.17 | 4.20 | 5.55 |
| Cheese | 0.08 | 0.04 | 2.37 | 1.32 | 1.86 | 2.21 | 2.93 | 4.51 |
| Eggs | | | | | | | | |
| Eggs | 0.05 | 0.06 | 2,69 | 2.31 | 2.71 | 2.88 | 2.84 | 2.68 |
| Meat | | | | | | | | |
| Beef | 0.05 | 0.06 | 2.62 | 1.76 | 2.33 | 2.62 | 3.36 | 3.65 |
| Pork | 0.05 | 0.06 | 4.04 | 2.64 | 3.73 | 3.84 | 5.33 | 5.62 |
| Chicken | 0.05 | 0.06 | 4.63 | 3.87 | 5.03 | 5.31 | 4.83 | 4.23 |
| Processed meat | 0.05 | 0.06 | 6.53 | 4.57 | 5.76 | 6.83 | 7.72 | 8.97 |
| Sugar | | | | | | | | |
| Sugar | 0.04 | 0.10 | 3.22 | 2.94 | 3.69 | 3.47 | 3.11 | 2.59 |
| Oils and fats | | | | | | | | |
| Butter | 0.08 | 0.04 | 0.40 | 0.26 | 0.31 | 0.40 | 0.53 | 0.65 |
| Margarine | 0.08 | 0.04 | 0.40 | 0.33 | 0.47 | 0.46 | 0.43 | 0.26 |
| Vegetable oil | 0.02 | 0.02 | 0.72 | 0.59 | 0.73 | 0.80 | 0.81 | 0.71 |
| Olive oil | 0.02 | 0.02 | 0.04 | 0.01 | 0.02 | 0.03 | 0.06 | 0.12 |
| Confectionery | | | | | | | | |
| 1Biscuits | 0.04 | 0.10 | 1.60 | 0.95 | 1.30 | 1.50 | 2.15 | 2.60 |
| 1Cake | 0.04 | 0.10 | 8.34 | 4.37 | 6.45 | 7.69 | 10.67 | 16.21 |
| 1Marmalade | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chocolate | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1Candy | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ice-Cream | 0.08 | 0.04 | 1.53 | 0.87 | 1.12 | 1.55 | 2.01 | 2.68 |
| Soups and broths | | | | | | | | |
| 2Soups and broths | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fast food | | | | | | | | |
| 1Pizza | 0.04 | 0.10 | 4.77 | 2.90 | 3.48 | 4.77 | 6.17 | 8.25 |
| Chips | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fish and seafood | | | | | | | | |
| Hake | 0.10 | 0.04 | 0.55 | 0.59 | 0.60 | 0.56 | 0.51 | 0.48 |
| Tuna | 0.10 | 0.04 | 0.58 | 0.29 | 0.50 | 0.53 | 0.74 | 1.06 |
| Mackerel | 0.10 | 0.04 | 0.39 | 0.39 | 0.46 | 0.39 | 0.46 | 0.21 |

### 10.2.6 Carbon footprint methodology

The LCA methodology was applied as a holistic tool for quantifying the CF of the Chilean dietary scenarios. The methodology reports the diet-related GHG emissions (or $CO_2$eq emissions), expressing impacts relative to a functional unit. The selected functional unit was defined as the daily food consumption per person ($g \cdot person^{-1} \cdot day^{-1}$). This is a very common functional unit used in the environmental assessment of diets, allowing the comparison of the Chilean food profile and other relevant studies (Esteve-Llorens et al., 2020a; González-García et al., 2020b)

In total, 31 cradle-to-gate LCA studies were considered to assess the effect of all foods that constitute the Chilean diet on climate-warming GHG emissions. Priority was given to cradle-to-farm or cradle-to-industry gate LCA per-reviewed journal articles, which considers the food production and processing stage. If studies took into consideration other additional life cycle stages (cradle-to-grave, cradle-to-retailer or cradle-to-consumer LCA studies), these were removed from the CF estimation. On the other hand, local LCA studies on food production were chosen when available. Although several food LCAs have been conducted in Chile in recent years, they were not sufficient to cover the entire Chilean food basket. There are no life cycle impact studies for all foodstuffs considered in the dietary scenarios, which considers Chile as the country of origin. To our best knowledge, it was found local LCA studies to estimate the CF of apples (Iriarte et al., 2021), tomato (Lam et al., 2018) and dried plum (Bravo et al., 2017), where Chile was considered as a country of origin. When there were not available, GHG emissions results were extracted from the LCA of food systems in the Latin American region (Bartl et al., 2012; de Figueirêdo et al., 2014; Hagemann et al., 2011; Prudêncio da Silva et al., 2014). If no LCA from peer-reviewed journal articles were available in Chile or Latin America context, an average global or European study was considered based mainly on the systematic literature review and meta-analysis of food LCA studies by Clune et al., (2017) and in other studies available in the literature (Berners-Lee et al., 2012; Heller et al., 2018; Werner et al., 2014). The CF values corresponded to the production stage for the foodstuffs included in the designed scenarios, as well as the country of origin of each foodstuff and the reference consulted were gathered in **Table 10.1**.

### 10.2.7 Water footprint methodology

The first two phases of the WFA: i) setting goals and scope and ii) accounting were undertaken to map the green, blue and grey WF of the Chilean dietary scenarios (WFN, 2020). Statistics on green, blue and grey WFs of crops, derived crops and livestock products were managed at national level. The scientific articles by Mekonnen and Hoekstra (2010, 2011) were used as the basic database for the calculation of the three components of WF for each food item following the methodological procedure developed by González-García et al. (2020b). The WF of marine capture fisheries (non-aquaculture) was assumed to be zero (Blas et al., 2019; Harris et al., 2017). Feed-related commercial water consumption was adopted for the farmed fish cultivated under an aquaculture regime (Pahlow et al., 2015).

### 10.2.8 Nutritional Quality Analysis

The nutritional quality index developed by van Dooren et al. (2014) aims to measure the overall quality of the individual diet based on nutrient density indicators. Ten components were thus identified: qualifying groups to encourage (fruits, vegetables and fish), disqualifying nutrients to limit (saturated fat, free sugars, sodium, total fats), qualifying nutrients to encourage (protein, fiber), proportion of energy from carbohydrates and total daily energy intake. The dietary intakes for nutrients values reported by the WHO and the WCRF were considered as a

reference (**Table 10.4)**. Detailed information about this index can be consulted in **Chapter 3 (Section I)**.

**Table 10.4. Nutritional quality index for the six dietary scenarios designed based on socioeconomic status**

| | Units | Reference value | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
|---|---|---|---|---|---|---|---|---|
| Vegetables | g | 200 | 147 | 111 | 147 | 154 | 161 | 172 |
| Fruits | g | 200 | 139 | 99 | 129 | 137 | 163 | 193 |
| Total fatty acids | % | 30 | 34 | 31 | 33 | 34 | 42 | 37 |
| Free sugars | % | 10 | 12 | 12 | 13 | 12 | 12 | 12 |
| Fiber | g | 30 | 22 | 19 | 21 | 22 | 24 | 24 |
| Sodium | g | 5 | 2 | 2 | 2 | 3 | 3 | 3 |
| Carbohydrates | % | 52 | 49 | 51 | 50 | 49 | 48 | 46 |
| Saturated fatty acids | % | 10 | 11 | 10 | 10 | 11 | 12 | 14 |
| Fish | g | 37 | 10 | 8 | 10 | 9 | 11 | 11 |
| Energy | kcal | 2000 | 2300 | 1765 | 2114 | 2333 | 2653 | 2913 |
| Nutritional Quality Index | | 100 | 86 | 75 | 84 | 87 | 94 | 98 |

Note: The dietary intakes for nutrients values reported by the World Health Organisation (WHO) and the World Cancer Research Fund International (WCRF) were considered as a reference.

### 10.2.9 Cost Analysis

The theoretical cost of the six dietary scenarios was calculated by multiplying the amounts of food consumed (g) per person and day by the corresponding price and adding up the total sum. The single national prices for each food item were obtained from the following data sources: food price database of the Office of Agricultural Studies and Policies, National Statistics Institute price publications and the prices reported by the VIII Family Budget Survey 2017 (Government of Chile, 2021).

## 10.3 RESULTS AND DISCUSSION

### 10.3.1 Environmental impacts of the average Chilean diet

Concerning $CO_2$eq emissions, the diet of an average Chilean citizen had a CF value of 3.42 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$. A major contribution (96%) was associated with the food production and processing stage. The remaining stages of the food value chain, wholesale and retail distribution and distribution from retailers to households, have a much smaller contribution to the carbon profile, accounting for 2% of total GHG emissions (see **Fig. 10.2a**). On the other hand, a considerable amount of food entering the food supply chain is wasted. GHG emissions from food waste and losses were 0.38 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$, representing about 12% of total CF associated with food production and processing stage (see **Table 10.3**).

The largest source of GHG emissions in the Chilean diet was meat, accounting for approximately 58% of the total CF derived from the food production and processing stage, followed by starch-based products (13%) and dairy products (10%) (see **Fig. 10.2b**). Emissions from beef and processed meat represented 37% and 47% of the total CF of meat, respectively (equivalent to 1.60 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$). The high emission intensities of meat in Chile were explained by the large proportion of meat consumption per capita as well as for the climate impact of beef (29 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$) (González et al., 2011) and processed meat (14.55 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$) (Noya et al., 2017). The CFs for the food production and processing

stage per foodstuff for the six dietary scenarios based on socioeconomic status could be seen in **Table 10.5**.

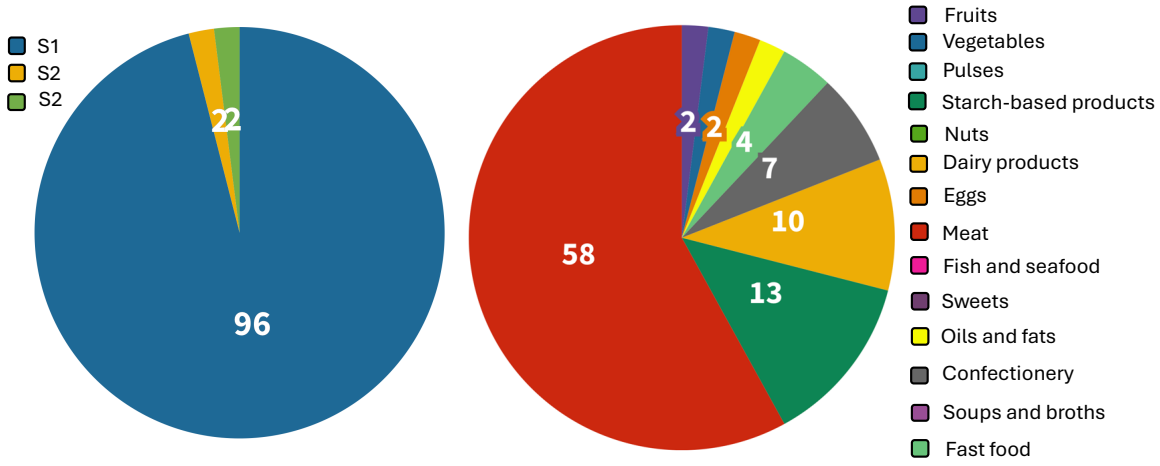


**Fig. 10.2. Breakdown of the greenhouse gas emissions across the life cycle stages (a) and per food categories for the average Chilean diet (b).**

**Table 10.5. Carbon footprints for the food production and processing stage per foodstuff for the six dietary scenarios designed based on socioeconomic status**

| Total Carbon Footprint (kg $CO_2$·person$^{-1}$day$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|
| | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| | | | Fruits | | | |
| Oranges | $3.01 \cdot 10^{-3}$ | $2.05 \cdot 10^{-3}$ | $2.66 \cdot 10^{-3}$ | $2.35 \cdot 10^{-3}$ | $3.70 \cdot 10^{-3}$ | $5.21 \cdot 10^{-3}$ |
| Bananas | $1.31 \cdot 10^{-2}$ | $9.56 \cdot 10^{-3}$ | $1.27 \cdot 10^{-2}$ | $1.25 \cdot 10^{-2}$ | $1.54 \cdot 10^{-2}$ | $1.73 \cdot 10^{-2}$ |
| Apples | $1.78 \cdot 10^{-3}$ | $1.30 \cdot 10^{-3}$ | $1.72 \cdot 10^{-3}$ | $1.81 \cdot 10^{-3}$ | $2.04 \cdot 10^{-3}$ | $2.26 \cdot 10^{-3}$ |
| Pears | $2.86 \cdot 10^{-3}$ | $2.09 \cdot 10^{-3}$ | $2.49 \cdot 10^{-3}$ | $2.72 \cdot 10^{-3}$ | $3.59 \cdot 10^{-3}$ | $4.05 \cdot 10^{-3}$ |
| Peaches | $1.08 \cdot 10^{-2}$ | $8.19 \cdot 10^{-3}$ | $9.30 \cdot 10^{-3}$ | $1.25 \cdot 10^{-2}$ | $1.20 \cdot 10^{-2}$ | $1.32 \cdot 10^{-2}$ |
| Grapes | $2.49 \cdot 10^{-3}$ | $1.73 \cdot 10^{-3}$ | $2.22 \cdot 10^{-3}$ | $2.81 \cdot 10^{-3}$ | $2.89 \cdot 10^{-3}$ | $3.16 \cdot 10^{-3}$ |
| Strawberries | $3.41 \cdot 10^{-3}$ | $2.09 \cdot 10^{-3}$ | $2.80 \cdot 10^{-3}$ | $3.48 \cdot 10^{-3}$ | $3.94 \cdot 10^{-3}$ | $5.75 \cdot 10^{-3}$ |
| Kiwis | $2.01 \cdot 10^{-3}$ | $1.34 \cdot 10^{-3}$ | $1.56 \cdot 10^{-3}$ | $2.01 \cdot 10^{-3}$ | $2.39 \cdot 10^{-3}$ | $3.41 \cdot 10^{-3}$ |
| Melon | $4.54 \cdot 10^{-3}$ | $3.53 \cdot 10^{-3}$ | $4.82 \cdot 10^{-3}$ | $4.68 \cdot 10^{-3}$ | $5.63 \cdot 10^{-3}$ | $4.07 \cdot 10^{-3}$ |
| Watermelon | $1.17 \cdot 10^{-3}$ | $9.62 \cdot 10^{-4}$ | $1.32 \cdot 10^{-3}$ | $1.10 \cdot 10^{-3}$ | $1.31 \cdot 10^{-3}$ | $1.09 \cdot 10^{-3}$ |
| Avocado | $1.27 \cdot 10^{-2}$ | $8.84 \cdot 10^{-3}$ | $1.13 \cdot 10^{-2}$ | $1.35 \cdot 10^{-2}$ | $1.52 \cdot 10^{-2}$ | $1.66 \cdot 10^{-2}$ |
| Lemon | $2.98 \cdot 10^{-3}$ | $1.89 \cdot 10^{-3}$ | $2.80 \cdot 10^{-3}$ | $3.16 \cdot 10^{-3}$ | $3.31 \cdot 10^{-3}$ | $4.68 \cdot 10^{-3}$ |
| Total | $6.09 \cdot 10^{-2}$ | $4.36 \cdot 10^{-2}$ | $5.58 \cdot 10^{-2}$ | $6.26 \cdot 10^{-2}$ | $7.14 \cdot 10^{-2}$ | $8.08 \cdot 10^{-2}$ |
| | | | Vegetables | | | |
| Lettuce | $2.35 \cdot 10^{-2}$ | $1.71 \cdot 10^{-2}$ | $2.47 \cdot 10^{-2}$ | $2.37 \cdot 10^{-2}$ | $2.61 \cdot 10^{-2}$ | $3.03 \cdot 10^{-2}$ |
| Pepper | $1.37 \cdot 10^{-2}$ | $9.13 \cdot 10^{-3}$ | $1.27 \cdot 10^{-2}$ | $1.51 \cdot 10^{-2}$ | $1.61 \cdot 10^{-2}$ | $3.88 \cdot 10^{-3}$ |
| Pumpkin | $3.50 \cdot 10^{-3}$ | $2.56 \cdot 10^{-3}$ | $3.45 \cdot 10^{-3}$ | $3.47 \cdot 10^{-3}$ | $3.57 \cdot 10^{-3}$ | $5.44 \cdot 10^{-3}$ |
| Tomato | $7.05 \cdot 10^{-4}$ | $5.42 \cdot 10^{-4}$ | $7.32 \cdot 10^{-4}$ | $7.40 \cdot 10^{-4}$ | $7.52 \cdot 10^{-4}$ | $8.58 \cdot 10^{-4}$ |
| Garlic | $6.59 \cdot 10^{-2}$ | $4.90 \cdot 10^{-3}$ | $6.73 \cdot 10^{-3}$ | $7.35 \cdot 10^{-2}$ | $7.62 \cdot 10^{-3}$ | $7.02 \cdot 10^{-3}$ |
| Carrot | $2.75 \cdot 10^{-3}$ | $2.41 \cdot 10^{-3}$ | $2.77 \cdot 10^{-3}$ | $2.81 \cdot 10^{-3}$ | $2.77 \cdot 10^{-3}$ | $3.23 \cdot 10^{-3}$ |
| Onion | $1.17 \cdot 10^{-2}$ | $8.97 \cdot 10^{-3}$ | $1.15 \cdot 10^{-2}$ | $1.24 \cdot 10^{-2}$ | $1.31 \cdot 10^{-2}$ | $1.43 \cdot 10^{-2}$ |
| Total | $6.25 \cdot 10^{-2}$ | $4.56 \cdot 10^{-2}$ | $6.26 \cdot 10^{-2}$ | $6.56 \cdot 10^{-2}$ | $7.01 \cdot 10^{-2}$ | $6.50 \cdot 10^{-2}$ |

**Table 10.5. (cont.) Carbon footprints for the food production and processing stage per foodstuff for the six dietary scenarios designed based on socioeconomic status**

| | Total Carbon Footprint (kg $CO_2$·person$^{-1}$day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| | | | Pulses | | | |
| Beans | $3.11 \cdot 10^{-3}$ | $3.22 \cdot 10^{-3}$ | $3.31 \cdot 10^{-3}$ | $3.14 \cdot 10^{-3}$ | $3.35 \cdot 10^{-3}$ | $2.25 \cdot 10^{-3}$ |
| Lentils | $2.45 \cdot 10^{-3}$ | $2.18 \cdot 10^{-3}$ | $2.83 \cdot 10^{-3}$ | $2.18 \cdot 10^{-3}$ | $2.36 \cdot 10^{-3}$ | $2.94 \cdot 10^{-3}$ |
| Total | $5.55 \cdot 10^{-3}$ | $5.40 \cdot 10^{-3}$ | $6.14 \cdot 10^{-3}$ | $5.32 \cdot 10^{-3}$ | $5.71 \cdot 10^{-3}$ | $5.19 \cdot 10^{-3}$ |
| | | | Starch-based products | | | |
| Bread | $2.36 \cdot 10^{-1}$ | $2.44 \cdot 10^{-1}$ | $2.63 \cdot 10^{-1}$ | $2.56 \cdot 10^{-1}$ | $2.35 \cdot 10^{-1}$ | $1.58 \cdot 10^{-1}$ |
| Wheat flour | $1.07 \cdot 10^{-2}$ | $8.98 \cdot 10^{-3}$ | $9.49 \cdot 10^{-3}$ | $1.06 \cdot 10^{-2}$ | $1.16 \cdot 10^{-2}$ | $8.53 \cdot 10^{-3}$ |
| Oat | $1.15 \cdot 10^{-3}$ | $6.02 \cdot 10^{-4}$ | $5.86 \cdot 10^{-4}$ | $1.14 \cdot 10^{-3}$ | $1.70 \cdot 10^{-3}$ | $2.86 \cdot 10^{-3}$ |
| Maize | $1.74 \cdot 10^{-2}$ | $1.36 \cdot 10^{-2}$ | $1.45 \cdot 10^{-2}$ | $1.72 \cdot 10^{-2}$ | $1.96 \cdot 10^{-2}$ | $1.83 \cdot 10^{-2}$ |
| Cereals | $1.47 \cdot 10^{-2}$ | $5.75 \cdot 10^{-3}$ | $1.03 \cdot 10^{-2}$ | $1.45 \cdot 10^{-2}$ | $1.96 \cdot 10^{-2}$ | $4.07 \cdot 10^{-2}$ |
| Potatoes | $2.92 \cdot 10^{-2}$ | $3.43 \cdot 10^{-2}$ | $3.44 \cdot 10^{-2}$ | $2.98 \cdot 10^{-2}$ | $2.70 \cdot 10^{-2}$ | $1.62 \cdot 10^{-2}$ |
| Pasta | $3.05 \cdot 10^{-2}$ | $2.20 \cdot 10^{-2}$ | $2.77 \cdot 10^{-2}$ | $3.01 \cdot 10^{-2}$ | $3.62 \cdot 10^{-2}$ | $3.84 \cdot 10^{-2}$ |
| Rice | $8.61 \cdot 10^{-2}$ | $6.89 \cdot 10^{-2}$ | $7.53 \cdot 10^{-2}$ | $8.48 \cdot 10^{-2}$ | $1.02 \cdot 10^{-1}$ | $9.31 \cdot 10^{-2}$ |
| Total | $4.25 \cdot 10^{-1}$ | $3.98 \cdot 10^{-1}$ | $4.35 \cdot 10^{-1}$ | $4.44 \cdot 10^{-1}$ | $4.53 \cdot 10^{-1}$ | $3.76 \cdot 10^{-1}$ |
| | | | Nuts | | | |
| Walnuts | $4.50 \cdot 10^{-4}$ | $1.64 \cdot 10^{-4}$ | $1.78 \cdot 10^{-4}$ | $3.31 \cdot 10^{-4}$ | $6.72 \cdot 10^{-4}$ | $1.60 \cdot 10^{-3}$ |
| Hazelnuts | $7.18 \cdot 10^{-5}$ | $2.62 \cdot 10^{-5}$ | $2.85 \cdot 10^{-5}$ | $5.29 \cdot 10^{-5}$ | $1.00 \cdot 10^{-4}$ | $2.55 \cdot 10^{-3}$ |
| Almonds | $5.43 \cdot 10^{-4}$ | $1.98 \cdot 10^{-4}$ | $2.15 \cdot 10^{-4}$ | $4.00 \cdot 10^{-4}$ | $7.58 \cdot 10^{-4}$ | $1.93 \cdot 10^{-3}$ |
| Dried plums | $3.60 \cdot 10^{-4}$ | $1.97 \cdot 10^{-4}$ | $1.93 \cdot 10^{-4}$ | $3.13 \cdot 10^{-4}$ | $5.09 \cdot 10^{-4}$ | $8.50 \cdot 10^{-4}$ |
| Raisins | $7.29 \cdot 10^{-4}$ | $3.99 \cdot 10^{-4}$ | $3.90 \cdot 10^{-4}$ | $6.33 \cdot 10^{-4}$ | $1.03 \cdot 10^{-3}$ | $1.72 \cdot 10^{-3}$ |
| Total | $2.15 \cdot 10^{-3}$ | $9.84 \cdot 10^{-4}$ | $1.00 \cdot 10^{-3}$ | $1.73 \cdot 10^{-3}$ | $3.02 \cdot 10^{-3}$ | $6.36 \cdot 10^{-3}$ |
| | | | Dairy products | | | |
| Milk | $1.12 \cdot 10^{-1}$ | $7.01 \cdot 10^{-2}$ | $8.90 \cdot 10^{-2}$ | $1.03 \cdot 10^{-1}$ | $1.39 \cdot 10^{-1}$ | $2.02 \cdot 10^{-1}$ |
| Yogurt | $3.77 \cdot 10^{-2}$ | $2.32 \cdot 10^{-2}$ | $3.33 \cdot 10^{-2}$ | $3.53 \cdot 10^{-2}$ | $4.68 \cdot 10^{-2}$ | $6.18 \cdot 10^{-2}$ |
| Cheese | $1.77 \cdot 10^{-1}$ | $9.90 \cdot 10^{-2}$ | $1.39 \cdot 10^{-1}$ | $1.65 \cdot 10^{-1}$ | $2.19 \cdot 10^{-1}$ | $3.37 \cdot 10^{-1}$ |
| Total | $3.27 \cdot 10^{-1}$ | $1.92 \cdot 10^{-1}$ | $2.61 \cdot 10^{-1}$ | $3.03 \cdot 10^{-1}$ | $4.04 \cdot 10^{-1}$ | $6.01 \cdot 10^{-1}$ |
| | | | Eggs | | | |
| Eggs | $6.44 \cdot 10^{-2}$ | $5.53 \cdot 10^{-2}$ | $6.50 \cdot 10^{-2}$ | $6.90 \cdot 10^{-2}$ | $6.81 \cdot 10^{-2}$ | $6.43 \cdot 10^{-2}$ |
| | | | Meat | | | |
| Beef | $7.11 \cdot 10^{-1}$ | $4.76 \cdot 10^{-1}$ | $6.31 \cdot 10^{-1}$ | $7.10 \cdot 10^{-1}$ | $9.12 \cdot 10^{-1}$ | $9.89 \cdot 10^{-1}$ |
| Pork | $2.16 \cdot 10^{-1}$ | $1.41 \cdot 10^{-1}$ | $1.99 \cdot 10^{-1}$ | $2.05 \cdot 10^{-1}$ | $2.85 \cdot 10^{-1}$ | $3.00 \cdot 10^{-1}$ |
| Chicken | $8.12 \cdot 10^{-2}$ | $6.79 \cdot 10^{-2}$ | $8.82 \cdot 10^{-2}$ | $9.31 \cdot 10^{-2}$ | $8.47 \cdot 10^{-2}$ | $7.42 \cdot 10^{-2}$ |
| Processed meat | $8.89 \cdot 10^{-1}$ | $6.21 \cdot 10^{-1}$ | $7.84 \cdot 10^{-1}$ | $9.29 \cdot 10^{-1}$ | $1.05 \cdot 10^{-0}$ | $1.22 \cdot 10^{-0}$ |
| Total | $1.90 \cdot 10^{-0}$ | $1.31 \cdot 10^{-0}$ | $1.79 \cdot 10^{-0}$ | $1.94 \cdot 10^{-0}$ | $2.33 \cdot 10^{-0}$ | $2.58 \cdot 10^{-0}$ |
| | | | Sugar | | | |
| Sugar | $1.04 \cdot 10^{-2}$ | $9.50 \cdot 10^{-3}$ | $1.19 \cdot 10^{-2}$ | $1.12 \cdot 10^{-2}$ | $1.00 \cdot 10^{-2}$ | $8.37 \cdot 10^{-3}$ |
| | | | Oils and fats | | | |
| Butter | $2.49 \cdot 10^{-2}$ | $1.61 \cdot 10^{-2}$ | $1.89 \cdot 10^{-2}$ | $2.47 \cdot 10^{-2}$ | $3.25 \cdot 10^{-2}$ | $3.98 \cdot 10^{-2}$ |
| Margarine | $7.25 \cdot 10^{-3}$ | $5.91 \cdot 10^{-3}$ | $8.60 \cdot 10^{-3}$ | $8.31 \cdot 10^{-3}$ | $7.74 \cdot 10^{-3}$ | $4.75 \cdot 10^{-3}$ |
| Vegetable oil | $1.48 \cdot 10^{-2}$ | $1.22 \cdot 10^{-2}$ | $1.49 \cdot 10^{-2}$ | $1.64 \cdot 10^{-2}$ | $1.65 \cdot 10^{-2}$ | $1.44 \cdot 10^{-2}$ |
| Olive oil | $3.91 \cdot 10^{-3}$ | $8.93 \cdot 10^{-4}$ | $1.67 \cdot 10^{-3}$ | $3.13 \cdot 10^{-3}$ | $6.05 \cdot 10^{-3}$ | $1.16 \cdot 10^{-2}$ |
| Total | $5.09 \cdot 10^{-2}$ | $3.50 \cdot 10^{-2}$ | $4.40 \cdot 10^{-2}$ | $5.25 \cdot 10^{-2}$ | $6.28 \cdot 10^{-2}$ | $7.06 \cdot 10^{-2}$ |

**Table 10.5. (cont.) Carbon footprints for the food production and processing stage per foodstuff for the six dietary scenarios designed based on socioeconomic status**

| | Total Carbon Footprint (kg $CO_2$·person$^{-1}$day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| | | | Confectionery | | | |
| Biscuits | $1.21 \cdot 10^{-2}$ | $7.22 \cdot 10^{-3}$ | $9.86 \cdot 10^{-3}$ | $1.14 \cdot 10^{-2}$ | $1.63 \cdot 10^{-2}$ | $1.97 \cdot 10^{-2}$ |
| Cake | $1.62 \cdot 10^{-1}$ | $8.47 \cdot 10^{-2}$ | $1.25 \cdot 10^{-1}$ | $1.49 \cdot 10^{-1}$ | $2.07 \cdot 10^{-1}$ | $3.15 \cdot 10^{-1}$ |
| Marmalade | $3.48 \cdot 10^{-3}$ | $2.11 \cdot 10^{-3}$ | $2.53 \cdot 10^{-3}$ | $3.40 \cdot 10^{-3}$ | $4.39 \cdot 10^{-3}$ | $6.36 \cdot 10^{-3}$ |
| Chocolate | $9.41 \cdot 10^{-3}$ | $3.77 \cdot 10^{-3}$ | $4.82 \cdot 10^{-3}$ | $6.63 \cdot 10^{-3}$ | $1.08 \cdot 10^{-2}$ | $2.94 \cdot 10^{-2}$ |
| Candy | $2.73 \cdot 10^{-3}$ | $1.03 \cdot 10^{-3}$ | $1.47 \cdot 10^{-3}$ | $1.95 \cdot 10^{-3}$ | $4.64 \cdot 10^{-3}$ | $6.44 \cdot 10^{-3}$ |
| Ice-Cream | $3.68 \cdot 10^{-2}$ | $2.09 \cdot 10^{-2}$ | $2.68 \cdot 10^{-2}$ | $3.72 \cdot 10^{-2}$ | $4.82 \cdot 10^{-2}$ | $6.42 \cdot 10^{-2}$ |
| Total | $2.26 \cdot 10^{-2}$ | $1.20 \cdot 10^{-1}$ | $1.71 \cdot 10^{-1}$ | $2.10 \cdot 10^{-1}$ | $2.92 \cdot 10^{-1}$ | $4.41 \cdot 10^{-1}$ |
| | | | Soups and broths | | | |
| Soups and broths | $1.49 \cdot 10^{-2}$ | $9.85 \cdot 10^{-3}$ | $1.14 \cdot 10^{-2}$ | $1.30 \cdot 10^{-2}$ | $1.70 \cdot 10^{-2}$ | $3.29 \cdot 10^{-2}$ |
| | | | Fast food | | | |
| Pizza | $8.77 \cdot 10^{-2}$ | $5.33 \cdot 10^{-2}$ | $6.40 \cdot 10^{-2}$ | $8.77 \cdot 10^{-2}$ | $1.13 \cdot 10^{-1}$ | $1.52 \cdot 10^{-1}$ |
| Chips | $4.70 \cdot 10^{-2}$ | $2.85 \cdot 10^{-2}$ | $3.43 \cdot 10^{-2}$ | $4.70 \cdot 10^{-2}$ | $6.08 \cdot 10^{-2}$ | $8.13 \cdot 10^{-2}$ |
| Total | $1.35 \cdot 10^{-1}$ | $8.18 \cdot 10^{-2}$ | $9.83 \cdot 10^{-2}$ | $1.35 \cdot 10^{-1}$ | $1.74 \cdot 10^{-1}$ | $2.33 \cdot 10^{-1}$ |
| | | | Fish and seafood | | | |
| Hake | $7.69 \cdot 10^{-5}$ | $2.29 \cdot 10^{-3}$ | $2.33 \cdot 10^{-3}$ | $2.15 \cdot 10^{-3}$ | $1.97 \cdot 10^{-3}$ | $1.84 \cdot 10^{-3}$ |
| Tuna | $2.75 \cdot 10^{-4}$ | $3.80 \cdot 10^{-3}$ | $6.62 \cdot 10^{-3}$ | $7.04 \cdot 10^{-3}$ | $9.75 \cdot 10^{-3}$ | $1.39 \cdot 10^{-2}$ |
| Mackerel | $1.59 \cdot 10^{-4}$ | $4.45 \cdot 10^{-3}$ | $5.20 \cdot 10^{-3}$ | $4.37 \cdot 10^{-3}$ | $5.16 \cdot 10^{-3}$ | $2.39 \cdot 10^{-3}$ |

Regarding the WF, the total WF linked to the average Chilean diet represented 2310 L·person$^{-1}$·day$^{-1}$, with a breakdown of green water (1683 L·person$^{-1}$·day$^{-1}$), blue water (339 L·person$^{-1}$·day$^{-1}$) and grey water (265 L·person$^{-1}$·day$^{-1}$). The contribution of food categories to WF are depicted in **Fig. 10.3**. The main food category contributing to this environmental indicator was meat, accounting for 41% (956 L·person$^{-1}$·day$^{-1}$), followed by starch-based products, 23% (528 L·person$^{-1}$·day$^{-1}$); confectionery, 8% (187 L·person$^{-1}$·day$^{-1}$); dairy, 7% (157 L·person$^{-1}$·day$^{-1}$) and oils and fats, 6% (129 L·person$^{-1}$·day$^{-1}$).

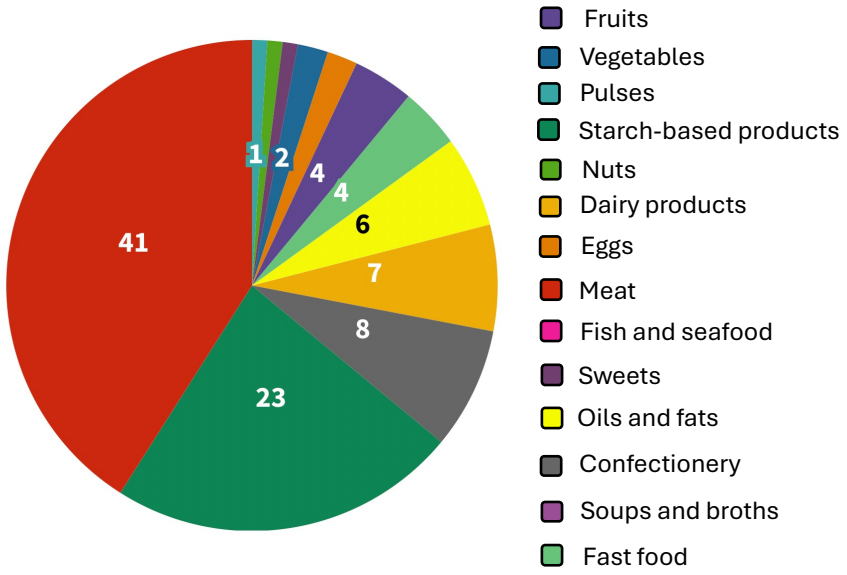


**Fig. 10.3. Breakdown of the water footprint per food categories for the average Chilean diet.**

### 10.3.2 Correlation of the environmental footprints with the household income level

As shown in **Fig. 10.4**, a high socio-economic level of households (quintile) implies higher environmental impacts related to dietary patterns. This trend was observed in both impact categories analysed. In the case of CF, the difference between first and fifth quintile was 2.42 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, with the first quintile scoring 2.32 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and the fifth quintile 4.74 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. Regarding the WF, this variation was 1427 L·person$^{-1}$·day$^{-1}$ with 1683 L·person$^{-1}$·day$^{-1}$ for the first quintile to 3110 L·person$^{-1}$·day$^{-1}$ for the fifth quintile. Detailed information on total WFs per food category and income quintiles was gathered in the **Table 10.6**.

Meat was found to represent a relevant environmental burden in the CF (56% - 59%) and WF (40% - 43%) indicators, followed by starch-based products (8% - 17% for CF and 16% - 29% for WF) as can be seen in **Fig. 10.4**. However, important differences between quintiles could be identified when looking at the contribution of both food groups to the total intake. While lower socio-economic status was associated with higher expected consumption of starch-based products and lower consumption of meat, households with higher socio-economic status bought and consumed more meat and less starch-based products. In particular, in the fifth quintile, higher meat intake was associated with an increase in red and processed meat, whereas poultry consumption was similar to that of the first quintile. Consequently, a strong correlation was observed between higher meat consumption and higher GHG emissions and WF score when Chilean households were analysed according to socio-economic quintiles. Moreover, with higher income, households tend to consume more fruits, vegetables, dairy, fish and seafood, oils and fats, confectionery and fast food (see **Table 10.1)**. However, these food categories did not have a significant influence on the environmental indicators assessed and were not primarily responsible for the notable differences between income quintiles in terms of environmental sustainability.

**Table 10.6. Total water footprints per foodstuff for the six dietary scenarios**

| | Total Water Footprint (L·person$^{-1}$day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| | | | Fruits | | | |
| Oranges | 16.5 | 11.2 | 14.5 | 12.9 | 20.2 | 28.5 |
| Bananas | 13.7 | 10.0 | 13.3 | 13.0 | 16.1 | 18.1 |
| Apples | 9.6 | 7.0 | 9.2 | 9.7 | 10.9 | 12.1 |
| Pears | 4.1 | 3.0 | 3.6 | 3.9 | 5.2 | 5.8 |
| Peaches | 9.4 | 7.2 | 8.1 | 10.9 | 10.5 | 11.6 |
| Grapes | 1.8 | 1.3 | 1.6 | 2.1 | 2.1 | 2.3 |
| Strawberries | 2.0 | 1.2 | 1.6 | 2.0 | 2.3 | 3.3 |
| Kiwis | 2.7 | 1.8 | 2.1 | 2.7 | 3.3 | 4.7 |
| Melon | 2.4 | 1.8 | 2.5 | 2.4 | 2.9 | 2.1 |
| Watermelon | 1.4 | 1.2 | 1.6 | 1.3 | 1.6 | 1.3 |
| Avocado | 28.0 | 19.5 | 24.9 | 29.8 | 33.5 | 36.5 |
| Lemon | 7.2 | 4.6 | 6.8 | 7.7 | 8.0 | 11.3 |
| Total | 98.8 | 69.7 | 90.0 | 98.5 | 116.6 | 137.7 |
| | | | Vegetables | | | |
| Lettuce | 14.2 | 10.4 | 15.0 | 14.4 | 15.8 | 18.3 |
| Pepper | 2.3 | 1.5 | 2.1 | 2.6 | 2.7 | 0.7 |
| Pumpkin | 3.8 | 2.8 | 3.7 | 3.7 | 3.8 | 5.8 |
| Tomato | 2.2 | 1.7 | 2.2 | 2.3 | 2.3 | 2.6 |
| Garlic | 10.1 | 7.5 | 10.3 | 11.2 | 11.7 | 10.7 |
| Carrot | 1.6 | 1.4 | 1.6 | 1.6 | 1.6 | 1.8 |
| Onion | 17.5 | 13.4 | 17.2 | 18.6 | 19.7 | 21.4 |
| Total | 51.6 | 38.6 | 52.1 | 54.3 | 57.6 | 61.4 |
| | | | Pulses | | | |
| Beans | 5.5 | 5.7 | 5.8 | 5.5 | 5.9 | 4.0 |
| Lentils | 9.6 | 8.6 | 11.1 | 8.6 | 9.3 | 11.6 |
| Total | 15.1 | 14.2 | 17.0 | 14.1 | 15.2 | 15.5 |
| | | | Starch-based products | | | |
| Bread | 270.0 | 279.1 | 301.0 | 293.3 | 269.4 | 181.5 |
| Wheat flour | 34.6 | 28.9 | 30.5 | 34.0 | 37.2 | 27.4 |
| Oat | 3.7 | 2.0 | 1.9 | 3.7 | 5.5 | 9.3 |
| Maize | 44.0 | 34.4 | 36.7 | 43.3 | 49.4 | 46.3 |
| Breakfast cereals | 17.3 | 6.8 | 12.1 | 17.0 | 23.0 | 47.8 |
| Potatoes | 17.5 | 20.6 | 20.7 | 17.9 | 16.2 | 9.7 |
| Pasta | 54.9 | 39.6 | 49.8 | 54.1 | 65.1 | 69.0 |
| Rice | 86.0 | 68.8 | 75.2 | 84.7 | 102.1 | 93.0 |
| Total | 528.0 | 480.0 | 527.9 | 548.1 | 568.1 | 484.0 |
| | | | Nuts | | | |
| Walnuts | 4.5 | 1.6 | 1.8 | 3.3 | 6.2 | 15.9 |
| Hazelnuts | 5.3 | 1.9 | 2.1 | 3.9 | 7.3 | 18.7 |
| Almonds | 6.2 | 2.3 | 2.5 | 4.6 | 8.7 | 22.2 |
| Dried plums | 1.7 | 0.9 | 0.9 | 1.5 | 2.4 | 4.1 |
| Raisins | 1.6 | 0.9 | 0.8 | 1.4 | 2.2 | 3.7 |
| Total | 19.3 | 7.6 | 8.1 | 14.6 | 26.9 | 64.6 |

**Table 10.6. (cont.) Total water footprints per foodstuff for the six dietary scenarios**

| | Total Water Footprint (L·person$^{-1}$·day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Average | Quintile 1 | Quintile 2 | Quintile 3 | Quintile 4 | Quintile 5 |
| **Dairy products** | | | | | | |
| Milk | 58.7 | 36.6 | 46.5 | 53.6 | 72.6 | 105.4 |
| Yogurt | 25.6 | 15.7 | 22.6 | 24.0 | 31.7 | 41.9 |
| Cheese | 72.6 | 40.5 | 56.9 | 67.6 | 89.6 | 138.2 |
| Total | 156.8 | 92.9 | 125.9 | 145.2 | 193.9 | 285.5 |
| **Eggs** | | | | | | |
| Eggs | 57.5 | 49.4 | 58.0 | 61.6 | 60.8 | 57.4 |
| **Meat** | | | | | | |
| Beef | 299.0 | 200.2 | 265.4 | 298.3 | 383.2 | 415.8 |
| Pork | 157.7 | 102.9 | 145.5 | 149.8 | 208.1 | 219.3 |
| Chicken | 127.8 | 106.9 | 138.8 | 146.5 | 133.3 | 116.8 |
| Processed meat | 371.6 | 259.7 | 327.8 | 388.4 | 439.1 | 510.3 |
| Total | 956.1 | 669.7 | 877.5 | 983.0 | 1163.8 | 1262.1 |
| **Sugar** | | | | | | |
| Sugar | 18.8 | 17.1 | 21.5 | 20.2 | 18.1 | 15.1 |
| **Oils and fats** | | | | | | |
| Butter | 11.5 | 7.4 | 8.7 | 11.4 | 15.0 | 18.3 |
| Margarine | 23.2 | 18.9 | 27.5 | 26.6 | 24.8 | 15.2 |
| Vegetable oil | 77.7 | 63.8 | 77.9 | 85.8 | 86.4 | 75.7 |
| Olive oil | 16.7 | 3.8 | 7.1 | 13.4 | 25.8 | 49.5 |
| Total | 129.1 | 93.9 | 121.3 | 137.2 | 151.9 | 158.7 |
| **Confectionery** | | | | | | |
| [1]Biscuits | 18.4 | 11.0 | 15.0 | 17.3 | 24.7 | 29.9 |
| [1]Cake | 100.6 | 52.6 | 77.8 | 92.7 | 128.7 | 195.5 |
| [1]Marmalade | 1.9 | 1.2 | 1.4 | 1.9 | 2.4 | 3.5 |
| Chocolate | 46.3 | 18.6 | 23.7 | 32.6 | 53.3 | 144.4 |
| [1]Candy | 1.2 | 0.5 | 0.7 | 0.9 | 2.1 | 2.9 |
| Ice-Cream | 18.6 | 10.6 | 13.5 | 18.8 | 24.4 | 32.4 |
| Total | 187 | 94 | 132 | 164 | 236 | 408.5 |
| **Soups and broths** | | | | | | |
| [2]Soups and broths | 1.7 | 1.1 | 1.3 | 1.5 | 1.9 | 3.7 |
| **Fast food** | | | | | | |
| [1]Pizza | 57.6 | 35.0 | 42.0 | 57.6 | 74.4 | 99.5 |
| Chips | 32.6 | 19.8 | 23.8 | 32.6 | 42.2 | 56.4 |
| Total | 90.2 | 54.8 | 65.8 | 90.2 | 116.6 | 155.9 |

Notes:

1. For calculation of the water footprint, some foodstuffs were assimilated to its main ingredient: biscuits (wheat flour), cake (wheat flour), pizza (wheat flour), marmalade (sugar), candy (sugar).

2. (Rivas Ibáñez et al., 2017)

### 10.3.3 Nutritional quality and cost analysis by income levels

The overall nutritional quality of the diet follows a socio-economic gradient in Chile (see **Fig. 10.4)**. The higher the socio-economic status, the higher the nutritional quality index. In this regard, the dietary quality index was 86 for an average Chilean diet. This percentage varies from 75 in the first quintile group to 98 in households in the fifth quintile. The dietary quality indices in all five quintiles showed lower results than the baseline (100). However, the dietary quality index in the fifth quintile was close to the baseline score. These results could be explained due to the higher socio-economic status enables an easier access to a wide variety of food products from the ten components included in the dietary quality index (see **Table 10.6**). Concerning these components, although there is an intake increased of fish, vegetables and fruits with socioeconomic status, it was lower than the amount recommended by the WHO and the WCRF International (see **Table 10.4)** in all quintiles. Thus, the first and fifth quintile ranging from 111 to 172 $g \cdot person^{-1} \cdot day^{-1}$ for vegetables, 99 to 193 $g \cdot person^{-1} \cdot day^{-1}$ for fruits and 8 to 11 $g \cdot person^{-1} \cdot day^{-1}$ for fish. Moreover, it was observed a high intake of free sugars (around 12% of total energy intake for all quintiles without considering sugar-sweetened beverages) and SFA (between 10% of total energy intake for the first quintile and 14% for the fifth), which also threatened the nutrient quality of Chilean dietary patterns. In contrast, carbohydrates were lower in the highest income quintile (46% of total energy intake) compared to the lowest quintile (51% of total energy intake) because of the high consumption of bread in the first quintile. Total energy intake for fatty acids was highest in the fourth quintile (42%) and lowest in the first quintile (31%). The reason behind this is the highest consumption of processed meat, confectionery products and vegetable oils in the fourth quintile. In addition, energy consumption was significantly higher in the fifth quintile (2917 kcal) with respect to the value recommended (2000 kcal) mainly due to the high consumption of meat and confectionery products. Finally, the fiber content of the Chilean diet analysed ranged from 19 $g \cdot person^{-1} \cdot day^{-1}$ (quintile 1) to 24 $g \cdot person^{-1} \cdot day^{-1}$ (quintile 5), containing less than the minimum amount of fiber set as a reference by the WHO daily recommendations (30 $g \cdot person^{-1} \cdot day^{-1}$).

Concerning the cost analysis by income level, the estimated cost for the average Chilean Diet was 2.74 $€ \cdot person^{-1} \cdot day^{-1}$. Diet costs in relation to socio-economic position showed relevant variations. Higher socioeconomic status was associated with higher daily dietary costs. Scores ranged from 1.87 $€ \cdot person^{-1} \cdot day^{-1}$ in quintile 1 to 4.07 $€ \cdot person^{-1} \cdot day^{-1}$ in quintile 5 as can be seen in **Fig. 10.4**. It is worth noting that considerable differences were observed between quintiles in terms of cost linked to the following food groups: meat, confectionery, fast food and starch-based products, considering noticeable differences in terms of food intake for these food categories by social class.

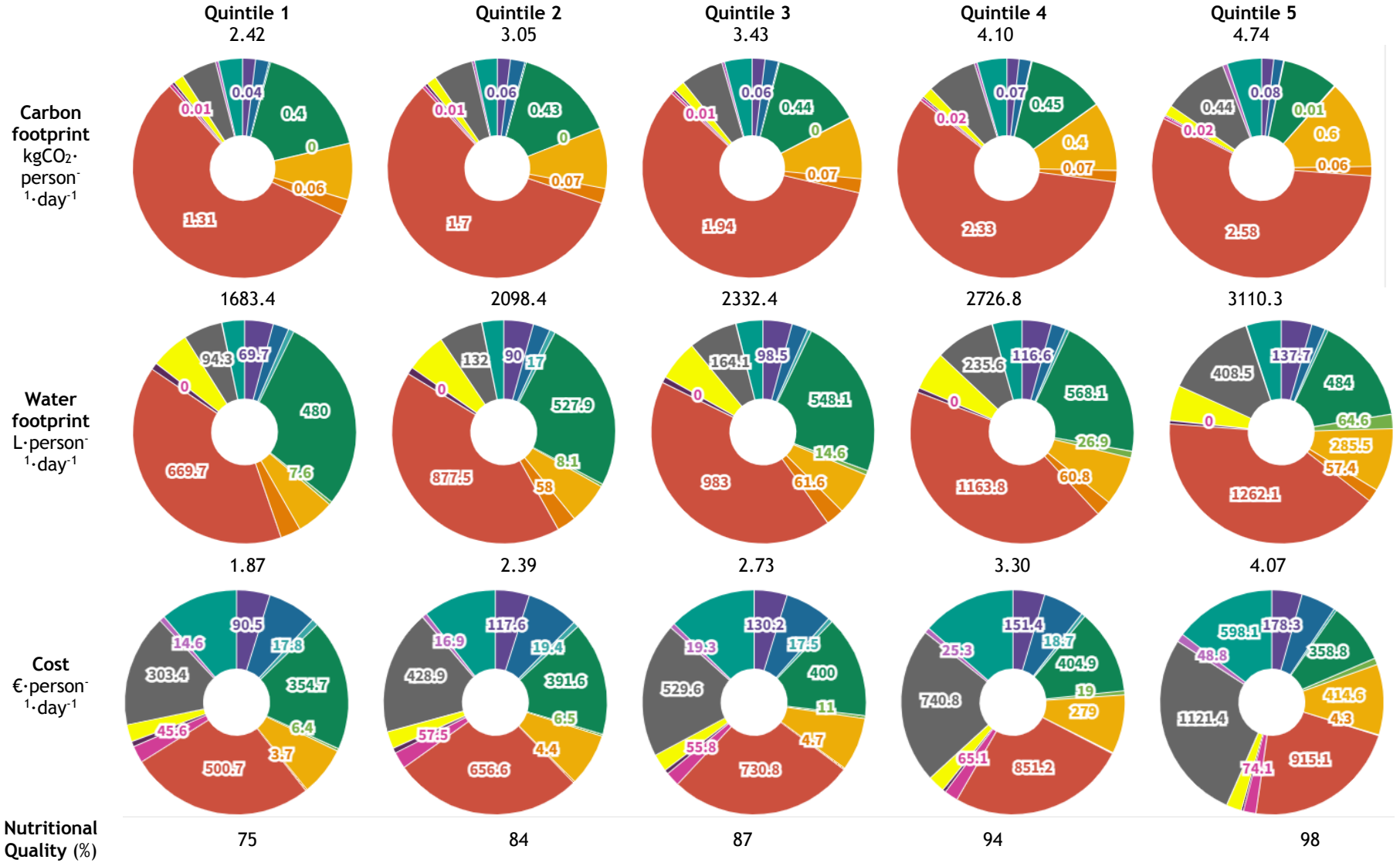


**Fig. 10.4. Daily carbon footprint (considering only the production stage), water footprint, cost per capita and nutritional quality index based in socioeconomic quintiles in Chile.**

### 10.3.4 Contextualizing the outcomes in other Latin American countries

The differences between the top and bottom socio-economic quintiles are very relevant from the perspective of environmental and nutritional value in the Chilean diet. Similar trends were found in other studies available in the literature for other Latin American countries. In fact, the CF for the richest quintile was 195.8% higher than for the poorest quintile in Chile. Vázquez-Rowe et al. (2017b) modelled several diet scenarios in Peru, including socioeconomic criteria. For Metropolitan Lima, GHG emissions (considering only the production stage) in quintile 1 amounted to 1.62 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, whereas in the case of quintile 5, this value was 3.8 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, with an increase of 234.2%. The variance between quintiles increased considerably for coastal Peru (260.1%), Andean Peru (426.5%) and Amazonian Peru (334.1%). As in the case of Chile, the rationale behind this variation is the fact that poorer income classes have limited access to those foods with high CF scores (mainly meat) and follow low-calorie diets. On the other hand, López-Eccher et al. (2021) identified that the fifth quintile (4.04 t $CO_2$·person$^{-1}$·year$^{-1}$) doubled the CF of the first quintile (1.98 t $CO_2$·person$^{-1}$·year$^{-1}$), when they assessed the environmental impacts of households in Santiago (Chile), considering aspects such as food, electricity, and fuel consumption, as well as municipal solid waste and wastewater treatment.

To our knowledge, the relationship between per capita income and WF of food consumption in Latin American countries has not been broadly studied in the literature. In this framework, Arrieta et al. (2021) investigated freshwater consumption to produce food for diets of ten different socio-economic status in Argentina showing large differences between diets in the lowest (94.5 L·day$^{-1}$) and highest income groups (316 L·day$^{-1}$). The effect of income on water resources for food consumption have also been assessed for other countries in the world, such as China (Li et al., 2021) or India (Athare et al., 2020; Koteswara Rao et al., 2021). It is also noteworthy to compare our estimated consumptive WF for the average Chilean diet (2021 L·person$^{-1}$·day$^{-1}$) with the result reported by Harris et al. (2020) for an average dietary pattern in South America (2932 L·person$^{-1}$·day$^{-1}$). Different dietary and water use data and the exclusion of beverages in our study could explain this variation.

Concerning the nutritional perspective, the results obtained showed a positive relationship between wealth and diet quality. These findings were consistent with previous studies that have observed the same association between healthy nutrition and different socioeconomic subgroups in Latin American countries. Gómez et al. (2021) found that the overall dietary quality, as assessed by several dietary quality indexes increased with socioeconomic status in Chile, Ecuador, Venezuela, Costa Rica, Brazil and Colombia. In addition, people in the lowest income category consumed fewer fruits, vegetables, whole grains, fiber and fish and seafood and more legumes than those in the highest socio-economic group. The calculation of dietary cost associated with different income quintiles also supported the finding that food prices and dietary cost contribute to socioeconomic disparities in diet quality in line with other studies available in the literature (Darmon and Drewnowski, 2015).

### 10.3.5 Contextualizing Chilean results at global scale

Other environmental studies of dietary patterns in different regions of the world have reached similar conclusions (see **Table 10.7**). In the North American region, Auclair and Burgos (2021) estimated the CF of Canadian self-selected diets and found that high GHG diets were motivated by the larger presence of animal-based foods, vegetables and fruit, and miscellaneous foods and beverages, whereas low GHG diets contained more cereals, grains, and bread. Bassi et al. (2022) estimated the $CO_2$eq of dietary patterns from individual self-selected diets in the United States from 2003 to 2018 and found that average GHG emissions

decreased from 4.02 to 2.45 kg $CO_2$-eq per day per capita (i.e., about 39%), although average caloric intake remained relatively stable due to a reduction in beef consumption.

In the Asian region, Xiong et al. (2020) investigated changes in urban diet and associated CF in Beijing, China, and found that diet-related CF was increased by 41% from 1980 to 2017 due to increasing consumption of animal-based products. Athare et al. (2020) estimated the embodied GHG emissions of the Indian diets at 1.36 to 3.62 kg $CO_2$eq per consumer unit per day. In this country, the consumption of cereals, sugar, and dairy products intake was higher, and the consumption of fruits and vegetables, pulses, and nuts was lower than recommended. In the European context, Treu et al. (2017) found that animal-based foods dominated the CF in conventional and organic diets in Germany. Moreover, the conventional diet contained 45% more meat than the organic diet, which contained 40% more vegetables, fruits, and legumes. Uçtuğ et al. (2021) calculated the CF of omnivorous, vegetarian, and vegan diets based on traditional Turkish cuisine, and found that the lower GHG emissions of vegetarian and vegan diets were mainly due to the absence of meat products in the vegetarian diet, and the absence of both meat and dairy products in the vegan diet. Mertens et al. (2019) estimated the impact of the Danish, Czech Republic, French and Italian diets and found that meat products were the main contributor to GHG emissions. Similarly, Hyland et al. (2017) found that red meat was the highest GHG contributor in the Irish diet. Similarly, Temme et al. (2015) found that meat, dairy products and beverages were the highest GHG contributors in the Dutch daily diet.

**Table 10.7. Contextualizing Chilean diet at global scale in terms of carbon footprint.**

| Country | CF (kg $CO_2$eq ·person$^{-1}$·day$^{-1}$) | Reference |
|---|---|---|
| China | 3.04 | (Xiong et al., 2020) |
| Canada | 3.98 | (Auclair and Burgos, 2021) |
| United States | 2.45 | (Bassi et al., 2022) |
| Germany | 3.42 | (Treu et al., 2017) |
| Ireland | 6.52 | (Hyland et al., 2017) |
| The Netherlands | 3 - 5 | (Temme et al., 2015) |
| Turkey | 2.64 - 5.03 | (Uçtuğ et al., 2021) |
| Denmark | 4.86 | (Mertens et al., 2019) |
| Czech Republic | 4.86 | |
| France | 4.94 | |
| Italy | 6.50 | |
| Spain | 2.48 - 3.27 | (Esteve-Llorens et al., 2020b) |
| Portugal | 4.20 | (Esteve-Llorens et al., 2020a) |
| Chile | 2.42 - 4.74 | This study |

Concerning the WF, according with Harris et al. (2020), the available evidence suggests that, on average, the consumptive WF of average diets in Europe (3227 L·person$^{-1}$·day$^{-1}$) and Oceania (3226 L·person$^{-1}$·day$^{-1}$) were greatest than for the rest of the continents. For instance, Vanham et al. (2018) estimated the consumptive WF in 2.757 L·person$^{-1}$·day$^{-1}$ (92% green and 8% blue) for the United Kingdom, in 2.929 L·person$^{-1}$·day$^{-1}$ (95% green and 5% blue) for Germany and in 3.861 L·person$^{-1}$·day$^{-1}$ (93% green and 7% blue) for France. North America (2617 L·person$^{-1}$·day$^{-1}$) and Asian dietary patterns (2862 L·person$^{-1}$·day$^{-1}$) had the lowest WFs (Harris et al., 2020). However, it is relevant to highlight that the comparisons with the scientific literature was highly dependent on data sources and models used.

### 10.3.6 Sustainable and healthier patterns for Chilean diet

The composition of diets has a relevant influence on CF values. Consequently, the potential for reducing GHG emissions through changes in food and dietary habits warrants further investigation. According to a study by Esteve-Llorens et al. (2019b), there is a positive correlation between the consumption of animal-based products in the food patterns and high dietary GHG emissions. As evidenced, by numerous studies, a transition from animal to plant-based products is the most effective strategy for reducing GHG emissions (Prag and Henriksen, 2020; Xu et al., 2021). In this context, González et al. (2011) reported that protein efficiency per unit of GHG is significantly higher for plant-based foods than for animal-based ones. Furthermore, Esteve-Llorens et al. (2020a) demonstrated that modifying select components of the Portuguese diet, including meat, fats, sugar, potatoes, and other, through the incorporation of alternative food items such as legumes, fruits, non-starchy vegetables, nuts and olive oil, could enhance the nutritional quality by approximately 67% while reducing the CF of the Portuguese diet by approximately 25%. In addition, legumes emit approximately 250 times fewer GHG emissions per gram of protein than ruminant meats (Tilman and Clark, 2014). The replacement of animal-based products with fruits, vegetables, legumes and cereals should also be carefully evaluated. For instance, among cereal grains, rice generates five times more GHG emissions than wheat in terms of gram of protein (González-Garcia et al., 2018). Finally, as meat plays a significant role in the Chilean diet and may be challenging to replace with plant-based alternatives in the near term, reducing meat consumption in favour of white meat (chicken and pork) could be a more readily achievable strategy for reducing environmental impacts (Esteve-Llorens et al., 2019b).

### 10.3.7 The role of beverages and spices

Beverages and spices were not included within the limits of the system. Spices were excluded from the analysis because they represent an insignificant fraction of the total daily intake. On the other hand, the diversity of beverages offered and consumed, the heterogeneity of the sector and the lack of specific CF information for the very diverse range of beverage products made it difficult to calculate a detailed CF for the Chilean dietary pattern considering sugar-sweetened and non-sugar-sweetened beverages.

Moreover, the exclusion of beverages facilitated the comparison with other previous analysis of the environmental sustainability of dietary patterns (González-García et al., 2020b; Kovacs et al., 2021). However, considering that the results of the "Radiography of Food in Chile" (Government of Chile, 2021) showed a high consumption of sugar-sweetened beverages among Chilean citizens, both environmental indicators (CF and WF) were calculated considering general values for sugar-sweetened beverages, coffee, tea, and infusions. The diet of an average Chilean would have a CF (including beverages) of 4.27 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$ (an increase of about 25%) compared to the value of CF obtained without beverages (3.42 $kgCO_2 \cdot person^{-1} \cdot day^{-1}$). On the other hand, the total WF associated with the average Chilean diet (including beverages) would be more than double that calculated without beverages.

### 10.3.8 Assumptions and limitations

Limitations and assumptions are relevant to understanding the reliability of the study. The CF assessment is sensitive to the wide variety of CF values for each food product reported in scientific articles and LCA reviews. Due to the lack of specific local studies for some food items, LCAs not framed in the Chilean context were also considered. A quantitative assessment of uncertainty using the general equation for error propagation was provided with the aim of determining the reliability and validity of the research. The CF uncertainty values of each food

item included in the six Chilean dietary scenarios were established considering the maximum and minimum values reported by Barilla Center for Food Nutrition (2016) and Clune et al. (2017) (see **Table 10.8**).

**Table 10.8. Uncertainty analysis in the dietary carbon footprint**

| | Uncertainty carbon footprint (kgCO2eq/kg) |
|---|---|
| **Fruits** | 0.59 |
| **Vegetables** | 2.24 |
| **Pulses** | 1.23 |
| **Starch-based products** | |
| Grains | 1.06 |
| Potatoes | 0.09 |
| **Nuts** | |
| Walnuts, hazelnuts | 1.22 |
| Almonds | 1.63 |
| **Dairy products** | |
| Milk | 1.36 |
| Yogurt | 0.83 |
| Cheese | 4.64 |
| **Eggs** | 2.77 |
| **Meat** | |
| Beef | 29.94 |
| Pig | 6.17 |
| Chicken | 7.69 |
| Other meat products | 6.17 |
| **Fish and seafood** | 7.74 |
| **Sweets** | |
| Sugar | 0.52 |
| **Oils and fats** | |
| Oils | 2.43 |
| Butter | 2.58 |

Note: Barilla Center for Food Nutrition, 2016; Clune et al., 2017

The uncertainty analysis establishes that the CF of the average Chilean diet was (mean [SD], 3.42 [0.77] $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$). The uncertainty interval is too wide since CF values have been obtained from the LCA results of a large variety of LCA reviews and peer reviewed journal articles available in the scientific literature. Major climate hotspots, such as meat and fish and seafood (Barilla Center for Food Nutrition, 2016; Clune et al., 2017), represented the biggest source of uncertainty in the dietary CF analysis. Notwithstanding the uncertainty, the CF results guide national programmers and policy makers to develop future FBDGs guidelines in Chile. Regarding the methodology used to quantify GHG emissions from retail and wholesale distribution, fish production in Chile was assumed to be all domestically produced. Moreover, due to the lack of information of trade data, some assumptions were made for pizza, soups and broths, candy, marmalade, cake and biscuits (see **Table 10.2**).

Shortcomings in the WF assessment were the absence of WF data for marine and freshwater (non-aquaculture) fish species. Some assumptions were also necessary due to the lack of WF values for some specific confectionery products, as they were assimilated to their

main ingredient. This is the case for biscuits, cake and pizza (assimilated as wheat flour), as well as marmalade and sweets (assimilated as sugar).

## 10.4 CONCLUDING REMARKS

This study demonstrated the impact of socio-economic status on the environmental profile of diets in Chile, showing that a higher income level involves higher food-related environmental impacts. The fifth quintile of individuals almost doubles the GHG emissions and WF of the first socio-economic quintile. The driver of these differences was higher meat consumption in the fifth quintile, which represents the largest contributor to overall CF and WF in the average Chilean diet. Furthermore, the environmental footprints obtained for the Chilean dietary patterns were consistent with the findings of other studies in the literature and exhibited comparable characteristics, such as the pivotal role of meat consumption.

A direct association between socio-economic position and diet quality was evidenced, as assessed by a nutritional quality score. Chilean citizens in the low socio-economic status consumed foods of lower nutritional value than those in the high-income quintile. Indeed, diets associated with high-income consumers were also found to be more expensive. However, malnutrition is an issue of concern not only in low-income households but also in middle- and high-income households, considering that the nutritional quality reference index (100) was not reached in any quintile. The findings of this study highlight the need for an official plan to implement and disseminate dietary guidelines for the Chilean population. The creation of consumption policies and the formulation of policies that advise prioritising vegetable proteins over animal products and avoiding fatty foods, sugar and sweets is a sure way to improve public health, avoid transgressing planetary boundaries and comply with international commitments to sustainable development. Further studies could focus on the energy approach of Chilean dietary patterns due to the fossil resource dependency of this country, as well as social aspects related to the socioeconomic groups evaluated.

# 11. BEYOND THE STONE AGE: A HOLISTIC ANALYSIS OF THE PALEO DIET IMPACT ON HEALTH, ECONOMY AND THE PLANET[9]

It is no secret that over the past few decades, the field of nutrition has witnessed a proliferation of dietary trends. Among the wide variety of diets, Palaeolithic diet has become so popular in social media as an example of a miracle diet capable of promoting weight loss. The main goal of this study is to evaluate the environmental and health sustainability of the Paleo diet, incorporating the health dimension to the economic, nutritional, and environmental indicators, such as carbon footprint and water footprint. Results were compared with those of the other dietary patterns globally.

It was concluded that the Paleo diet is a diet low in carbohydrates (24.5% of energy intake) and high in protein (29.6% of energy intake), cholesterol (835 $mg \cdot day^{-1}$) and polyunsaturated fatty acids (15.3% of energy intake). The diet quality score was 260, a result well above the recommended. Regarding the health assessment of the food categories that contribute most to the Paleo diet, vegetables and fruits were associated with a lower risk of cardiovascular disease, type 2 diabetes mellitus, colorectal cancer, obesity and stroke. The opposite result was observed for red meat. Fish and seafood, as well as poultry, were associated with a relative risk higher than one for type 2 diabetes mellitus and obesity, but not for cardiovascular disease, colorectal cancer or stroke. Based on the economic assessment, a higher dietary cost was estimated for Paleo diet (8.6 $€ \cdot person^{-1} \cdot day^{-1}$). The environmental metrics in terms of carbon footprint and water footprint were estimated in 5.44 kg $CO_2 \cdot person^{-1} \cdot day^{-1}$ and 3499 $L \cdot person^{-1} \cdot day^{-1}$ respectively, a worse environmental profile than that of the recommended diets in Spain.

Navigating optimal dietary choices can be a complex task. Environmental and health sustainability assessments provide a valuable tool for policymakers to establish clear dietary guidelines and empower citizens to make informed choices.

[9] Cambeses-Franco, C., González-García, S., Feijoo, G., Moreira, M. T., 2021. Is the Paleo diet safe for health and the environment?. Science of The Total Environment, 781, 146717.

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## 11.1 INTRODUCTION

A growing emphasis on health and weight management within Europe has led to the emergence of a diverse array of dietary trends (Modi and Priefer, 2020). These diets can be categorised as carbohydrate-limiting: Atkins, Zone, Ketogenic and South Beach; Caveman-Like: Paleo diet; miscellaneous: Grapefruit diet, Whole30 diet; commercialized: Weight Watchers diet, Jenny Craig; or lifestyle modification: Dietary approaches to stop hypertension, and MD (Modi and Priefer, 2020).

Among the set of dietary guidelines, the Paleo diet has experienced a rapid increase in popularity, particularly among young adults and athletes (Singh and Singh, 2023). The Paleo diet seems to be on everyone's lips and is gaining many followers who perceive this method as an effective means of enhancing their physical condition by reducing their consumption of processed foods (Pięta et al., 2023). But is the Paleo diet a healthy and sustainable diet or is it a "hype" or "fad"?

### 11.1.1 The Paleo diet

The Paleo diet, also called the caveman or Stone-Age diet, is an eating pattern that draws inspiration from the consumption of wild foods and animals that were commonly consumed during the Palaeolithic era (2.5-0.01 million years before present) (de la O et al., 2021). The contemporary Paleo diet tries to emulate and adapts the knowledge about the diet of our ancestors to the common food groups available in western countries (Zazpe et al., 2020). The rationale behind the diet is that the human body is genetically incompatible with the modern food that emerged with farming practices — an idea known as the discordance hypothesis (Turner and Thompson, 2013). Based on this approach, different proposals on the food categories that should be recommended and avoided following the contemporary Paleo diet were studied in the literature. Most definitions included the following food groups: fruits, vegetables, meat, fish, nuts and eggs and, excluded grains, pulses and dairy products, as well as sugar, salt and processed food (Blomquist et al., 2018; Manousou et al., 2018; Otten et al., 2019). However, the inclusion or exclusion of some foodstuffs, such as alcohol and potatoes, is debatable (Lindeberg et al., 2007; Österdahl et al., 2008). Consequently, nutrient intake, caloric and lipid profiles and fat quality are a function of the selected definition of the Paleo diet.

### 11.1.2 Delving into the scientific evidence on the health and nutritional effects of the Paleo diet.

Most studies suggested that the Paleo diet may provide some benefits in the prevention of several health outcomes such as MetS (Shemirani et al., 2022), T2D (Yan and Louie, 2024), overweight/obesity (de Menezes et al., 2019), CVD (de la O et al., 2022) and cancer (Shah et al., 2023). However, judgements are unclear due to the limited number of studies with a large sample size and over a long period (Zazpe et al., 2020). In addition, the relationship between the main food categories of the Paleo diet and NCDs based on the results of prospective cohort studies has not been analysed yet. Evaluation of the effects of the Paleo Diet on chronic diseases together with a nutritional analysis (in terms of nutrient intake as well as caloric and lipid profile) will allow characterizing how it impacts on human health and well-being.

### 11.1.3 Is the Paleo diet the path to a healthy planet?

On the other hand, keeping in mind that food system are responsible for a third of global anthropogenic GHG emissions (Crippa et al., 2021) and contributes to water scarcity problems (Schyns et al., 2022), CF and WF have been considered as representative environmental indicators. Numerous studies can be found in the literature that consider the CF (Komati et al.,

2024; Tucci et al., 2022) and the WF (Blas et al., 2019; Harris et al., 2020) of European dietary patterns. However, despite its popularity, none of the studies have so far focused on the environmental analysis of the Paleo diet.

### 11.1.4 The Paleo Diet: a sustainability trilemma – Balancing affordability, environment, and nutrition

Diet sustainability assessments emphasize positive net gains in sustainability now and in the future in food systems (Garcia-Alvarez-Coque et al., 2021). They are considered a useful tool for decision and policy makers in the challenge of promoting biodiversity-friendly, affordable, nutritionally adequate, and healthy dietary patterns (Burlingame and Dernini, 2012). Thus, this study aims to provide a global vision of the Paleo diet, not only from an environmental point of view, but also from health, nutritional and economic perspectives. It has a four-fold objective: to quantify the CF and WF of the Paleo diet, to evaluate the quality of the diet, to estimate its daily cost and to establish its correlation (through cohort studies) with NCDs such as CVD, T2D, CRCA, stroke and all-cause mortality. The results of the assessment of the environmental and health sustainability of the Paleo diet allow a further comparison with the other dietary patterns globally.

## 11.2 Materials and methods

### 11.2.1 Designed dietary scenario

The composition of the contemporary Paleo diet was established considering the relative contribution of each food category to the total energy intake. The apportionment of daily energy was made considering an approximately energy weighting of 15% for vegetables, fruits and nuts and 27.5% for fish and meat food groups (Cordain, 2002). The following foodstuffs were limited: eggs (≤2 eggs per day), nuts (preferentially walnuts), potatoes (≤1 medium-sized per day) and olive oil (≤1 tablespoon per day) (Jönsson et al., 2009). The daily energy intake was adjusted as much as possible to 2228 $kcal \cdot person^{-1} \cdot day^{-1}$, which was recommended by the Panel on Dietetic Products, Nutrition and Allergies from the EFSA (2017).

The wide climatic transitions, the biogeographical differences of resources and the culinary culture are responsible for the great differences in the consumption habits of the Spanish people between north and south, west and east (López-Costas and Alexander, 2019). Faced with this wide variety of diets and consumption patterns, Spain has become one of the European countries most dependent on sustainability studies. For this reason, Spain was chosen as a case study.

For each food category, only the most consumed foodstuffs in Spain were considered according to MAPA (2019). For the group of fruits, oranges, apples and bananas, with a contribution of 18%, 11% and 14% of total fruits consumed on average in Spain, represented the available choices. For vegetables, three types (tomatoes, onions and peppers) were selected because they represented 23%, 13% and 9% of total vegetables consumed in Spain in 2019, respectively. Beef, chicken and pig were considered in the meat category, and they together constituted around 56% of the total meat consumption in Spain. Within the fish and seafood group, hake, salmon, pilchard, prawns and tuna represented the fish and seafood choices in the Paleo diet. Together, they contributed with a significant percentage (40%) of the total fish and seafood consumption in Spain (MAPA, 2019).

Based on these considerations, **Table 11.1** shows the average daily intake and the energy weightings per food category and foodstuff for the Paleo diet. Note that although eggs, olive oil and potatoes were considered independent food categories because they have specific

recommendations established by the Paleo diet (Jönsson et al., 2009), they were included in the meat and vegetables categories when the distribution of daily energy intake was made.

### 11.2.2 Nutritional and health assessment

Nutritional assessment includes the study of nutrient intake (protein, carbohydrates, fat and others), the caloric profile of the diet (percentage of energy from protein, fat and carbohydrates) and the lipid profile (percentage of energy from SFA, monounsaturated fatty acids (MUFA) and PUFA (ALCE, 2020). DIAL, a specialized software in diet evaluation and planning, was used as a tool in the nutritional assessment of the Paleo diet (ALCE, 2020). Moreover, the Health Gain Score (van Dooren et al., 2014) described in **Chapter 3 (Section I)** was calculated in a complementary manner.

In terms of health assessment, the implication of the Paleo diet food categories for chronic diseases was analysed. The disease endpoints selected were T2D, obesity, CRCA, CVD, stroke and all-cause mortality, as in previous studies available in the literature (Springmann et al., 2016, 2018b).

To study the impact of the Paleo diet on health, meta-analyses of prospective cohort studies were taken from the literature (Clark et al., 2019; Schwingshackl et al., 2017d; Yang et al., 2020). The measure of the association between a food category and a NCD in cohort studies is the RR of disease due to the consumption of an additional plate of food per day in comparison with the average intake in an observational study (Clark et al., 2019; Springmann et al., 2018b) as explained in **Chapter 3 (Section I)**.

### 11.2.3 Cost assessment

Economic factors, rather than a lack of knowledge, are often the primary barrier to achieving a balanced and healthy diet (Vilar-Compte et al., 2021). From this perspective, a cost index (€·person$^{-1}$·day$^{-1}$) was calculated for the Paleo diet, taking into account the average prices (€·kg$^{-1}$) per foodstuff gathered in the national database of the Spanish Ministry of Agriculture, Food and Environment (MAPA, 2019). The cost assessment was made establishing as functional unit (calculation basis) the recommended daily intake for each individual.

**Table 11.1. Average daily-recommended intake, energy contribution, carbon footprint per food category and nutritional parameters for Paleo diet**

| Energy contribution and carbon footprint | | | | |
|---|---|---|---|---|
| Food category | Paleo Diet ($g \cdot person^{-1} \cdot day^{-1}$) | Energy (kcal) | CF ($kgCO2eq \cdot kg^{-1}$) | Source |
| Fruits | 495 | 315.3 | | |
| Orange | 211 | 96.2 | 0.15 | (Aguilera et al., 2015b) |
| Apples | 124 | 67.0 | 0.12 | (Aguilera et al., 2015a) |
| Banana | 160 | 152.2 | 0.64 | (Aguilera et al., 2015b) |
| Vegetables | 1000 | 244.5 | | |
| Tomatoes | 528 | 117.1 | 0.22 | (Aguilera et al., 2015a) |
| Onion | 281 | 89.7 | 0.24 | (Aguilera et al., 2015a) |
| Peppers | 191 | 37.6 | 0.22 | (Aguilera et al., 2015a) |
| Starch-based products | 100 | 73.6 | | |
| Potatoes | 100 | 73.6 | 0.24 | (Aguilera et al., 2015a |
| Nuts | 48 | 311.5 | | |
| Walnut | 48 | 311.5 | 1.62 | (Clune et al., 2017) |
| Eggs | 53 | 79.5 | | |
| Eggs | 53 | 79.5 | 1.80 | (Nielsen et al., 2013) |
| Meat | 290 | 498.7 | | |
| Beef | 40 | 52.3 | 24.69 | (van Oort and Andrew, 2016) |
| Chicken | 166 | 275.6 | 2.50 | (González-García et al., 2014) |
| Pork | 110 | 170.8 | 4.96 | (Noya et al., 2017) |
| Fish and seafood | 415 | 578.0 | | |
| Hake | 117 | 74.8 | 5.98 | (Iribarren et al., 2010b) |
| Salmon | 58 | 110.4 | 2.26 | (Sherry and Koester, 2020) |
| Pilchard | 58 | 90.7 | 0.52 | (González-García et al., 2015a) |
| Prawns | 83 | 78.4 | 14.85 | (Clune et al., 2017) |
| Tuna | 99 | 223.7 | 1.60 | (Hospido and Tyedmers, 2005) |
| Oils and fats | 15 | 134.9 | | |
| Olive oil | 15 | 134.9 | 2.36 | (Sellás Olive Oil, 2013) |
| Total | 2416 | 2236.0 | | |

| Other nutritional parameters | | | |
|---|---|---|---|
| Protein (g) | 166.0 | MUFA (g) | 37.2 |
| Carbohydrates (g) | 121.0 | PUFA (g) | 38.2 |
| Lipids (g) | 114.0 | SFA (g) | 24.7 |
| Cholesterol (mg) | 835.0 | Sodium (mg) | 927.0 |
| Iron (mg) | 22.2 | Calcium (mg) | 580.0 |
| Potassium (mg) | 5985.0 | Magnesium (mg) | 466.0 |
| Fibre (g) | 64.4 | Vitamin A (µg) | 2288.0 |
| Vitamin C (µg) | 528.0 | Vitamin E (µg) | 19.5 |

### 11.2.4 Environmental assessment

The CF (kg $CO_2$·person$^{-1}$·day$^{-1}$) was used as a measure of the amount of GHG emissions caused by the production, manufacture and delivery to the consumer of the foodstuffs that were included in the designed Paleo diet. As with the cost evaluation, the recommended daily intake for each person was established as the functional unit. The system boundaries included only up to the distribution to household stage to facilitate the comparison with other studies available in the literature (González-García et al., 2020b). The pre-cooking stages included primary agricultural production or industrial production (S1) and distribution activities, from factory or farm gate to wholesalers and retailers (S2) and from retailers to households (S3). Food removed from the supply chain (food loss and food waste) was also considered. **Fig. 11.1** shows graphically the system boundaries considered.

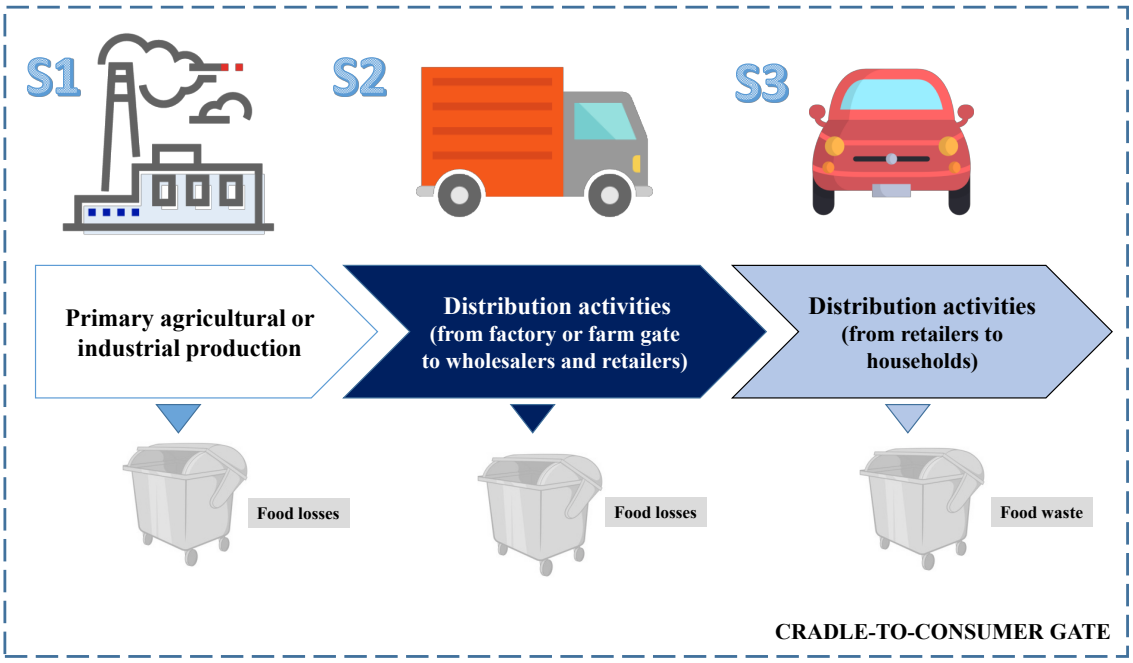


**Fig. 11.1. System boundaries considered in the carbon footprint analysis of Paleo diet**

Eleven LCA studies from a "cradle-to-gate" approach, which covered either primary agricultural production or the industrial production stage (S1) of the different foodstuffs included in the Paleo diet, were managed. Their corresponding CF scores were displayed in **Table 11.1**. The CF scores associated to the S2 and S3 stages were estimated following the methodology proposed by González-García et al. (2020b). Therefore, in S2, the distribution distance per food item was calculated considering the average import and national distances and the percentages of national and imported foodstuffs. This information was taken from the open access multidimensional database DATACOMEX provided by the Spanish Ministry of Economy and Competitiveness (Ministerio de Economia, 2019). For food produced in Spain, an average national distance of 400 km by Euro 5 diesel freight lorries (>32 tons) was considered as an optimistic assumption (Castañé and Antón, 2017). The emissions factors used were 92.10 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$ and 18.60 mg $CO_2$eq·kg$^{-1}$·km$^{-1}$ for lorry (national and international) and transoceanic transport respectively, accordingly with the Ecoinvent ® v3.2 database and the characterization factors from IPCC. In the S3, it was assumed that every six

days (once a week) a purchase of all products included in the Paleo diet was made. The shopping trip to the grocery store was made by a diesel vehicle of 3.3 km with an emission rate of 106 $gCO_2eq \cdot km^{-1}$ (Batlle-Bayer et al., 2019b). Finally, food waste at the retail (S2) and consumer (S3) levels were estimated from average food waste ratios published by Gustavsson et al. (2013) and Garcia-Herrero et al. (2018), respectively.

The second environmental metric used was the WF ($L \cdot person^{-1} \cdot day^{-1}$). The calculation of the WF was based on the methodology proposed by the WFN. Therefore, the WF for the Paleo diet ($L \cdot person^{-1} \cdot day^{-1}$), under the same functional unit as for the CF, was calculated considering the Green WF, Blue WF and Grey WF for each food item as well as the total amount of a food item supplied per person and day, see **Chapter 3 (Section I)**.

For the estimation of the WF of each food, the comprehensive reports of the quantification of the green, blue and grey WF of crops, crop products and agricultural commodities at international level were considered (Mekonnen and Hoekstra, 2011, 2012). Furthermore, taking into account that climatic and production conditions influence the consumptive WF, it has been necessary to trace the geographical origin of food items. For this purpose, the procedure described by González-García et al. (2020b) was followed.

Regarding fish and seafood, two assumptions were made. Firstly, all the production was considered to be produced at a national level (González-García et al., 2020b) because the LCA studies consulted imply their unloading in Galician ports (González-García et al., 2015a; Hospido and Tyedmers, 2005; Iribarren et al., 2010b). Secondly, the approach established by Pahlow et al. (2015) was also assumed in this study for fish and seafood. Therefore, a WF of zero was assigned to marine species. In contrast, the WF associated with aquaculture species was estimated considering the commercial aquafeed consumed.

## 11.3 Results

### 11.3.1 Nutritional & health assessment

The main nutritional parameters of the Paleo diet are shown in **Table 11.1**. Detailed nutrient content is shown in **Table 11.2**. These data are average values of daily consumption. Taking these results into account, the quality of the diet was judged based on different indexes or benchmarks in accordance with current recommendations: caloric and lipid profiles and fat quality.

Regarding the caloric profile, the Paleo diet is rich in fats and proteins and low in carbohydrates as can be seen in **Fig. 11.2a.** Protein intake contributes 29.6% of the total energy intake, higher than the recommended daily allowance (10-15% of energy contribution) (ALCE, 2020). Higher protein needs were observed in the athletic population. Exercise can increase protein needs by 50-10% for endurance athletes and improve muscle development for strength athletes (Hoffman and Falvo, 2004). This explains why celebrities and professional athletes are particularly interested in the Paleo diet. Total energy from lipids was 45.9%, also exceeding recommendations (20-35% energy intake) (EFSA, 2020). However, the Paleo diet restricted energy from carbohydrates to 24.5% of total energy intake, while dietary guidelines recommend that carbohydrates should constitute 45-60% of total daily calories (EFSA, 2020). Low-carb approaches are typical of weight-loss diets. The hypothesis behind this reasoning is that reducing carbohydrate intake reduces the amount of insulin in the blood. Insulin is a hormone that produces an anabolic and fat-storage state, improves cardiometabolic function, and induces weight loss (Ebbeling et al., 2018).

**Fig. 11.2b** shows the lipid profile of the Paleo diet. SFA and MUFA intakes meet the nutritional recommendations (ALCE, 2020; EFSA, 2020). Intakes of SFA should provide no more than 10% of energy (9.9% of energy contribution in the Paleo diet) (EFSA, 2020). The

average percentage composition of MUFA was 14.9% of energy intake. PUFA intake was higher than the acceptable range (6 and 11% of energy contribution) (Todd, 2010). According to experimental studies, this high intake of PUFA increases the risk of lipid peroxidation (Todd, 2010).

**Table 11.2. Nutritional content of Paleo diet per person**

| Nutrient | Input·day$^{-1}$ | Nutrient | Input·day$^{-1}$ | Nutrient | Input·day$^{-1}$ |
|---|---|---|---|---|---|
| Water (g) | 2088 | Iron (mg) | 22.2 | Arginine (mg) | 9269 |
| Protein (g) | 166 | Iodine (µg) | 261 | Aspartic acid (mg) | 15388 |
| Carbohydrates (g) | 121 | Magnesium (mg) | 466 | Cystine (mg) | 1709 |
| Simple sugars (g) | 99 | Zinc (mg) | 13.6 | Phenylalanine (mg) | 5867 |
| Added sugars (g) | 0 | Sodium (mg) | 927 | Glycine (mg) | 8676 |
| Starch (g) | 20.8 | Potassium (mg) | 5985 | Histidine (mg) | 4535 |
| Vegetal fibre (g) | 32.2 | Phosphorus (mg) | 2113 | Isoleucine (mg) | 7607 |
| Soluble fibre (g) | 12 | Selenium (µg) | 259 | Leucine (mg) | 11056 |
| Insoluble fibre (g) | 20.2 | Copper (mg) | 2.2 | Lysine (mg) | 12005 |
| Lipids (g) | 114 | Chrome (µg) | 159 | Methionine (mg) | 3916 |
| SFA (g) | 24.7 | Nickel (µg) | 170 | Proline (mg) | 6171 |
| MUFA (g) | 37.2 | Chlorine (mg) | 1090 | Serine (mg) | 6728 |
| PUFA (g) | 38.2 | Fluorine (µg) | 615 | Tyrosine (mg) | 5225 |
| Cholesterol (mg) | 835 | Manganese (mg) | 3.1 | Threonine (mg) | 6722 |
| Vitamin B1 (µg) | 2.6 | C14:0 (g) | 2.1 | Tryptophan (mg) | 1782 |
| Vitamin B2 (µg) | 2.0 | C16:0 (g) | 16.7 | Valine (mg) | 8165 |
| Niacin (mg) | 94.2 | C18:0 (g) | 5.3 | Glucose (g) | 28.7 |
| Vitamin B6 (µg) | 6.3 | C16:1 (g) | 3.9 | Fructose (g) | 35.1 |
| Vitamin B12 (µg) | 31.5 | C18:1 (g) | 33 | Saccharose (g) | 32.7 |
| Folic acid (µg) | 508 | C18:2 (g) | 24.2 | Lactose (g) | 0 |
| Vitamin C (µg) | 528 | C18:3(g) | 5.1 | Galactose (g) | 0 |
| Vitamin A (µg) | 2288 | C20:4 (g) | 0.8 | Oxalic Acid (g) | 0.05 |
| Retinol (µg) | 942 | C20:5 (g) | 2.8 | Citric Acid (g) | 5.4 |
| Carotenes (µg) | 7724 | C22:5 (g) | 0.5 | Malic Acid (g) | 2.3 |
| Vitamin D (µg) | 15.9 | C22:6 (g) | 4.6 | Lactic Acid (g) | 0.03 |
| Vitamin E (µg) | 19.5 | PUFA w3 (g) | 13 | ß-Sitosterol (mg) | 143 |
| Vitamin K (µg) | 89.6 | PUFA w6 (g) | 25.1 | Campesterol (mg) | 15.4 |
| Pantothenic acid (mg) | 10.5 | Fatty acids cis (g) | 68.9 | Estigmasterol(mg) | 24.2 |
| Biotin (µg) | 59.2 | Fatty acids t (g) | 0.32 | Caffeine (mg) | 0 |
| Calcium (mg) | 580 | Alanine (mg) | 9009 | Theobromine (mg) | 0 |

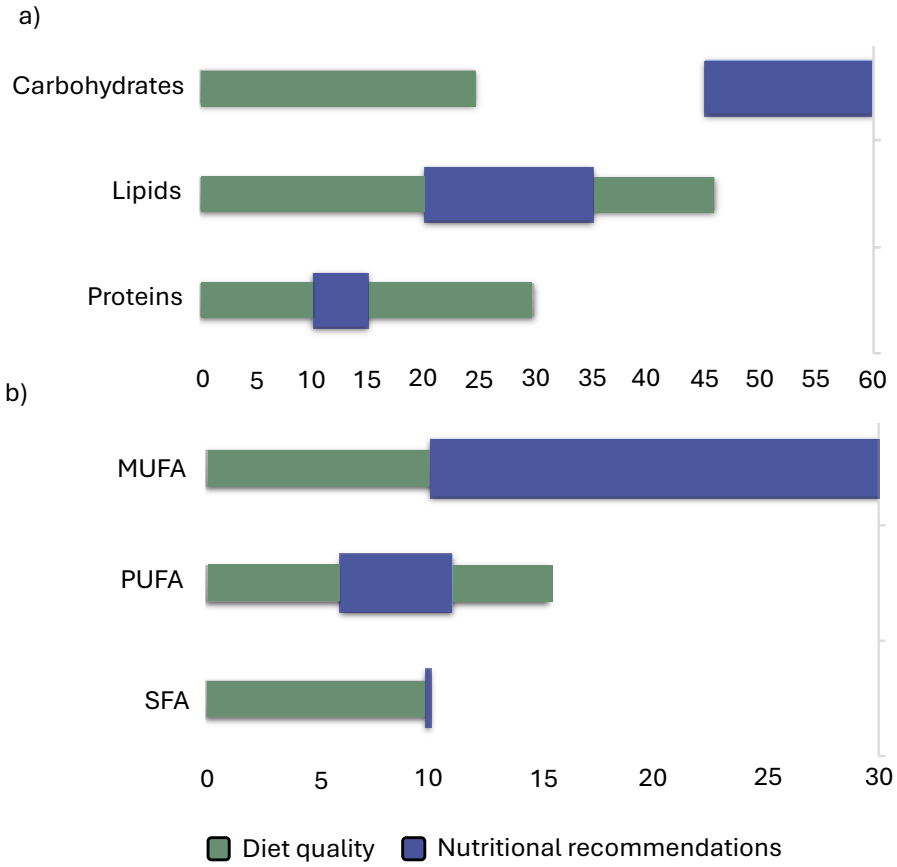


**Fig. 11.2. a) Caloric profile b) Lipid profile of Paleo diet (distribution range in terms of energy contribution)**

Following the FDA (2020) dietary recommendations, healthy people should consume no more than 300 mg of dietary cholesterol per day. The Paleo diet had worsened cholesterol levels as can be seen in **Table 11.3**. Despite this recommendation, extensive research to date has not demonstrated the relationship of dietary with the development of CVD (Soliman, 2018). Moreover, omega-3 long-chain PUFA, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) were in excessive in the Paleo diet (7400 mg/day). It should be mentioned than an excess of EPA and DHA supplementation in the diet could lead to negative long-term health effects, increasing cancer risk (Lange et al., 2019).

**Table 11.3. Fat quality for Paleo diet**

| | Diet quality | Nutritional recommendation |
|---|---|---|
| Total lipids (g) | 114 | |
| SFA (g) | 24.7 | |
| MUFA (g) | 37.2 | |
| PUFA (g) | 38.2 | |
| PUFA/SFA | 1.5 | More than 0.5 (ALCE, 2020) |
| PUFA + MUFA/SFA | 3.1 | More than 2 (ALCE, 2020) |
| Cholesterol (mg) | 835 | Less than 300 mg·day$^{-1}$ (FDA, 2020) |
| Cholesterol (mg)/1000 kcal | 373 | Less than 100 mg/1000 kcal (FDA, 2020) |
| % Energy AG omega-3 (g) | 5.2 | 1-2% Energy (ALCE, 2020) |
| EPA-DHA (mg·day$^{-1}$) | 7400 | 500 mg/day (ALCE, 2020) |

Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), Saturated fatty acids (SFA), Monounsaturated fatty acids (MUFA), Polyunsaturated fatty acids (PUFA)

Regarding the diet quality index analysed, the Paleo diet achieved a score of 260, a result higher than the reference value (100). Background information required for the estimation of this index was summarized in **Table 11.4**.

**Table 11.4. Recommended and calculated values for Paleo diet necessary for the estimation of the Diet Quality Index (van Dooren et al., 2014)**

| Contributing factors | | Recommended | NND |
|---|---|---|---|
| 1 | Vegetables | >200 g | 1000 g |
| 2 | Fruit | >200 g | 495 g |
| 3 | Total Fatty acids | <31.5% | 44% |
| 4 | Free sugars | <10.0% | 17% |
| 5 | Fibre | >25 g | 32 g |
| 6 | Sodium | <6 g | 1 g |
| 7 | Carbohydrates | <52% | 25% |
| 8 | Saturated fatty acids | <10% | 10% |
| 9 | Fish | >37 g | 415 g |
| 10 | Energy | 2228 kcal | 2236 kcal |

The association between the different food categories included in the Paleo diet and the risk of NCDs such as obesity, CVD, T2D, CRCA and stroke, was displayed in **Fig. 11.3**. While fruits and vegetables were consistently associated with improved health (disease specific RR<1 for T2D, CVD, stroke, obesity and CRCA), red meat was associated with increased risk for the five health indicators. Regarding the other animal-based foods, while the RR-value of eggs for obesity, CVD, and stroke was 0.95, 0.98, and 0.99 respectively (less than 1), the RR-value of eggs for T2D and CRCA was higher than 1. Poultry, fish and seafood were associated with increased risk of T2D and obesity, but not with CRCA, CVD, or stroke.

The opposite result could be seen with potatoes, for which a RR higher than 1 was reported for T2D, CRCA and CVD. Nuts and olive oil reduced the risk of four of the five diseases analysed. The RR value was higher than 1 for stroke in the case of nuts and for obesity in the case of olive oil. A more detailed description of the analysed cohort studies with their corresponding serving sizes was gathered in **Tables 11.5 - 11.13**.

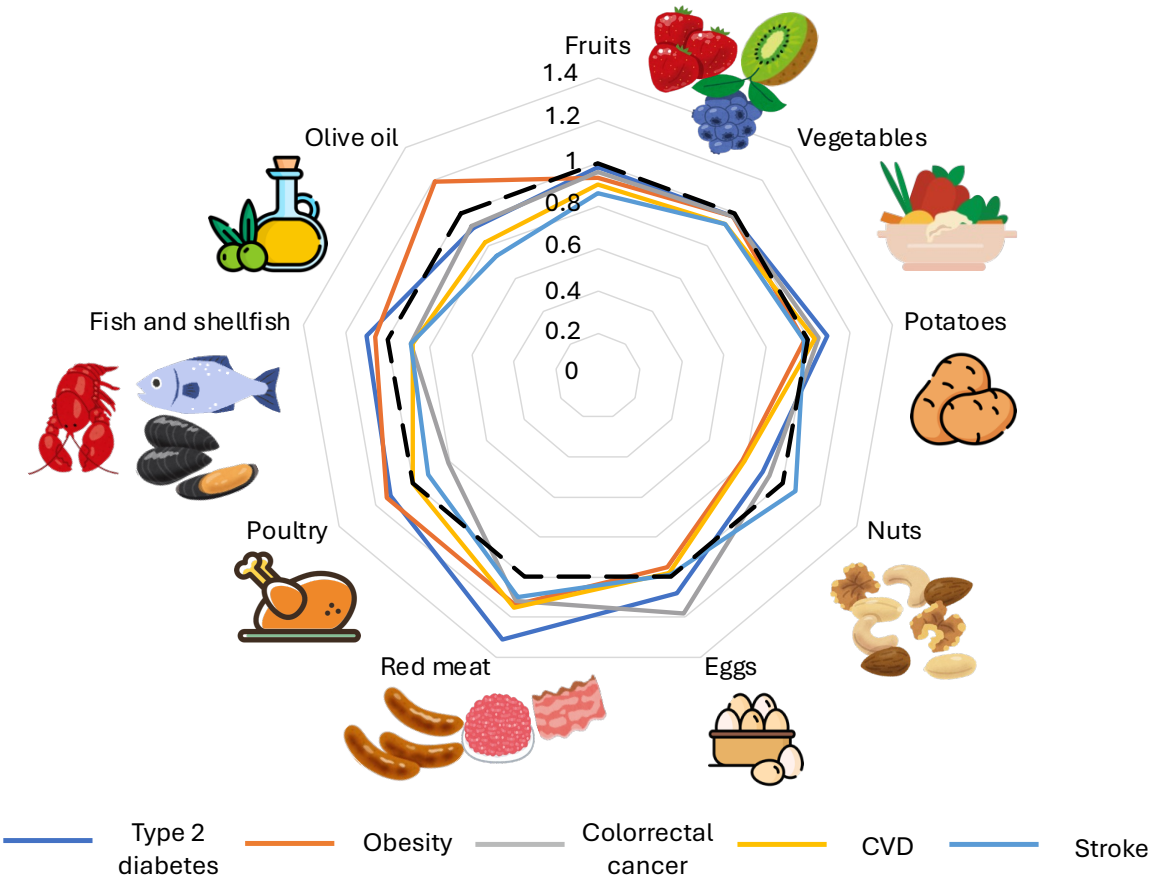


**Fig. 11.3. Radar plot of the relative risks (RR) of diabetes mellitus 2 (T2D), obesity, colorectal cancer, cardiovascular diseases (CVD) and stroke per serving of food categories included in Paleo diet.** Note: Meat category was subdivided in red meat and white meat (poultry) according to the cohort studies analysed. Black dotted line indicates the reference value (RR=1)

**Table 11.5. Cohort studies on fruit consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 100 | 0.98 | 0.97, 1.00 | (Schwingshackl et al., 2017a) |
| CVD | 100 | 0.90 | 0.88, 0.92 | (Aune et al., 2017) |
| Obesity | 100 | 0.93 | 0.86, 1.00 | (Schlesinger et al., 2019) |
| CRCA | 100 | 0.96 | 0.93, 1.00 | (Vieira et al., 2017) |
| Stroke | 80 | 0.86 | 0.83, 0.89 | (Bechthold et al., 2019) |
| All-cause mortality | 100 | 0.94 | 0.92,0.97 | (Schwingshackl et al., 2017d) |

T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer).

**Table 11.6. Cohort studies on vegetables consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 100 | 0.98 | 0.96, 1.00 | (Schwingshackl et al., 2017a) |
| CVD | 100 | 0.93 | 0.92, 0.95 | (Aune et al., 2017) |
| Obesity | 100 | 0.98 | 0.93, 1.03 | (Schlesinger et al., 2019) |
| CRCA | 100 | 0.98 | 0.96, 0.99 | (Vieira et al., 2017) |
| Stroke | 80 | 0.93 | 0.90,0.97 | (Bechthold et al., 2019) |
| All-cause mortality | 100 | 0.96 | 0.95,0.98 | (Schwingshackl et al., 2017d) |

T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer).

**Table 11.7. Cohort studies on potatoes consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 150 | 1.09 | 1.01, 1.18 | (Schwingshackl et al., 2019) |
| CVD | 150 | 1.03 | 0.96, 1.09 | (Schwingshackl et al., 2019) |
| Obesity | 150 | 0.98 | 0.93,1.03 | (Schlesinger et al., 2019) |
| CRCA | 150 | 1.05 | 0.92, 1.20 | (Schwingshackl et al., 2019) |
| Stroke | 150 | 0.98 | 0.93, 1.03 | (Schwingshackl et al., 2019) |
| All-cause mortality | 150 | 0.88 | 0.69, 1.12 | (Schwingshackl et al., 2019) |

Note: T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer). RR for CVD was related to the risk of coronary heart disease.

**Table 11.8. Cohort studies on nuts consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 28 | 0.89 | 0.71, 0.99 | (Schwingshackl et al., 2017a) |
| CVD | 28 | 0.79 | 0.70, 0.88 | (Kwok et al., 2019) |
| Obesity | 28 | 0.78 | 0.58, 1.06 | (Schlesinger et al., 2019) |
| CRCA | 28 | 0.93 | 0.76, 1.21 | (Schwingshackl et al., 2018) |
| Stroke | 28 | 1.07 | 0.93, 1.22 | (Bechthold et al., 2019) |
| All-cause mortality | 28 | 0.76 | 0.69,0.84 | (Schwingshackl et al., 2017d) |

T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer).

**Table 11.9. Cohort studies on eggs consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 50 | 1.08 | 0.95, 1.22 | (Schwingshackl et al., 2017a) |
| CVD | 50 | 0.98 | 0.93, 1.03 | (Drouin-Chartier et al., 2020) |
| Obesity | 50 | 0.95 | 0.63, 1.43 | (Schlesinger et al., 2019) |
| CRCA | 50 | 1.18 | 0.89, 1.56 | (Schwingshackl et al., 2018) |
| Stroke | 55 | 0.99 | 0.92, 1.06 | (Bechthold et al., 2019) |
| All-cause mortality | 50 | 1.15 | 0.99, 1.34 | (Schwingshackl et al., 2017d) |

**Table 11.10. Cohort studies on red meat consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 100 | 1.31 | 1.19, 1.45 | (Yang et al., 2020) |
| CVD | 100 | 1.15 | 1.05, 1.26 | (Kwok et al., 2019) |
| Obesity | 100 | 1.14 | 1.03, 1.26 | (Schlesinger et al., 2019) |
| CRCA | 100 | 1.12 | 1.00, 1.25 | (Vieira et al., 2017) |
| Stroke | 85 | 1.10 | 1.03, 1.16 | (Bechthold et al., 2019) |
| All-cause mortality | 100 | 1.10 | 1.04,1.18 | (Schwingshackl et al., 2017d) |

Note: T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer). RR for obesity is related to the risk of weight gain.

**Table 11.11. Cohort studies on poultry consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 80 | 1.12 | 1.03, 1.21 | (Yang et al., 2020) |
| CVD | 100 | 1.00 | 0.87, 1.15 | (Kwok et al., 2019) |
| Obesity | 100 | 1.14 | 1.03,1.26 | (Schlesinger et al., 2019) |
| CRCA | 100 | 0.81 | 0.53, 1.25 | (Vieira et al., 2017) |
| Stroke | 100 | 0.92 | 0.82, 1.03 | (Mohammadi et al., 2018) |
| All-cause mortality | 100 | 0.90 | 0.73, 1.11 | (Abete et al., 2014) |

Note: T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer). It was assimilated poultry as meat for the calculation of RR of obesity.

**Table 11.12. Cohort studies on fish and seafood consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 100 | 1.10 | 0.50, 1.23 | (Yang et al., 2020) |
| CVD | 100 | 0.88 | 0.79, 0.99 | (Bechthold et al., 2019) |
| Obesity | 100 | 1.06 | 0.99, 1.14 | (Schlesinger et al., 2019) |
| CRCA | 100 | 0.89 | 0.80, 0.99 | (Vieira et al., 2017) |
| Stroke | 100 | 0.89 | 0.79,1.00 | (Bechthold et al., 2019) |
| All-cause mortality | 100 | 0.93 | 0.88, 0.98 | (Schwingshackl et al., 2017b) |

Note: T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer). RR for CVD was related to the risk of coronary heart disease.

**Table 11.13. Cohort studies on olive oil consumption and type 2 diabetes mellitus, cardiovascular diseases, obesity, colorectal cancer and all-cause mortality risk.**

| | Increment | Relative Risk | 95% CI | Source |
|---|---|---|---|---|
| T2D | 10 | 0.91 | 0.87, 0.95 | (Schwingshackl et al., 2017b) |
| CVD | 25 | 0.82 | 0.70, 0.96 | (Kwok et al., 2019) |
| Obesity | 10 | 1.19 | 0.73, 1.95 | (Bes-Rastrollo et al., 2006) |
| CRCA | 10 | 0.92 | 0.86, 0.99 | (Clark et al., 2019) |
| Stroke | 25 | 0.74 | 0.60, 0.92 | (Martínez-González et al., 2014) |
| All-cause mortality | 10 | 0.92 | 0.86, 0.99 | (Clark et al., 2019) |

Note: T2D (type 2 diabetes mellitus), CVD (cardiovascular disease), CRCA (colorectal cancer). Risk measure for obesity is an odd ratio (OR) and due to the lack of information in literature RR for colorectal cancer was assimilated to the risk of all-cause mortality.

### 11.3.2 Cost Assessment

The monetary cost of the Paleo diet was 8.6 €·person$^{-1}$·day$^{-1}$. This high cost is not affordable to low-income consumers. Fish and seafood represented 44% of the food expenses, followed by meat (21%), vegetables (19%) and fruits (8%). The most expensive foodstuffs in the shopping basket were salmon (10.65 €·kg$^{-1}$), prawns (11.01 €·kg$^{-1}$) and tuna (9.64 €·kg$^{-1}$). **Fig. 11.4** shows the distribution of the daily cost among the eight categories of the Paleo diet. A detailed description of the Spanish average prices per foodstuffs that were included in the Paleo diet was reported in **Table 11.14**.

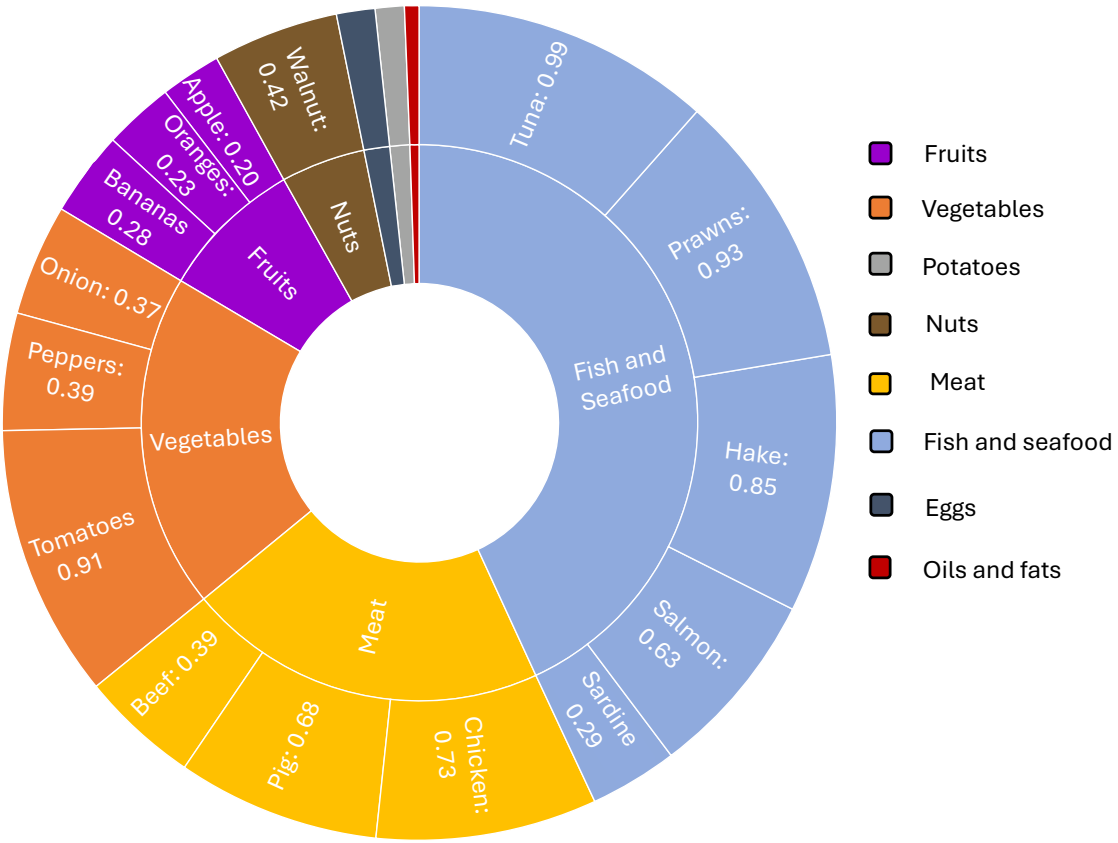


**Fig. 11.4. Daily cost per food categories (€·person$^{-1}$·day$^{-1}$) for Paleo diet**

**Table 11.14. Spanish and European average prices per foodstuffs that were included in the designed Paleo Diet (MAPA, 2019)**

| Food category | Average Spain (€/kg) | Average Europe (€/kg) |
|---|---|---|
| Fruits | | |
| Orange | 0.95 | 0.65 |
| Apples | 1.45 | 0.66 |
| Banana | 1.60 | 1.38 |
| Vegetables | | |
| Tomatoes | 1.69 | 1.26 |
| Onion | 1.26 | 0.45 |
| Peppers | 1.94 | 1.06 |
| Starch-based products | | |
| Potatoes | 0.95 | 0.30 |
| Nuts | | |
| Walnut | 7.95 | 7.95 |
| Eggs | | |
| Eggs | 2.34 | 1.31 |
| Meat | | |
| Beef | 9.69 | 3.37 |
| Chicken | 4.33 | 1.89 |
| Pork | 6.11 | 1.72 |
| Fish and seafood | | |
| Hake | 7.22 | 4.85 |
| Salmon | 10.65 | 6.52 |
| Pilchard | 5.04 | 1.82 |
| Prawns | 9.64 | 4.25 |
| Tuna | 11.01 | 9.10 |
| Oils and fats | | |
| Olive oil | 3.21 | 2.43 |

Note: For walnut the same price was considered for Spain and average Europe

### 11.3.3 Environmental Assessment

GHG emissions related to the Paleo diet were estimated at 5.44 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. Agricultural production or industrial production stage (S1) was the major contributor to GHG emissions through the food chain. GHG emissions from transport, food loss and food waste account for a very small amount of the total emissions from the Paleo diet. Therefore, S1 was responsible for 96% of the emissions, while S2 and S3 together represented 4% (see **Fig. 11.5a)**. In S1, fish and seafood contributed about a half of the diet-related GHG emissions (48%), closely followed by meat, which contributed about two fifths (39%). In contrast, despite the high intakes allocated to these food categories (20% and 41% of the daily-recommended intake, respectively), lower GHG emissions were estimated for fruits and vegetables. **Fig. 11.5b** displays the breakdown of the CF per food category for the agricultural or industrial production stage (S1).

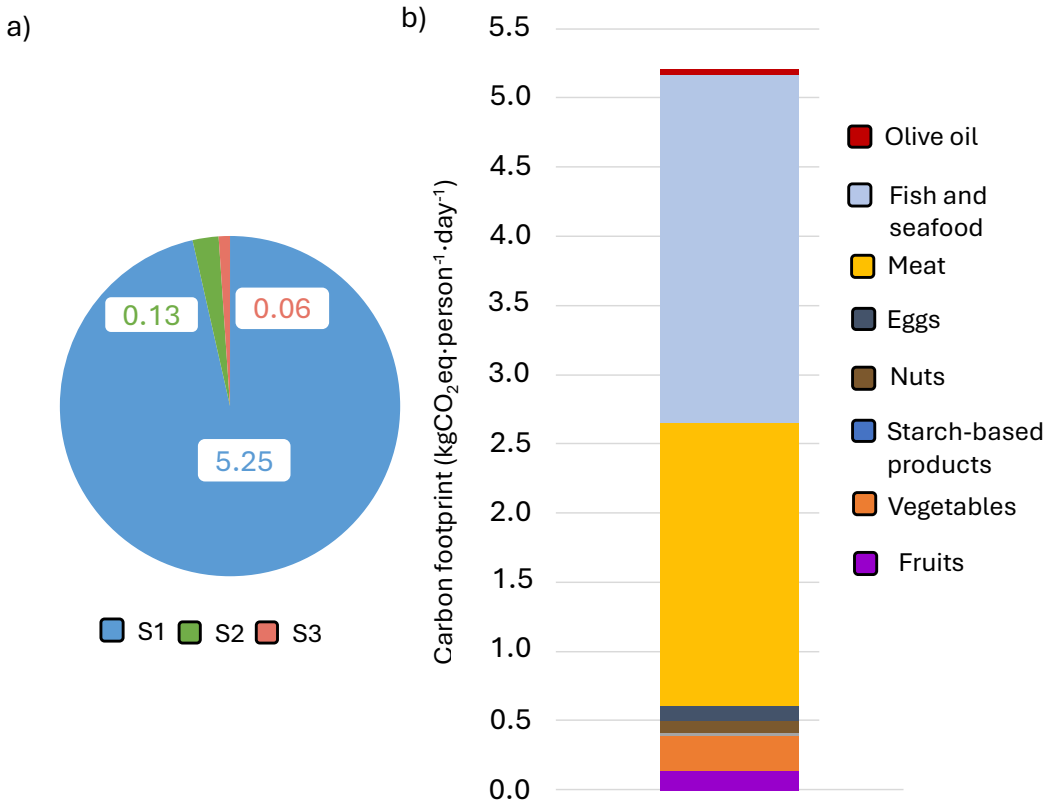


**Fig. 11.5. Breakdown of carbon footprint across the life cycle stages of the supply chain for the Paleo diet (left) and per food categories (right) for the primary agricultural or industrial production stage (S1).**

The average value of daily GHG emissions was 0.06 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ and 0.13 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ for transportation (from farm or industry to retailer and from retailer to households, respectively). Food waste emissions contributed to global warming by about 0.45 kg $CO_2$eq·person$^{-1}$·day$^{-1}$. A detailed description of the average distribution distances and food waste per type of food category was displayed in **Table 11.15**.

**Table 11.15. Exporting volume, importing volume, percentage produced domestically and imported, average distribution distances (import and national) and food waste per type of food category.**

| Food category | Export (t) | Import (t) | National/ Abroad (%) | Imported distance (km) | National distance (km) | Average distance (km) | Food waste ($g \cdot person^{-1} \cdot day^{-1}$) |
|---|---|---|---|---|---|---|---|
| Fruits | | | | | | | |
| Oranges | 1756863 | 148549 | 91/9 | 412 | 366 | 777 | 58.6 |
| Apples | 127076 | 217563 | 70/30 | 320 | 281 | 600 | 30.8 |
| Banana | 99999 | 391506 | 43/57 | 4149 | 173 | 4323 | 37.5 |
| Vegetables | | | | | | | |
| Tomatoes | 767370 | 198203 | 96/4 | 35 | 382 | 417 | 70.6 |
| Onion | 404587 | 81834 | 93/7 | 676 | 371 | 1047 | 44.3 |
| Peppers | 828961 | 63259 | 90/10 | 69 | 360 | 429 | 32.4 |
| Starch based products | | | | | | | |
| Potatoes | 302981 | 839271 | 70/30 | 261 | 280 | 541 | 8.6 |
| Nuts | | | | | | | |
| Walnut | 2527 | 32035 | 32/68 | 6413 | 128 | 6541 | 5.8 |
| Eggs | | | | | | | |
| Eggs | 119301 | 21334 | 97/3 | 21 | 388 | 410 | 3.3 |
| Meat | | | | | | | |
| Beef | 217937 | 136605 | 76/24 | 493 | 304 | 797 | 2.1 |
| Poultry | 180799 | 95870 | 83/17 | 482 | 331 | 813 | 10.4 |
| Pork | 2184047 | 114686 | 99/1 | 12 | 396 | 408 | 5.7 |
| Fish and Seafood | | | | | | | |
| Hake | - | - | - | - | - | 400 | 12.9 |
| Salmon | - | - | - | - | - | 400 | 7.0 |
| Sardine | - | - | - | - | - | 400 | 6.4 |
| Tuna | - | - | - | - | - | 400 | 14.3 |
| Prawns | - | - | - | - | - | 400 | 9.2 |
| Oils and fats | | | | | | | |
| Olive oil | 1077213 | 148562 | 83/17 | 231 | 330 | 561 | 0.3 |

The WF for the Paleo diet was estimated on 3499 $L \cdot person^{-1} \cdot day^{-1}$ (70% green, 16% blue and 14% grey) (see **Fig. 11.6a**). Foods of animal origin were the major contributors to the WF (over 64% of the total WF). By far, the largest representation of all animal products comes from the meat category. Approximately 49% of the total WF (1709 $L \cdot person^{-1} \cdot day^{-1}$) in the Paleo diet was due to meat consumption. However, meat does not represent the most consumed category. It was the fourth in terms of consumption, behind fish and seafood. Additionally, nuts, fish and seafood accounted for 15% and 10% of the dietary WF, respectively. **Fig. 11.6b** shows the distribution of the WF between the eight food categories for the Paleo diet. The general findings on green WF were the same. Animal products was largely responsible for the green WF compared to crop products, with meat and fish and seafood having the largest green WF (1373 $L \cdot person^{-1} \cdot day^{-1}$ and 254 $L \cdot person^{-1} \cdot day^{-1}$, respectively). Olive oil, with an associated green WF per tonne of 15 $L \cdot g^{-1} \cdot day^{-1}$, was the major water consuming product, even more than beef meat (11 $L \cdot g^{-1} \cdot day^{-1}$).

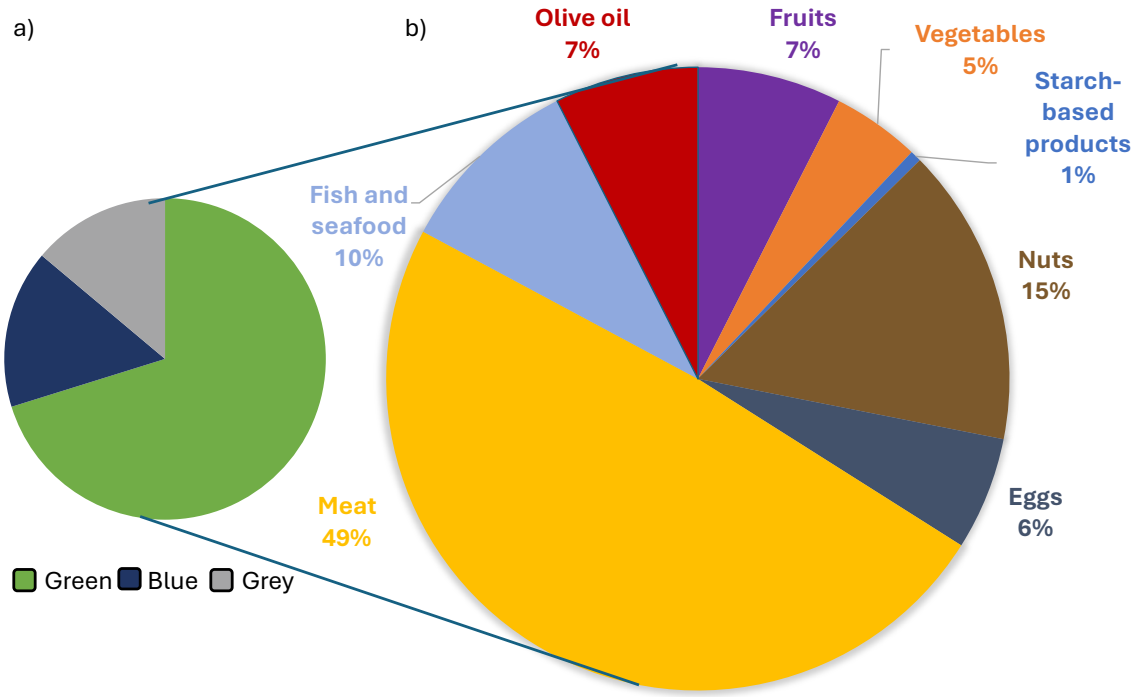


**Fig. 11.6. Breakdown of water footprint (L·person$^{-1}$·day$^{-1}$) expressed as water footprint green, blue and grey (left) and per food categories (right).**

However, although animal-based foods were the major contributors to the green and total WF, plant-based food featured as the major contributor to the blue WF (61% of the total), with nuts as an outstanding element (30% of the blue WF). These results were consistent with the conclusions of the meta-analysis conducted by Harris et al. (2020), who reported that plant-based foods dominated the blue WF of healthy diets. The detailed WF for the foodstuffs included in the Paleo diet were reported in **Table 11.16**.

**Table 11.16. Total, green, blue and grey water footprint (WF) per food group**

| Food category | Total WF (l) | Green WF (l) | Blue WF (l) | Grey WF (l) |
|---|---|---|---|---|
| **Fruits** | 262.0 | 155.8 | 82.2 | 24.0 |
| Orange | 121.4 | 63.9 | 43.3 | 14.2 |
| Apples | 71.9 | 41.8 | 23.0 | 7.2 |
| Banana | 68.6 | 50.2 | 15.9 | 2.6 |
| **Vegetables** | 159.1 | 56.9 | 51.3 | 50.9 |
| Tomatoes | 49.3 | 20.9 | 13.8 | 14.6 |
| Onion | 91.3 | 26.4 | 36.5 | 28.4 |
| Peppers | 18.5 | 9.6 | 1.0 | 7.9 |
| **Starch-based products** | 20.4 | 9.2 | 6.3 | 4.9 |
| Potatoes | 20.4 | 9.2 | 6.3 | 4.9 |
| **Nuts** | 541.8 | 224.4 | 165.3 | 152.1 |
| Walnut | 541.8 | 224.4 | 165.3 | 152.1 |
| **Eggs** | 205.3 | 158.3 | 20.3 | 26.7 |
| Eggs | 205.3 | 158.3 | 20.3 | 26.7 |
| **Meat** | 1709.3 | 1373.2 | 154.0 | 182.1 |
| Beef | 527.1 | 446.9 | 37.0 | 43.2 |
| Chicken | 580.4 | 460.3 | 49.3 | 70.8 |
| Pork | 601.7 | 466.0 | 67.7 | 68.0 |
| **Fish and seafood** | 339.4 | 254.3 | 40.7 | 44.4 |
| Hake | 0.0 | 0.0 | 0.0 | 0.0 |
| Salmon | 136.1 | 97.2 | 13.0 | 25.9 |
| Pilchard | 0.0 | 0.0 | 0.0 | 0.0 |
| Prawns | 203.3 | 157.1 | 27.7 | 18.5 |
| Tuna | 0.0 | 0.0 | 0.0 | 0.0 |
| **Oils and fats** | 261.3 | 223.4 | 37.2 | 0.7 |
| Olive oil | 261.3 | 223.4 | 37.2 | 0.7 |
| Total | 3498.6 | 2455.7 | 557.1 | 485.8 |

## 11.4 DISCUSSION

The discussion section focused on integrating the environmental, economic and health indicators calculated for the Paleo Diet to have a holistic view of the environmental and health sustainability of the diet. The results of this multidisciplinary approach were used for further comparison with other dietary patterns globally.

### 11.4.1 Health and economic aspects of the Paleo diet and their correlation with environmental impacts

Three of the four domains of Sustainable Food Systems Science (Nutrition-Health, Economics and Environment) were analysed for the Paleo Diet (Drewnowski et al., 2020). **Fig 11.7** was used to visualize the multivariate outcomes analysed: WF and CF (see **Fig 11.7a)** and the association of the latter with the cost (see **Fig 11.7b)** and the RR of all-cause mortality (**Fig 11.7c)** per food category. Vegetables, fruits and potatoes were associated with lower impacts on environmental, economic and disease metrics. Eggs were associated with environmental benefits (low CF and WF), but not with benefits for health impacts in terms of all-cause mortality risk. Conversely, red meat was associated with the greatest increases in all-cause mortality risk and with the largest negative environmental impacts and expenses. However, the other type of meat, poultry, commonly referred to as white meat, showed lower WF and CF values than red meat and was not associated with a RR of all-cause mortality higher than 1. Regarding fish and seafood group, it resulted an expensive category with a relatively high CF. Finally, nuts and olive oil presented a high WF, but low CF and RR of all-cause mortality. Nuts were the second most expensive food category after fish and shellfish.

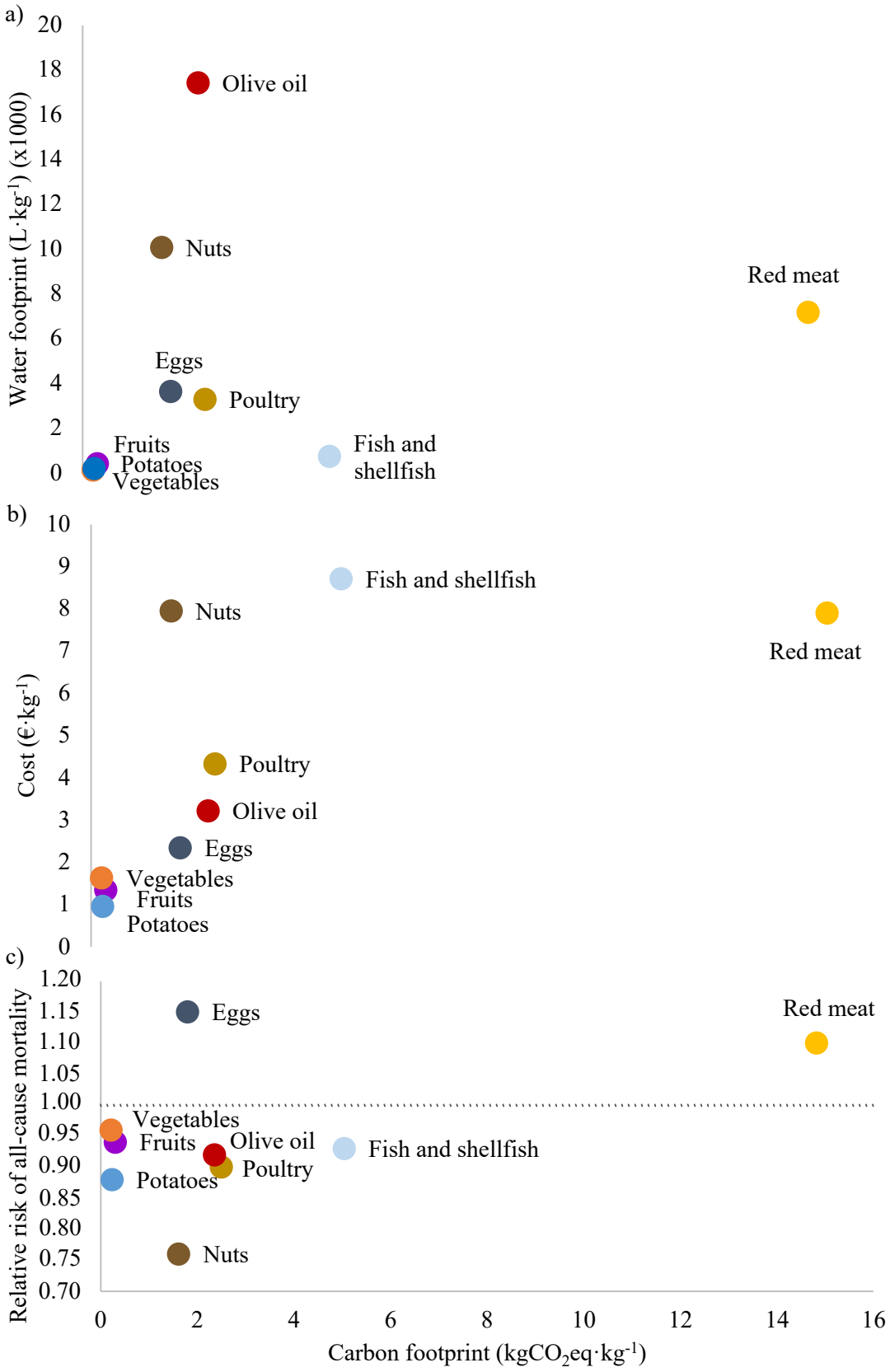


**Fig 11.7. Association per food category between the carbon footprint ($kgCO_2eq \cdot kg^{-1}$) and a) the water footprint (expressed as L of water consumed per g of daily intake), b) the cost (expressed as € per kg of food in a food category c) the relative risk of all-cause mortality.**

### 11.4.2 Comparison of the Paleo Diet with the other well-known diets dietary patterns

Decision-making processes regarding individual diets are becoming increasingly difficult. The wide variety of diets available makes it difficult to select the best option if adequate information is not available about their sustainability, costs, health-promotion potential and nutritional quality. Therefore, the comparison between the Paleo diet and the other well-known dietary patterns at global level in terms of nutritional quality index, CF and WF is of great importance.

The nutritional quality index for other well-positioned diets such as the recommended Dutch Diet (105), vegetarian (100), semi-vegetarian (103) and vegan (118) (van Dooren et al., 2014) was lower than those identified for the Paleo Diet (260) and for the MD (178) the NAOS strategy (159) and the Southern European Atlantic Diet (150) (González-García et al., 2020b). The higher intake of fish, fruits and vegetables in the Paleo Diet was associated with the high value obtained for the nutritional quality index. Note that although our formula differs slightly from that used by van Dooren et al. (2014), who considered as a reference for energy value of 2000 kcal instead of 2228 kcal, this deviation hardly affects the result of the diet quality index.

In terms of caloric profile, in contrast to the high protein, low-carb Paleo diet, recommended diets in Spain, MD, SEAD and NAOS fit reasonably well with the nutritional recommendations, as can be seen in **Table 11.17**. As for the lipid profile, SFA and MUFA energy percentages complied with the recommended limits for MD (9.0% of total energy intake for SFA and 18.4% of total energy intake for MUFA) and SEAD (9.7% of total energy intake for SFA and 14.0% of total energy intake for MUFA), and almost complied with the recommended limits for NAOS (10.6% of total energy intake for SFA and 17.6% of total energy intake for MUFA). However, PUFA energy percentage was below the recommendations for the three Spanish diets (see **Table 11.18**). Therefore, while the Paleo diet is rich in PUFA (15.3% of total energy intake), the opposite was observed for MD (4.8% of total energy intake), SEAD (4.7% of total energy intake) and NAOS (4.9% of total energy intake). Notably, the minimum recommended level of PUFA in the hope of reducing LDL and total cholesterol, increasing HDL cholesterol, and decreasing the risk of coronary heart disease events is 6% of total energy intake (EFSA, 2020). The results of the caloric profile and the lipid profile of the MD, the NAOS and the SEAD were estimated with the computer program DIAL, based on the average of the recommended daily intake by food category established by González-García et al. (2020b).

Cholesterol and EPA-DHA levels in MD (105 $mg \cdot day^{-1}$ and 450 $mg \cdot day^{-1}$, respectively) were in compliance with the recommended intake. However, cholesterol and EPA-DHA intake was 348 $mg \cdot day^{-1}$ and 680 $mg \cdot day^{-1}$ for SEAD, and 327 $mg \cdot day^{-1}$ and 750 $mg \cdot day^{-1}$ for NAOS, respectively, values higher than the nutritional recommendation (300 $mg \cdot day^{-1}$ for cholesterol intake and 500 $mg \cdot day^{-1}$ for EPA-DHA) (ALCE, 2020). Even so, they were lower than those estimated for the Paleo diet (835 $mg \cdot day^{-1}$ for cholesterol intake and 7400 $mg \cdot day^{-1}$ for EPA-DHA intake). A detailed summary of the fat quality for MD, SEAD, and NAOS was reported in **Table 11.19**.

**Table 11.17. Caloric Profile of the recommended dietary patterns in Spain**

| Caloric profile | MD | SEAD | NAOS | Nutritional recommendation |
|---|---|---|---|---|
| Protein energy (% kcal) | 13.2 | 15.6 | 15.1 | 10-15% (ALCE, 2020) |
| Lipid energy (% kcal) | 35.4 | 31.5 | 36.3 | 20-35% (EFSA, 2020) |
| Carbohydrate energy (% kcal) | 51.3 | 52.8 | 48.6 | 45-60% (EFSA, 2020) |

**Table 11.18. Lipid Profile of the recommended dietary patterns in Spain**

| Lipid Profile | MD | SEAD | NAOS | Nutritional recommendation |
|---|---|---|---|---|
| SFA (%kcal) | 9.0 | 9.7 | 10.6 | Less than 10% (EFSA, 2020) |
| PUFA (% kcal) | 4.8 | 4.7 | 4.9 | 6-11% (Todd, 2010) |
| MUFA (%kcal) | 18.4 | 14.0 | 17.6 | Rest of the fat (ALCE, 2020) |

Saturated fatty acids (SFA), Monounsaturated fatty acids (MUFA), Polyunsaturated fatty acids (PUFA)

**Table 11.19. Fat quality for the recommended dietary patterns in Spain.**

| | MD | SEAD | NAOS | Nutritional recommendation |
|---|---|---|---|---|
| Total lipids (g) | 92 | 97.8 | 95.5 | |
| SFA (g) | 23.3 | 30 | 28 | |
| MUFA (g) | 47.9 | 43.5 | 46.2 | |
| PUFA (g) | 12.5 | 14.7 | 12.9 | |
| PUFA/SFA | 0.54 | 0.49 | 0.46 | More than 0.5 (ALCE, 2020) |
| PUFA+MUFA/SFA | 2.6 | 1.9 | 2.1 | More than 2 (ALCE, 2020) |
| Cholesterol (mg) | 246 | 348 | 327 | Less than 300 mg·day-1 (FDA, 2020) |
| Cholesterol (mg)/1000 kcal | 105 | 125 | 138 | Less than 100 mg/1000 kcal (FDA, 2020) |
| % Energy AG omega-3 (g) | 0.88 | 0.93 | 0.99 | 1-2% Energy (ALCE, 2020) |
| EPA-DHA | 430 | 680 | 750 | 500 mg/day (ALCE, 2020) |

Saturated fatty acids (SFA), Monounsaturated fatty acids (MUFA), Polyunsaturated fatty acids (PUFA), Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA).

In terms of economic evaluation, the large variability of market prices between countries and reference years causes discrepancies and makes the comparison in economic terms not very useful. For comparison, the price of the Paleo diet for an average European citizen has been calculated using the Agriview Market Price Database (European Commission, 2019a) and the European Price Report (FAO, 2019f) (see **Table 11.14** for further details). The average price obtained was 5.0 €·person$^{-1}$·day$^{-1}$, a value far from that obtained using the Spanish database (8.6 €·person$^{-1}$·day$^{-1}$). Compared to recommended diets in Spain, the Paleo diet has a higher cost. The average daily cost of the Paleo diet was 8.58 €·person$^{-1}$·day$^{-1}$, approximately double than for MD (4.18 €·person$^{-1}$·day$^{-1}$), SEAD (4.86 €·person$^{-1}$·day$^{-1}$) and NAOS (4.01 €·person$^{-1}$·day$^{-1}$). The cost index calculated for the MD, SEAD and NAOS by González-García et al. (2020b) was updated to 2019 according with the data gathered in MAPA (2019).

In relation to environmental metrics, GHG emissions for the Paleo diet were estimated in 5.44 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, a value more than 1.5 times greater than for the recommended diets in Spain (González-García et al., 2020b). The rationale behind the high value of the Paleo diet is due to the average daily recommended intake of meat, and fish and seafood, was much higher than that for MD, SEAD and NAOS. The comparison is perfectly acceptable considering

that the methodology proposed by them was followed in detail for the environmental assessment of the Paleo diet. The CF of the Paleo Diet was also above the values of the different studies available in the literature for the NND (Ulaszewska et al., 2017), vegan (Castañé and Antón, 2017), Portuguese (Esteve-Llorens et al., 2020a) and American (Rose et al., 2019). A correct comparison requires a detailed analysis of the system boundaries for the selected LCA studies.

The CF of the NND (3.88 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) (Ulaszewska et al., 2017) and vegan (1.86 kg $CO_2$eq·person$^{-1}$·day$^{-1}$) (Castañé and Antón, 2017) was assessed from a cradle-to-consumer approach, including household consumption (cooking) and excluding beverages, as well as food loss and waste along the supply chain. Esteve-Llorens et al. (2020a) considered the same approach but took into account food loss and food waste along the supply chain for the Portuguese diet (4.20 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). Even without considering the cooking stage in this study (around 0.53 kg $CO_2$eq·person$^{-1}$·day$^{-1}$ for an omnivorous diet) (Corrado et al., 2019), the CF for the Paleo diet is above the Portuguese, vegan and New Nordic diets. Rose et al. (2019) considered a cradle-to-farm gate without including processing, packaging and transportation in their CF analysis for the American Diet (4.72 kg $CO_2$eq·person$^{-1}$·day$^{-1}$). They included impacts associated with food loss and food waste at the retailer and consumer levels and estimated that transportation would increase the CF by 5% resulting in 4.96 kg $CO_2$eq·person$^{-1}$·day$^{-1}$, a value not far from that obtained for the Paleo Diet.

The WF for the Paleo Diet (3499 L·person$^{-1}$·day$^{-1}$) is in line with the results reported by Harris et al. (2020) for the WF of "average" dietary patterns in Europe (3227), and above than the WF for other continents such as Africa (2846 L·person$^{-1}$·day$^{-1}$), Asia (2862 L·person$^{-1}$·day$^{-1}$), North America (2617 L·person$^{-1}$·day$^{-1}$), and South Africa (2932 L·person$^{-1}$·day$^{-1}$). Local climate, agricultural factors, food origin and diet composition may explain the large heterogeneity in dietary WFs between continents (Harris et al., 2020). On the other hand, the WF of the Paleo Diet is above that reported for the vegetarian diet (2655 L·person$^{-1}$·day$^{-1}$) (Vanham et al., 2013). The contrasting results are reasonable since meat has a much higher WF than vegetables, grains and beans (Mekonnen and Hoekstra, 2012).

### 11.4.3 Limitations of the study

Interpretation of the results must take into account the scarce information for calculating the WF of non-aquaculture species. In addition, the LCA studies consulted for the estimation of the CF are very diverse (e.g., different system boundaries, climatic variations or farming techniques), which increases the complexity of the analysis for the integration of different approaches for the estimation of GHG emissions. On the other hand, we have used national data (such as the Spanish Household consumption database (MAPA, 2019) and average European or global data when specific information for Spain was not available. Considering that environmental metrics have a geographic connotation, this assumption may lead to a bias in the results. The inclusion of future local and site-specifics assessments in the food process and organisation could help to obtain more robust results, more practical relevance especially for decision-making and a local database instead of using the global one in a less accurate way.

## 11.5 Concluding remarks

Dietary trends have come and gone over the years. Nowadays, the concern on adequate weight and body shape is having a significant impact on dietary trends. This concern, along with the impact of social media in our lives, made the Paleo diet sweep the wellness and food scene. The present study evaluates the environmental and health sustainability of this caveman-like diet in

terms of nutritional quality, health, environment and economy to determine whether the popular Paleo diet is environmentally and health-friendly or just a fad.

According to the main results of this study, the Paleo diet can be considered an expensive dietary choice with a significant effect on GHG emissions. Fish and seafood and meat products were the largest emitters of carbon dioxide in the Paleo diet, although their average daily per capita consumption was not as significant as that of other food categories such as fruits or vegetables. Moreover, while fruits and vegetables were associated with better adult health, food groups with the largest CF (red meat, fish and seafood, and poultry) were also associated with the largest increases in diet-related diseases. In terms of nutritional profile, the Paleo diet is rich in fats, proteins and PUFA and restricts carbohydrates, which leads to lose weight and improve muscle development. However, the high levels of cholesterol and EPA in the Paleo diet could cause negative health effects, increasing the risk of cancer and CVD.

Future research should pay special attention to the design of social campaigns and educational programs that are strategically designed to combat misinformation about dietary patterns and reduce fake news and cyber-propaganda. Moreover, to obtain a global vision of the sustainability of these diets, sociocultural and socioeconomic determinants should be specifically considered for assessing a sustainable diet.

In summary, the burden of choosing healthy and sustainable diets in the future is not only on consumers, but also on governments, which can benefit from sustainability research. Governments can carry out different actions for promoting healthy eating habits and lifestyle behaviours, as for instance, promote the FBDGs, coordinate all sector involved, create awareness and training programs with social impact, incorporate nutrition in education planning or prioritise local, family and organic production. To sum up, governments should use the adequate means to inform citizens about dietary choices, fostering social transition and acceptance to sustainable food systems.

# SECTION V

## FOSTERING FOOD SUSTAINABILITY IN FORMAL EDUCATION THROUGH MEMOGAMES AND LEARNING STRATEGIES

# 12. EAT HEALTHY… EAT SUSTAINABLY[10]

A balanced diet is essential for children's growth and development, as eating habits developed in early life often persist into adulthood. As childhood obesity rates rise, children are more likely to become obese adults and to develop non-communicable diseases, cancer and premature death at a younger age. On the other hand, the dietary habits of children, and by extension the population as a whole, have a profound impact on environmental pressures, particularly on carbon and water footprint indicators. “Eat healthy... Eat sustainably” is an educational game for primary school children that aims to make students aware of the importance of their actions for health, the environment and sustainable development. The game, which consists of 62 cards representing foods commonly consumed in Spain, challenges players to calculate the carbon and water footprints associated with their personal diets. By converting these values into equivalent measurements, such as the distance a car could drive to produce the same greenhouse gas emissions or the amount of water used in a bathtub, the game provides a tangible and relatable understanding of the environmental impact of dietary choices. Building on this knowledge and using cooperative learning methods, students can design a sustainable and healthy diet that promotes individual well-being while also promoting environmental sustainability.

[10] Feijoo, G., Moreira, M.T., Arias, A., Cambeses-Franco, C., Lorenzo-Moledo, M.M., Rodríguez-Fernández, J.E., Crespo-Comesaña, J.M., Rico-Díaz, J., García-Álvarez, J., 2024. Come San…Come Sostible (03/2024/1394). Ministerio de Cultura, España.

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## 12.1 INTRODUCTION

### 12.1.1 Childhood Obesity: Policies, interventions and future directions

Childhood obesity has emerged as a major global health crisis, particularly among children and adolescents. The WHO has sounded the alarm on this escalating problem, highlighting its significant impact on mortality and its strong association with sedentary lifestyles (WHO, 2020e). To address this pressing issue, the WHO launched the European Childhood Obesity Surveillance Initiative (COSI) in 2007. This system has been collecting data on overweight and obesity in primary school children in the WHO European Region for more than 10 years. It provides nationally representative data and insights into the determinants of these health problems (WHO, 2022).

Unfortunately, Spain is one of the European countries with the highest prevalence of overweight and obesity in children. Between 32.5% and 39% of Spanish children are overweight (Cadenas-Sanchez et al., 2020; Gómez et al., 2020). The findings of de Bont et al. (2022) show a worrying upward trend in childhood overweight and obesity rates among 2-9 years-old children in Spain. This is particularly pronounced in boys and peaks at age 6-7 (the start of primary school).

Governments around the world have responded to rising childhood obesity rates by implementing policies to promote healthy eating among young people. Global frameworks, such as the Global Action Plan on Physical Activity 2018-2030 (WHO, 2018b), and regional strategies, such as Spanish National Strategic Plan for the Reduction of Childhood Obesity (2022-2030) (Gobierno de España, 2022a), exemplify a concerted effort to create an environment in which children can thrive. These initiatives are in line with SDG 3, which aims to ensure healthy lives and promote well-being for all at all ages. The Plan's action lines focus on promoting a social ecosystem that encourages healthy eating, physical activity, emotional well-being and adequate rest; strengthening the public system; protecting children's health; and facilitating a cultural shift toward healthy lifestyles.

Like the rest of Spain, Galicia is experiencing an increase in childhood obesity. The 2014 Xermola Plan, an initiative of the Galician Ministry of Health to prevent childhood obesity, reveals a stark reality: nearly 40% of Galician children are overweight or obese, affecting approximately one-third of the adolescent population. The Xermola Plan identifies the school environment as a critical setting for intervention. The plan establishes regulations for food offerings in schools and implements physical activity programs in line with current recommendations (SERGAS, 2013).

### 12.1.2 Integrating environmental awareness into the curriculum

Polo Blanco and Piñeiro Aguiar (2019) argue that society's misguided efforts to control the natural world and the overexploitation of resources have served to aggravate a critical global problem: environmental protection. As highlighted by the UN (2023) and WHO (2021), the prospect of human survival is seriously threatened by several interrelated issues. Climate change and global warming, driven by air pollution from fossil fuels, pose significant health risks. Drought and desertification, exacerbated by climate change, threaten water resources, agriculture and biodiversity. Overexploitation of resources, including excessive mining, overuse of water, overfishing, intensive agriculture and dependence on non-renewable energy, hinders regeneration of resources. Deforestation, particularly in Africa and South America, disrupts ecosystems and reduces carbon sinks, while plastic pollution from single-use packaging and improper waste disposal, particularly in marine ecosystems, further contaminate the planet. Together, these issues are exacerbating the environmental crisis.

Protecting the environment has become a global priority, as evidenced by initiatives such as the SDGs. This growing awareness has permeated the educational landscape, with environmental education now being integrated across the curriculum, especially in primary schools. By exploring the causes of pollution, young learners can become initiative-taking agents of change. Five of the 17 SDGs are explicitly aligned with the "Eat healthy... Eat sustainably" initiative: health and well-being (SDG3), quality education (SDG4), clean water and sanitation (SDG6), responsible production and consumption (SDG12) and climate action (SDG13).

Decree 155/2022 outlines three main pillars for environmental education (Xunta de Galicia, 2022b): (1) Sustainable development by promoting the responsible use of resources and the need to preserve the environment for future generations. (2) Appreciation and protection of nature, promoting responsible use of the environment (3) The importance of recycling and resource efficiency. The recently introduced curriculum for primary education in Galicia (Decree 155/2022) explicitly establishes a connection between the educational system and environmental protection (Xunta de Galicia, 2022b). The curriculum emphasizes sustainable development, including education for ecological transition. To shape the desired profile of students at the end of primary education, the curriculum takes into account the challenges outlined in UNESCO's Key Drivers of Curricula Change in the 21st Century (Marope, 2020) and is aligned with the SDGs.

The concept of sustainable development is integrated throughout the curricula of natural and social sciences. Topics such as "Life on the planet" and "The world and sustainable development" are core components of these subjects. In addition, the concept has implications that go beyond these areas. For example, the concepts of "efficient and sustainable interaction with the environment" and "sustainable development and environmental ethics" are addressed in the branches of Physical Education and Civics and Ethical Values Education.

### 12.1.3 The Educational game: "Eat healthy... Eat sustainably"

"Eat healthy... Eat sustainably" is an educational game for primary school children that teaches them about food choices, personal health and environmental sustainability (**Fig. 12.1**). Through playful learning experiences, students understand the importance of a balanced diet for growth and well-being, especially when started at an early age; explore the benefits of different food groups; and learn to make informed choices that support their physical and mental health.

Beyond personal health, the game highlights the environmental impact of food choices. Students discover how their food consumption affects the planet's resources, such as water, and contributes to carbon emissions. By examining the connection between their meals and their environment, they develop a sense of responsibility for sustainable practices.

As a valuable educational tool "Eat healthy...Eat sustainably" promotes cognitive development, problem-solving skills and critical learning. Through active participation in the game, students learn about nutrition and sustainability and explore questions such as What is a balanced diet? What foods are essential for good health? How much food is needed? What is the environmental impact of food choices? How can we make sustainable food choices in our daily lives?

**Fig. 12.1. Board game cover**

## 12.2 MATERIALS AND METHODS

### 12.2.1 Context, target audience and duration

"Eat healthy... Eat sustainably" is a game designed for primary education, specifically for 4th, 5th and 6th-course students. It is in line with the general objectives, content and assessment criteria of various subjects, including Natural Sciences, Social Sciences, Mathematics, Physical Education and Education in Civic and Ethical Values. The activity is designed to be completed in four 50-minute sessions. However, if the final reflection or large group discussions require additional time, it is recommended that an extra session be scheduled for older students.

Although "Eat healthy...Eat sustainably" was developed primarily for the educational system, it is also an excellent tool for working with families. As food and nutrition are deeply rooted in the family environment, this game provides a platform for shared experiences. Furthermore, "Eat healthy... Eat sustainably" can be effectively used in other educational contexts, such as social and community organisations, while maintaining the core philosophy of the game.

### 12.2.2 Key competences

The implementation of the game facilitates the development of key competences for lifelong learning, as outlined in the Council Recommendation of 22 May 2018 on key competences for lifelong learning (European Parliament and Council of the European Union, 2018). The game has been carefully designed to take into account the specificities of the school context and is in line with the fundamental principles and objectives of the education system.

Of the eight key competences, "Eat healthy... Eat sustainably" contributes to the acquisition of the following: (1) Personal, social and learning to learn competence; (2) Mathematical competence and competence in science, technology and engineering; (3) Citizenship competence; (4) Cultural awareness and expression; (5) Multilingual competence. The game also develops other skills closely related to key competences, such as problem solving, critical thinking, analytical skills and creativity.

### 12.2.3 Objectives

The main objectives of the educational game are:

- Familiarize with the main food groups that constitute a balanced diet and recognize the basic characteristics of the foods most commonly consumed in Spain.
- Identify the main types of food for a healthy diet and the appropriate proportions for a balanced diet.
- Raise awareness of the environmental pillar of sustainability by measuring two environmental indicators related to eating habits: CF and WF.
- Encourage teamwork and promote values essential to living in a free, fair, pluralistic, and egalitarian society.

### 12.2.4 Materials

"Eat healthy...Eat sustainably" includes the following materials:

- A box containing 62 cards. Each card (**Fig. 12.1**) represents one of the 62 most consumed foods in Spain, according to the MAPA (2023). The cards are colour-coded according to the eight food groups, as follows: Yellow, eggs and dairy products; Green, vegetables and pulses; Light blue, fish and seafood; Lilac, beans; Brown, cereals; Grey, meat (chicken, pork and beef); Red, meat (pork and beef); Dark blue, olive oil. One side of each card shows the name of the food and a reference quantity (e.g. half a kilo), while the reverse side shows the CF and WF indicators for that reference quantity (see **Fig. 12.2**).
- Cards of the 5 SDGs referred in **Section 12.1.3** for group playing (**Fig. 12.3**)

**Fig. 12.2. Front and back of a food card. The front shows the reference amount and the relationship with the Sustainable Development Goals, while the back illustrates the carbon footprint and water footprint indicators.**

**Fig. 12.3. Cards SDGs**

- Sheet 1 (My Diet) (**Table 12.1**) designed to facilitate the calculation of CF and WF, where students can record the amount of food in their daily diet and convert it into CF and WF.
- Sheet 2 (Our sustainable diet) (**Figure 12.4**) for recording data on the sustainable diet of each group (after individual analysis) or the whole class group (after group analysis). The sheet to be completed is the same as the one shown in **Table 12.1,** but this is a team activity.
- Sheet 3 (Characterisation factors) (**Table 12.2**) to calculate the CF ($kgCO_2eq/kg$), WF ($L\ H_2O/kg$) and cost (€/kg) for each of the 62 food items in the game.
- Sheet 4 (Conversion factors) (**Table 12.3**) for calculating quantities of each food in relation to a common measure or value.
- Sheet 5 (Calculation example for the teacher) (**Table 12.4**)
- An evaluation questionnaire for students (see **Section 12.4**)

**Table 12.1. Sheet 1: My diet**

| My diet | Amount to eat | Daily diet | | | |
|---|---|---|---|---|---|
| | | Carbon footprint | | Water footprint | |
| | | Characterisation factor (kg $CO_2$ per 500 g)[a] | kg $CO_2$ (eq)[b] | Characterisation factor (L $H_2O$ per 500 g)[a] | L $H_2O$ (eq)[b] |
| Olive oil (mL) | | | | | |
| Meat (g) | | | | | |
| Chicken | | | | | |
| Pork | | | | | |
| Beef | | | | | |
| Cereals (g) | | | | | |
| Rice | | | | | |
| Wholemeal biscuits | | | | | |
| Coffee | | | | | |
| Wholemeal cereals | | | | | |
| Bread | | | | | |
| Pasta | | | | | |
| Sweets (g) | | | | | |
| White sugar | | | | | |
| Honey | | | | | |
| Fruits | | | | | |
| Plums | | | | | |
| Figs | | | | | |
| Strawberries | | | | | |
| Kiwi | | | | | |
| Orange | | | | | |
| Mandarins | | | | | |
| Apple | | | | | |
| Melon | | | | | |
| Nectarine | | | | | |
| Raisins | | | | | |
| Peach | | | | | |
| Pineapple | | | | | |
| Banana | | | | | |
| Watermelon | | | | | |
| Grapes | | | | | |
| Orange juice (amount in mL) | | | | | |
| Eggs (number) | | | | | |
| Dairy products | | | | | |
| Yoghurt (number of classic size) | | | | | |
| Milk (amount in mL) | | | | | |
| Cow cheese (g) | | | | | |
| Fresh cheese (g) | | | | | |
| Curd (g) | | | | | |

**Table 12.1. (cont.) Sheet 1: My diet**

| | | Daily diet | | | |
|---|---|---|---|---|---|
| | | Carbon footprint | | Water footprint | |
| My diet | Amount to eat | Characterisation factor (kg $CO_2$ per 500 g)[a] | kg $CO_2$ (eq)[b] | Characterisation factor (L $H_2O$ per 500 g)[a] | L $H_2O$ (eq)[b] |
| Fish and seafood (g) | | | | | |
| Tuna | | | | | |
| Cod | | | | | |
| Cockles | | | | | |
| Squids | | | | | |
| Cuttlefish | | | | | |
| Octopus | | | | | |
| Sardines | | | | | |
| Mackerel | | | | | |
| Vegetables, legumes (g) | | | | | |
| Garlic | | | | | |
| Celery | | | | | |
| Pumpkin | | | | | |
| Onion | | | | | |
| Carrot | | | | | |
| Mushrooms | | | | | |
| Peas | | | | | |
| Brussels sprouts | | | | | |
| Cauliflower | | | | | |
| Asparagus | | | | | |
| Beans | | | | | |
| Lettuce | | | | | |
| Potatoes | | | | | |
| Pepper | | | | | |
| Cucumber | | | | | |
| Leek | | | | | |
| Radish | | | | | |
| Beetroot | | | | | |
| Cabbage | | | | | |
| Tomato | | | | | |
| | | SUM | A: | | B: |
| | | | C[c]: | | D[d]: |

[a] Write the value that appears on the cards [b] The quantity (in g) is divided by 500 g or (1000 ml) (ratio) and multiplied by the characterisation factor. [c] Conversion in km travelled by a car considering an average emission of 110 g of $CO_2$ per km (C=1·1000/110) [d] Conversion of full bathtubs considering that a bathtub contains 120 L (D=B/120).

**Table 12.2. Characterisation factors (Feijoo and Moreira, 2020)**

| | Carbon footprint | Water footprint | Cost |
|---|---|---|---|
| | Kg $CO_2$ eq/kg | L $H_2O$ /kg | €/kg |
| | Oils | | |
| Olive oil | 1.17 | 14.4 | 4.24 |
| | Meat | | |
| Chicken | 3.00 | 3900.0 | 1.52 |
| Pork | 3.42 | 4800.0 | 2.74 |
| Beef | 9.33 | 15000.0 | 10.39 |
| | Cereals | | |
| Rice | 1.66 | 2.5 | 2.89 |
| Wholemeal biscuits | 4.00 | 437.5 | 5.78 |
| Coffee | 0.50 | 11.5 | 6.40 |
| Wholemeal cereals | 4.00 | 1644.0 | 2.78 |
| Bread | 0.67 | 1300.0 | 2.60 |
| Pasta | 0.45 | 1.8 | 1.18 |
| | Sweets | | |
| White sugar | 0.55 | 1782.0 | 0.69 |
| Honey | 2.50 | 0.7 | 8.70 |
| | Fruits | | |
| Plums | 0.12 | 2200.0 | 5.50 |
| Figs | 0.12 | 3350.0 | 4.50 |
| Strawberries | 0.33 | 347.0 | 6.00 |
| Kiwi | 0.33 | 514.0 | 5.00 |
| Orange | 0.15 | 560.0 | 2.00 |
| Mandarins | 0.15 | 748.0 | 2.50 |
| Apple | 0.12 | 822.0 | 2.20 |
| Melon | 0.24 | 181.0 | 2.00 |
| Nectarine | 0.12 | 910.0 | 2.80 |
| Raisins | 1.80 | 2433.0 | 6.50 |
| Peach | 0.12 | 910.0 | 5.20 |
| Pineapple | 0.95 | 255.0 | 2.00 |
| Banana | 0.30 | 790.0 | 2.36 |
| Watermelon | 0.30 | 235.0 | 2.52 |
| Grapes | 0.12 | 608.0 | 4.10 |
| Orange juice | 0.67 | 1080.0 | 2.20 |
| | Eggs | | |
| Eggs | 1.80 | 3300.0 | 0.15 |

**Table 12.2. (cont.) Characterisation factors (Feijoo and Moreira, 2020)**

| | Carbon footprint | Water footprint | Cost |
|---|---|---|---|
| | Kg $CO_2$ eq/kg | L $H_2O$ /kg | €/kg |
| Fish and seafood | | | |
| Tuna | 1.56 | | 14.66 |
| Cod | 2.43 | 650.0 | 21.44 |
| Cockles | 1.59 | | 10.74 |
| Squids | 3.86 | | 14.00 |
| Cuttlefish | 6.39 | | 15.50 |
| Octopus | 4.11 | | 16.00 |
| Sardines | 0.36 | | 9.00 |
| Mackerel | 0.80 | | 8.00 |
| Dairy products | | | |
| Yoghurt | 1.77 | 204.0 | 2.80 |
| Milk | 1.23 | 1000.0 | 0.74 |
| Cow cheese | 10.44 | 5000.0 | 12.93 |
| Fresh cheese | 7.42 | 603.0 | 7.45 |
| Curd | 1.77 | 603.0 | 5.24 |
| Vegetables and legumes | | | |
| Garlic | 0.39 | 81.0 | 5.60 |
| Celery | 0.57 | 194.0 | 5.75 |
| Pumpkin | 0.30 | 336.0 | 2.80 |
| Onion | 0.24 | 272.0 | 0.90 |
| Carrot | 0.23 | 86.0 | 1.08 |
| Mushrooms | 4.42 | 3.1 | 3.96 |
| Peas | 0.23 | 63.0 | 3.82 |
| Brussels sprouts | 0.30 | 285.0 | 2.18 |
| Cauliflower | 0.30 | 285.0 | 1.18 |
| Asparagus | 0.24 | 2150.0 | 7.50 |
| Beans | 0.23 | 15.0 | 3.32 |
| Lettuce | 0.24 | 237.0 | 1.18 |
| Potatoes | 0.10 | 5.3 | 1.12 |
| Pepper | 0.22 | 379.0 | 1.80 |
| Cucumber | 0.18 | 80.0 | 1.85 |
| Leek | 0.24 | 200.0 | 3.90 |
| Radish | 0.24 | 17.2 | 6.65 |
| Beetroot | 0.24 | 132.0 | 1.75 |
| Cabbage | 0.24 | 280.0 | 1.20 |
| Tomato | 0.22 | 214.0 | 1.11 |

**Table 12.3. Conversion factors**

| | Common value | Value in material or in volume |
|---|---|---|
| | Oils (mL) | |
| Olive oil | 1 spoon | 15 mL |
| | Meat (g) | |
| Chicken | 1 fillet | 120 g |
| Pork | 1 chop | 150 g |
| Beef | 1 steak | 200 g |
| | Cereals (g) | |
| Rice | 1 bowl | 200 g |
| Wholemeal biscuits | 1 | 10 g |
| Coffee | 1 spoon | 15 g |
| Wholemeal cereals | 1 bowl | 30 g |
| Bread | 1 | 250 g |
| Pasta | 2 packets | 250 g |
| | Sweets (g) | |
| White sugar | 1 sachet | 8 g |
| Honey | 1 spoon | 30 g |
| | Fruits (g) | |
| Plums | 1 | 65 g |
| Figs | 1 | 50 g |
| Strawberries | 1 | 15 g |
| Kiwi | 1 | 130 g |
| Orange | 1 | 250 g |
| Mandarins | 1 | 115 g |
| Apple | 1 | 180 g |
| Melon | 1 slice | 400 g |
| Nectarine | 1 | 159 g |
| Raisins | 1 handful | 65 g |
| Peach | 1 | 190 g |
| Pineapple | 1 slice | 100 g |
| Banana | 1 | 90 g |
| Watermelon | 1 slice | 400 g |
| Grapes | 1 | 8 g |
| Orange juice (amount in mL) | 1 glass | 150 mL |
| | Eggs (number) | |
| Eggs | | |
| | Fish and seafood (g) | |
| Tuna | Tuna in a can | 80 g |
| Cod | 1 small piece | 200 g |
| Cockles | 1 | 8 g |
| Squids | 1squid ring | 20 g |
| Cuttlefish | 1 | 850 g |
| Octopus | 1 tentacle | 220 g |
| Sardines | 1 | 200 g |
| Mackerel | 1 fillet | 150 g |

**Table 12.3. Conversion factors**

| | Common value | Value in material or in volume |
|---|---|---|
| | Dairy products | |
| Yoghurt (number of classic size) | | |
| Milk | 1 glass | 250 mL |
| Cow cheese | 1 slice | 20 g |
| Fresh cheese | 1 slice | 25 g |
| Curd | 1 | 125 g |
| | Vegetables and legumes | |
| Garlic | 1 clove | 8 g |
| Celery | 1 | 40 g |
| Pumpkin | 1 small piece | 225 g |
| Onion | 1 | 150 g |
| Carrot | 1 | 125 g |
| Mushrooms | 1 | 30 g |
| Peas | 1 handful | 60 g |
| Brussels sprouts | 1 | 20 g |
| Cauliflower | 1 | 900 g |
| Asparagus | 1 | 20 g |
| Beans | 1 | 5 g |
| Lettuce | 1 | 300 g |
| Potatoes | 1 | 125 g |
| Pepper | 1 | 125 g |
| Cucumber | 1 | 250 g |
| Leek | 1 | 125 g |
| Radish | 1 | 70 g |
| Beetroot | 1 | 125 g |
| Cabbage | 1 | 1250 g |
| Tomato | 1 | 250 g |

**Table 12.4. Calculation example for the teacher**

| My diet | Amount to eat | Daily diet | | | |
|---|---|---|---|---|---|
| | | Carbon footprint | | Water footprint | |
| | | Characterisation factor (kg $CO_2$ per 500 g)[a] | kg $CO_2$ (eq)[b] | Characterisation factor (L $H_2O$ per 500 g)[a] | L $H_2O$ (eq)[b] |
| Olive oil (mL) | 15 | 1.28 | 0.02 | 15.80 | 0.24 |
| Meat (g) | | | | | |
| Chicken | 120 | 1.50 | 0.36 | 1950 | 468.00 |
| Pork | 150 | 1.71 | 0.51 | 2400 | 720.00 |
| Beef | | | | | |
| Cereals (g) | | | | | |
| Rice | | | | | |
| Wholemeal biscuits | 50 | 2.00 | 0.20 | 219 | 21.90 |
| Coffee | | | | | |
| Wholemeal cereals | | | | | |
| Bread | 125 | 0.34 | 0.09 | 650 | 162.50 |
| Pasta | | | | | |
| Sweets (g) | | | | | |
| White sugar | 8 | 0.28 | 0.00 | 891 | 14.26 |
| Honey | 30 | 1.25 | 0.08 | 0.34 | 0.02 |
| Fruits | | | | | |
| Plums | | | | | |
| Figs | | | | | |
| Strawberries | | | | | |
| Kiwi | 130 | 0.17 | 0.04 | 257 | 66.82 |
| Orange | | | | | |
| Mandarins | | | | | |
| Apple | 180 | 0.06 | 0.02 | 411 | 147.96 |
| Melon | | | | | |
| Nectarine | | | | | |
| Raisins | 65 | 0.90 | 0.12 | 1217 | 158.21 |
| Peach | | | | | |
| Pineapple | | | | | |
| Banana | | | | | |
| Watermelon | | | | | |
| Grapes | | | | | |
| Orange juice (amount in mL) | 150 | 0.67 | 0.10 | 1080 | 162.00 |
| Eggs (number) | | | | | |
| Dairy products | | | | | |
| Yoghurt (number of classic size) | 1 | 0.44 | 0.44 | 51 | 51.00 |
| Milk (amount in mL) | 250 | 1.23 | 0.31 | 100 | 25.00 |
| Cow cheese (g) | | | | | |
| Fresh cheese (g) | | | | | |
| Curd (g) | | | | | |

**Table 12.4. Calculation example for the teacher**

| My diet | Amount to eat | Daily diet | | | |
|---|---|---|---|---|---|
| | | Carbon footprint | | Water footprint | |
| | | kg $CO_2$ per 500 g[a] | kg $CO_2$ (eq)[b] | L $H_2O$ per 500 g[a] | L $H_2O$ (eq)[b] |
| Fish and seafood (g) | | | | | |
| Tuna | 75 | 0.78 | 0.12 | 0 | |
| Cod | | | | | |
| Cockles | | | | | |
| Squids | | | | | |
| Cuttlefish | | | | | |
| Octopus | | | | | |
| Sardines | 500 | 0.18 | 0.18 | 0 | |
| Mackerel | | | | | |
| Vegetables, legumes (g) | | | | | |
| Garlic | 1 | 0.44 | 0.44 | 51 | 51.00 |
| Celery | 250 | 1.23 | 0.31 | 100 | 25.00 |
| Pumpkin | | | | | |
| Onion | | | | | |
| Carrot | | | | | |
| Mushrooms | | | | | |
| Peas | | | | | |
| Brussels sprouts | | | | | |
| Cauliflower | | | | | |
| Asparagus | | | | | |
| Beans | | | | | |
| Lettuce | 150 | 0.12 | 0.04 | 190 | 57.00 |
| Potatoes | 200 | 0.05 | 0.02 | 2.67 | 1.07 |
| Pepper | | | | | |
| Cucumber | | | | | |
| Leek | | | | | |
| Radish | | | | | |
| Beetroot | | | | | |
| Cabbage | | | | | |
| Tomato | 250 | 0.11 | 0.06 | 107 | 53.50 |
| | | SUM | A: 2.70 | | B: 17.6 |
| | | | C[c]: 24.5 | | D[d]: 17.6 |

[a] Write the value that appears on the cards [b] The quantity (in g) is divided by 500 g or (1000 ml) (ratio) and multiplied by the characterisation factor. [c] Conversion in km travelled by a car considering an average emission of 110 g of $CO_2$ per km (C=1·1000/110) [d] Conversion of full bathtubs considering that a bathtub contains 120 L (D=B/120).

### 12.2.5 Description of the activity

The “Eat healthy...Eat sustainably” initiative uses cards to help participants identify their dietary choices and the corresponding CF and WF associated with those diets. Players then independently calculate these environmental indicators and compare them with real-world examples that illustrate the impact of their dietary choices.

Subsequently, this individual work is carried out in a group of 4 or 5 people who share an organized use of the cards and where each participant has templates for recording dietary data, indicator calculations, and other necessary game information. Group play enriches the educational experience by promoting the exchange of perspectives, collaborative problem solving, and increased motivation through interpersonal interaction.

#### 12.2.5.1 Phase I. Organisation (only the teacher)

The teacher is responsible for preparing the classroom and organizing the students for the game. The teacher divides the class into teams of four to five students, ensuring that the teams are diverse in terms of gender, ability and other factors. Students who need additional support should be paired together and function as a unit within their team. Each team should be given a name, with the suggestion that these names correspond to one of the SDGs relevant to the game. The teacher should prepare all the necessary materials, both individual and group-based, required for the game.

#### 12.2.5.2 Phase II. Preparing for the game

The purpose of this phase is to help students understand the context of the game, including its objectives and how to play it. Each team should be assigned a specific area of the classroom and form a circle. The teacher introduces the game by asking the following questions What can we do to improve the well-being of people and the health of our planet? Can our daily food choices help improve people's lives and the environment? The teacher also explains or refreshes the basic concepts of sustainability, CF and WF. The glossary shown in **Table 12.5** is integrated into the game.

A set of the game “Eat healthy...Eat sustainably” and the sheets needed to calculate both footprints are distributed. To illustrate the steps of the game, the trainer can use his/her own diet as an example and explain the results accordingly.

#### 12.2.5.3 Phase III. Assessing the environmental impact of our diet.

In this phase, each student takes an active role in learning. The task to be completed is individual, but within a collaborative framework that encourages mentoring between team members to facilitate the resolution of any questions or concerns. The phase ends with a group reflection.

Each student selects cards (front view) representing the foods they typically consume on a daily basis, taking into account their intake from the previous day or an average weekday (Monday through Friday). Holidays and weekends are excluded. For each food, record the amount in grams (g) in column 1 of Sheet 1 (**Table 12.1**) and the characterisation factors for the CF (column 3) and WF (column 5) indicated on the back of each card. **Table 12.3** provides reference examples for different foods.

To calculate the CF, multiply the value in column 2 by the value in column 3 (**Table 12.1**), and then divide by 500 (if in grams) or by 1000 (if in millilitres). To calculate the WF, multiply the value in column 2 by the value in column 5 (**Table 12.1**), and then divide the product by 500 if the measurement is in grams or by 1000 if it is in millilitres. Add the values from columns 4 and 6 (**Table 12.1**) and enter the totals in the appropriate cells (Cell A and Cell B). Convert

the CF to the equivalent distance travelled by car, using the average emission factor of 110 g $gCO_2$/km (**Eq. 12.1**) and the WF to litres (L) of water used per bath, using the average volume of 120 litres per bath (**Eq. 12.2**).

Finally, encourage the group to reflect by asking the following questions: What foods are commonly consumed by group members? Which food groups are missing from your diet? Which two foods in your diet have the highest CF? What two foods in your diet have the highest WF?

$$cell\ C = \frac{cell\ A \cdot 1000}{110} \tag{12.1}$$

$$cell\ D = \frac{cell\ B}{120} \tag{12.2}$$

12.2.5.4 Phase IV. Designing a sustainable diet

In the Diet Planning Phase, the team works together to design the most sustainable diet using the knowledge gained in the previous phases. Participants select foods from the eight food groups and create a comprehensive list. The selected foods are then identified on the game cards, looking at both the front and back. If necessary, the group can agree to substitute up to two foods to improve the overall quality of the diet. The next step is to determine and record the amount of each selected food. The calculations from Phase III are then repeated to assess the impact of the new dietary choices. Finally, the team develops a proposal for a sustainable diet for the whole class and completes Sheet 2 (Our Sustainable Diet).

12.2.5.5 Phase V. Large group discussion

For the final reflection, it is beneficial to analyse the results in a large group, with the active participation of the students and the teacher leading the discussion. The aim is to raise awareness of the importance of a balanced diet and the environmental impact of certain eating habits.

The teacher displays the different sustainable diets and their environmental impacts in a designated area of the classroom and facilitates group reflection by asking questions such as Is there an improvement in the diet from the original to the new version? If we eliminate certain foods from our diet, do you think this will help improve our planet? Can we improve our environment through our food choices? Which SDGs are we supporting with our improved diet? At the end of the activity, participants are asked “What have we learnt from this game?”. This question serves to summarize the main points and reinforce the lessons learned.

**Table 12.5. Glossary**

| Term | Definition |
|---|---|
| Paris Agreement | International treaty under the United Nations Framework Convention on Climate Change that outlines global efforts to reduce GHG emissions. It entered into force in 2020, following the Kyoto Protocol. |
| Balanced diet | An approach to nutrition that tailors nutrient intake to an individual's specific health needs. It involves providing sufficient energy by adjusting calories based on activity levels. |
| Proximity or zero-kilometre food | Food produced within 100 km of the point of sale. |
| Life cycle assessment | A methodology that enables the conversion of emissions (expressed as quantities of materials and energy) generated throughout the life cycle of a process, product or service - including raw material extraction, transportation, manufacturing, distribution, consumption and waste management - into environmental impacts. These impacts represent adverse effects on human health, degradation of ecosystems, and depletion of natural resources. |
| Calorie | Unit of energy used to define the nutritional value of food. |
| Climate change | Long-term changes in temperature and weather patterns. For example, the rainfall regime. |
| Sustainable development | Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. |
| Desertification | The process by which natural or human causes reduce the biological productivity of arid areas. |
| Diet | Combination of solid and liquid foods typically consumed by an individual or group. |
| Atlantic diet | Traditional diet of the people of northwestern Spain and Portugal. The Atlantic diet emphasizes high consumption of fish and vegetables from the area. It also includes milk, dairy products (especially cheese), cereals, pork, beef and poultry, and olive oil. |
| Mediterranean diet | This approach typically includes plenty of vegetables, fruits, legumes, as well as whole grains, fish, soft meats, nuts, and olive oil. It is historically followed in places around the Mediterranean, including Greece, Spain, and Italy. |
| Ecology | Branch of biology that studies the interactions between living organisms and their environment. |
| Ecological | Produced without harm to the environment, human, animal or plant health. |
| Greenhouse gas emissions | Release of gases that trap heat in the Earth’s atmosphere, intensifying the greenhouse effect and contributing to global warming. The main greenhouse gases are carbon dioxide and methane. |

**Table 12.5. (cont.) Glossary**

| Term | Definition |
|---|---|
| Best available techniques | The most eco-efficient technologies developed on a scale that allows their application in the productive sector. |
| Sustainable Development Goals | They are a set of 17 global goals set by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. They aim to address global challenges such as poverty eradication, economic growth, education, health, social protection, employment prospects, climate change, environmental degradation and peace, and to ensure that development is sustainable for future generations. |
| WHO | World Health Organisation. It is a specialized agency of the United Nations responsible for global health prevention, promotion and intervention. |
| UN | International organisation established in 1945, after World War II, to promote peace, security, human rights and cooperation among nations. |
| Carbon footprint | Environmental indicator that represents the amount of carbon dioxide equivalent emitted directly or indirectly during the lifecycle stages of a product. It is linked to climate change and SDG13 |
| Water footprint | Environmental indicator that quantified the total volume of freshwater used throughout the different stages of the life cycle or production chain of a product. This indicator is aligned with SDG6. |
| Food waste | Loss of mass (dry matter) or nutritional value (quality) of food originally intended for human consumption |
| Food pyramid | Visual representation of foods in different groups based on the recommended frequency of consumption for a healthier diet. Foods at the base of the pyramid are those that should be consumed more often, while those at the top indicate a lower frequency of consumption. |
| Ecological, biological or organic production | Agri-food production and management system that combines best environmental practices with a high level of biodiversity and conservation of natural resources |
| Cleaner production | Integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to people and the environment |
| Radiation | Emission or transmission of energy in the form of waves or particles through space or a medium. |
| Health | State of complete physical, mental and social well-being. |
| Healthy | Practices that promote the overall well-being of body and mind. |
| Dry | A period (of varying length) characterised by precipitation levels below normal for a given area. |
| Overweight and obesity | An abnormal or excessive accumulation of fat in the body that can adversely affect an individual's health. It is defined as a body weight that exceeds the norm or is unhealthy for a given height. |

### 12.2.6 Methodological strategies

The teaching and learning methodology, which includes both individual and cooperative elements, is consistent with the requirements of the game. The cooperative approach provides a framework for individual tasks and emphasizes both teacher-student and student-student interactions. Peer tutoring is a central component of this approach.

According to Slavin (2002), cooperative learning is effective because of five key principles: (1) positive interdependence, (2) heterogeneous groups, (3) individual and group responsibility, (4) meaningful verbalization and (5) cooperative skill training (mutual support).

"Eat healthy...Eat sustainably" is designed to position students as central participants, with the teacher facilitating a context of curiosity, knowledge and reflection. This approach promotes critical teaching and learning processes and increases interest in environmental issues. The game is well suited to a variety of educational methodologies, including problem-based learning, inquiry-based learning, cooperative learning, discussion groups, and project-based learning. These methods involve a range of educational stakeholders and allow for a deeper exploration of sustainable development from different perspectives.

### 12.2.7 Content

The game "Eat healthy...Eat sustainably" has been designed according to the themes established in the Decree 155/2022 that defines the curriculum for primary education in Galicia (Xunta de Galicia, 2022b): Healthy lifestyles; A varied, balanced and sustainable diet; Life on our planet; The world and sustainable development; Efficient and sustainable use of the environment; Environmental Ethics and Sustainable Development; Valuation of natural resources.

These themes are explored in a cross-cutting manner throughout the game, creating synergies to raise awareness of the need to change behaviours and habits to improve people's quality of life.

## 12.3 ASSESSMENT

At the end of the activity, each student completes a short anonymous questionnaire to measure their satisfaction with different aspects of the game. The evaluation uses a semantic differential scale where students rate their level of satisfaction from 1 to 5. The questionnaire consists of 33 items divided into five sections: (1) The game as a whole (11 items), (2) The activities of the game (6 items), (3) Their learning (4 items), (4) The teacher's involvement (5 items), (5) Their involvement (7 items). There is space for students to make any additional comments or observations they feel are relevant at the end of the questionnaire.

**Table 12.6. Student questionnaire**

The following questionnaire is designed to collect your feedback on the game “Eat healthy ... Eat sustainably”. Your opinion is very important, so please make sure you answer all the questions. We also encourage you to make any suggestions you may have in the “Other comments” section. Your insights are crucial to improving the game. Thanks for your cooperation

VERY IMPORTANT

Please read the example carefully. The assessment procedure is as follows. A particular aspect of the programme is presented, for example “Comprehension”. You are then asked to indicate whether you find it "easy" by answering as follows.

Program comprehension

| | | 1 | 2 | 3 | 4 | 5 | | |
|---|---|---|---|---|---|---|---|---|
| If you point out | Difficult | X | | | | | Easy | We recognize that it is “very difficult” |
| If you point out | Difficult | | X | | | | Easy | We acknowledge that it is “a bit difficult” |
| If you point out | Difficult | | | X | | | Easy | We realize that it is “neither difficult nor easy” |
| If you point out | Difficult | | | | X | | Easy | We understand that it is “a bit easy” |
| If you point out | Difficult | | | | | X | Easy | We perceive that it is “very easy” |

PLEASE AIM TO CRITICALLY EVALUATE ALL THE ISSUES AND CONCEPTS PRESENTED (EASY-DIFFICULT), ADDRESSING EACH ASPECT THOROUGHLY AS EXPLAINED.

| The overall game | | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| Useless | | | | | | Useful |
| Insufficient | | | | | | Sufficient |
| Inappropriate | | | | | | Appropriate |
| Tired | | | | | | Rested |
| Passive | | | | | | Active |
| Short | | | | | | Long |
| Messy | | | | | | Orderly |
| Confused | | | | | | Clear |
| Theoretical | | | | | | Practical |
| Discouraging | | | | | | Motivating |
| Not recommended | | | | | | Recommended |

**Table 12.6 (cont.) Student questionnaire**

| Game activities | | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| Difficult | | | | | | Easy |
| Incomprehensible | | | | | | Understandable |
| Inappropriate | | | | | | Appropriate |
| Boring | | | | | | Interesting |
| Useless | | | | | | Useful |
| Scarce | | | | | | Abundant |
| **Your learnings** | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | |
| Useless | | | | | | Useful |
| Unsatisfactory | | | | | | Satisfactory |
| Few | | | | | | Many |
| Inapplicable | | | | | | Applicable |
| **Teacher involvement** | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | |
| Distant | | | | | | Close |
| Passive | | | | | | Active |
| Confused | | | | | | Clear |
| Discouraging | | | | | | Motivating |
| Insufficient | | | | | | Sufficient |
| **Your involvement** | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | |
| Passive | | | | | | Active |
| Impassive | | | | | | Enthusiastic |
| Unsatisfactory | | | | | | Satisfactory |
| Fickle | | | | | | Constant |
| Insufficient | | | | | | Sufficient |
| Inadequate | | | | | | Adequate |
| Difficult | | | | | | Easy |
| **Further comments** | | | | | | |

## 12.4 REGULATORY FRAMEWORK AND THEMATIC CONTEXT FOR THE TEACHER.

In accordance with Organic Law 3/2020, of 29 December, which amends Organic Law 2/2006, of 3 May, on education (Gobierno de España, 2020b), the curriculum must be designed to facilitate the educational development of students. This includes providing a comprehensive education, promoting the full development of the individual personality, and preparing students for the full exercise of human rights and active democratic citizenship in contemporary society.

Decree 155/2022, of September 15, which establishes the organisation and curriculum of primary education in the Autonomous Community of Galicia (Xunta de Galicia, 2022b) provides further detail on the provisions of Law 3/2020 (Gobierno de España, 2020b) and Royal Decree 157/2022, of March 1, which establishes the organisation and minimum teaching of primary education (Gobierno de España, 2022b). First of all, it should be noted that in recent

years there have been significant changes in social behaviour, which in turn have affected the role of education and society's perception of it. The Galician education system is affected by these ongoing changes and must incorporate these evolving dynamics into its lifelong learning strategies, adapting educational methods to current and future needs. Among these approaches, sustainable development and education for ecological transition are of particular importance.

The objectives of this stage of education include understanding the norms of coexistence, developing effective work habits and positive attitudes, conflict resolution and violence prevention, and respect for cultural and gender diversity. There is a strong emphasis on the effective use of the official languages of the Autonomous Community, in addition to the knowledge of at least one foreign language. Emotional intelligence, technological skills, and artistic expression are also emphasized. In relation to the reference game, this stage of education also includes a comprehensive understanding of the fundamental aspects of science, social science, geography, history and culture, as well as the acquisition of basic mathematical skills and the ability to apply them to everyday life situations. The value of health and the role of nutrition and other factors in personal and social growth are also emphasized.

The primary education stage is fundamental for the acquisition of key competences for lifelong learning, as set out in the Council Recommendation of May 22, 2018 (European Parliament and Council of the European Union, 2018). This decree adapts these key competences to the school context, aligning them with the principles and objectives of the education system.

The exit profile of students at the end of basic education, which is common throughout Spain, serves as a basis for defining the principles and objectives of the Galician education system for this stage. The exit profile is based on a structural and functional vision of the key competences that are essential for the personal development of students. These competences enable them to cope with situations in their personal and professional lives, to create new opportunities for improvement, to ensure continuity in their educational pathways, and to facilitate their integration and active participation in society, as well as in the care of people, the natural environment and the planet.

Linking key competences to the challenges of the 21st century makes learning more meaningful by connecting school to real life. The goal is to ensure that all students who complete basic education and meet the exit criteria are able to meet the key challenges they will face throughout their lives. This includes cultivating a responsible attitude by raising awareness of environmental degradation and animal mistreatment, recognizing the different aspects of responsible consumption, and adopting a healthy lifestyle by evaluating the functions of the body and critically reflecting on the internal and external factors that influence them.

The characteristics of “Eat healthy...Eat sustainably” suggest a stronger alignment with specific branches of the curriculum. An analysis of Decree 155/2022 reveals numerous connections to sustainable development, as outline below.

### 12.4.1 Natural Sciences

The Natural Sciences area develops active, responsible and respectful students who are aware of the world in which they live. It provides children with essential knowledge about the natural world, enabling them to contribute to a more equitable, just, and sustainable society.

The Natural Sciences area emphasizes an understanding of science as a process of inquiry through systematic observation, measurement, experimentation, and hypothesis formulation, which is at the core of the scientific method. This approach addresses key challenges facing a globalized society, taking into account rapid advances in science and technology.

Students develop concepts, skills, and attitudes related to the organisation of living organisms, matter, forces, forms of energy, and the functioning of the human body. This knowledge provides a foundation for recognizing the importance of health and emotional well-being, respect for living beings, and the environment, all of which are critical to achieving the SDGs.

12.4.1.1 Objectives

**OBJ 1.** Investigate and address complex scientific questions using different techniques, tools, and models of scientific thinking to interpret and explain phenomena in the natural environment.

To achieve this objective, it is essential to harness students' innate curiosity about their environment and to encourage their active engagement in the processes of inquiry and exploration inherent in scientific thinking. Contextualizing activities within the students' immediate environment ensures that they can apply their knowledge to different contexts and situations. This approach enhances the learning experience and stimulates interest in acquiring new knowledge and developing solutions to everyday challenges.

**OBJ 2.** Know and be aware of one's own body and one's own and others' emotions and feelings, using scientific knowledge to develop healthy habits and achieve physical, emotional and social well-being.

The scientific knowledge about the human body and health risks that students acquire during their education should be linked to preventive actions through the development of healthy habits, lifestyles and behaviours.

**OBJ 3.** Identify the characteristics of the different elements or systems of the natural environment, analyse their organisation and properties, and establish relationships between them in order to recognize their value, conserve them, improve them, and take actions for their responsible use.

Understanding the different elements and systems that make up the natural environment is fundamental to appreciating its richness and diversity. The goal of this objective is for students to systematically learn about their environment and make connections between its elements, while recognizing, valuing, and protecting it and its living beings.

**OBJ 4.** Identify the causes and consequences of human intervention in the environment in order to enhance the ability to face problems, seek solutions, and act individually and cooperatively in their resolution, and to practice sustainable lifestyles consistent with respect, care, and protection of people and the planet.

Students must approach the challenges of contemporary society from a sustainability perspective and understand the relationships between interdependence and eco-dependence. It is essential that they recognize the importance of respecting living beings and the environment, especially the value of biodiversity and the development of sustainable lifestyles. Therefore, students need tools that facilitate their empowerment as agents of eco-social change from an entrepreneurial perspective and with a critical and collaborative attitude. This means designing activities that facilitate contextualized progress towards the SDGs. In this way, they contribute to building models of relationships and coexistence based on empathy, cooperation, and respect for people and the planet.

12.4.1.2 Evaluation criteria and content

**2nd Cycle, 4th Year,**

Block 1. Scientific culture

CA1.1. Formulate questions and make reasoned predictions about objects, facts and phenomena in the natural environment through observation (OBJ1).

CA1.2. Find and select information from a range of safe and reliable sources, acquire basic scientific vocabulary and use it in investigations related to the natural environment (OBJ1).

Content: The importance of using science and technology to understand the causes of one's actions, to make reasoned decisions and to perform tasks more efficiently; fostering curiosity, initiative and perseverance in carrying out different types of research through observation and hypothesis formulation; basic scientific vocabulary related to different types of research.

Block 2. Life on our planet

CA2.1. Understand the external and internal morphology of the body and identify the organs and systems involved in conducting vital functions (OBJ2).

CA2.2. Adopt healthy lifestyles, appreciating the importance of a varied, balanced and sustainable diet, physical activity, contact with nature, rest, hygiene, the correct use of new technologies and the prevention of accidents and diseases (OBJ2).

CA2.3. Identify attitudes that promote emotional and social well-being by managing one's own emotions and respecting those of others, showing empathy and building healthy emotional relationships (OBJ2).

Content: The significance of nutrition for human beings and the identification of the physiological systems involved; recommendations for a healthy and sustainable diet; the food pyramid and classification of the main nutrients; guidance for the prevention of diseases, risks and accidents in the immediate environment; diseases related to the process of eating and self-acceptance.

Block 3. Matter, forces and energy

CA3.4. Identify eco-social problems, propose solutions and practice sustainable lifestyles. Recognize behaviours that demonstrate care and protection of the environment, promote sustainable use of natural resources, and express the positive and negative changes caused by human actions (OBJ4)

Content: Responsible use of the planet's natural resources; the importance of air and water quality in our environment.

**3rd cycle, 5th year,**

Block 1. Scientific culture

CA1.1. Formulate questions and make reasoned predictions about objects, facts and phenomena in the natural environment through observation (OBJ1).

CA1.2. Find and select information from a range of safe and reliable sources, acquire basic scientific vocabulary and use it in investigations related to the natural environment (OBJ1).

Content: Science, technology and engineering as human activities; the current state of STEM professions from a gender perspective in relation to the development of sustainable lifestyles and care for the planet; fostering curiosity, initiative, perseverance and a sense of responsibility in carrying out different types of research; scientific vocabulary related to different areas of research.

Block 2. Life on our planet

CA2.3. Make connections between different elements of the natural environment, demonstrating an understanding of the relationships within it (OBJ3).

CA2.4. Protect and promote the conservation and enhancement of the natural environment through proposals and actions that reflect commitments and guidelines in favor of sustainability (OBJ3).

Content: The relationship between humans and ecosystems to meet societal needs; examples of the beneficial and detrimental use of natural resources and their consequences; recognition of human actions that alter the natural environment and contribute to the species extinction; the importance of biodiversity.

Block 3. Matter, forces and energy.

CA3.2. Identify and explain the different forms and sources of energy, their uses in everyday life and their impact on sustainable development (OBJ4).

CA3.3. Apply an entrepreneurial approach to comparing and evaluating proposals for solving eco-social problems. Take action to solve them through critical analysis of the causes and consequences of human intervention in the environment (OBJ4).

Content: Renewable and non-renewable energy sources; the impact of renewable energy sources on sustainable development; sources, transformation, transfer and responsible use of energy in everyday life to address environmental problems.

**3rd cycle. 6th year.**

Block 1. Scientific culture

CA1.1. Formulate questions and make reasoned predictions about objects, facts and phenomena in the natural environment through observation (OBJ1).

CA1.2. Find and select information from a range of safe and reliable sources, acquire basic scientific vocabulary and use it in investigations related to the natural environment (OBJ1).

Content: Science, technology and engineering as human activities; the current state of STEM professions from a gender perspective in relation to the development of sustainable lifestyles and care for the planet; fostering curiosity, initiative, perseverance and a sense of responsibility in carrying out different types of research; scientific vocabulary related to different areas of research.

Block 2. Life on our planet

CA2.2. Adopt healthy lifestyles, appreciating the importance of a varied, balanced and sustainable diet, physical activity, contact with nature, rest, hygiene, the correct use of new technologies and the prevention of accidents and diseases (OBJ2).

Content: Guidelines for healthy and sustainable eating, including the preparation of nutritious and balanced meal plans; the importance of understanding food labels and shopping choices to assess nutrient content and energy intake; diseases affecting the body's systems and those related to nutrition; strategies for preventing such diseases and promoting body acceptance.

Block 3. Matter, forces and energy.

CA3.2. Identify and explain the different forms and sources of energy, their uses in everyday life and their impact on sustainable development (OBJ4).

Content: Renewable and non-renewable energy sources and their role in contributing to the sustainable development of society.

12.4.1.3 Pedagogical orientations and lines of action in the teaching and learning process.

Given the critical importance of human interaction with the environment, activities centred on observation and experimentation facilitate a hands-on and integrated understanding of natural phenomena in everyday life and environmental changes caused by human activity. Emphasis is placed on promoting positive attitudes towards personal, social and physical well-

being and developing respect for the diversity of others. Activities will help students to take care for their bodies, to identify factors that affect physical and mental health and to emphasise the importance of maintaining healthy habits.

### 12.4.2 Social Sciences

The Social Sciences curriculum develops active, responsible and respectful individuals who are deeply involved in their local and global communities. In a diverse and complex world, it is imperative to promote innovative ways of thinking, feeling and acting, and to create inclusive learning environments based on the principles of equity, empowerment and sustainability. As human activity continues to shape our planet, students need to develop a deep understanding of themselves and their environment.

Students acquire the knowledge, skills and attitudes needed to use information sources safely and reliably, alongside education for sustainable development and global citizenship, including support for the SDGs. This initiative creates children who care about the planet and its inhabitants, preparing them to become adults who are actively engaged in environmental protection.

By providing students with a solid and well-structured scientific foundation, the curriculum helps them to understand the world in which they live in, encourages them to care for and respect it, and promotes a path towards a just environmental transition.

#### 12.4.2.1 Objectives

**OBJ 3.** Identify the characteristics of the different elements or systems of the natural environment, analyse their organisation and properties, and establish relationships between them in order to recognize their value, conserve them, improve them and take action for their responsible use.

In this context, resources are provided to help students understand, appreciate, preserve and protect their environment. Awareness of the current use and exploitation of natural resources should motivate students to implement actions for the sustainable use and conservation of both the natural and cultural heritage of the Galician territory, considering it as a common good.

**OBJ 4.** Identify the causes and consequences of human intervention in the environment in order to improve the ability to face problems, seek solutions and act individually and cooperatively in their resolution, and to practice sustainable lifestyles consistent with respect, care and protection of people and the planet.

Given the use and exploitation of common goods through increasingly advanced technological processes, it is crucial for students to reflect on the limits of the biosphere, the challenges associated with the rapid consumption of resources and the implications of an energy model based on fossil fuels. This awareness will better equip them to address the challenges of contemporary society in a sustainable manner.

Therefore, students need tools that facilitate their empowerment as agents of eco-social change from an entrepreneurial perspective and with a critical and collaborative attitude. This means designing activities that facilitate contextualized progress towards the SDGs. In this way, they contribute to building models of relationships and coexistence based on empathy, cooperation and respect for people and the planet.

12.4.2.2 Evaluation criteria and content

**2nd cycle. 4th year**

Block 2. The world and sustainable development

CA2.1. Identify and analyse the characteristics, organisation and properties of elements in the natural, social and cultural environment through inquiry, using appropriate tools and methods (OBJ3).

CA2.2. Identify synergistic relationships among different elements of the natural, social and cultural environments and demonstrate an awareness of the relationships among them (OBJ3).

CA2.3. Identify environmental and social challenges, formulate potential solutions, and adopt sustainable lifestyles. This requires cultivating a deep respect for the environment, a sense of shared responsibility, and an appreciation for the wise use of natural resources, as well as articulating the positive and negative environmental impacts of human actions (OBJ4).

Content: Relationships between elements, movements and dynamics in the universe, with specific physical phenomena that affect the Earth and impact on daily life and the environment; climate change, including an introduction to its causes, consequences and impact on the Earth's landscapes; mitigation measures; eco-social responsibility; transformation and degradation of natural ecosystems due to human activities; conservation and protection of nature; sustainable lifestyles; responsible consumption and production; balanced and sustainable diets; efficient use of water and energy; safe and sustainable mobility; waste prevention and management.

Block 4. Lessons from the past

CA4.1. Protect and value natural and cultural heritage as a common good, through respectful behaviour for its enjoyment and by proposing actions for its conservation and enhancement (OBJ3).

Content: Natural and cultural heritage; distinctions between national, regional and nature parks; protected natural areas, their use, maintenance and conservation.

**3rd cycle. 5th year**

Block 2. The world and sustainable development

CA2.1. Identify and analyse the characteristics, organisation and properties of elements in the natural, social and cultural environment through inquiry, using appropriate tools and methods (OBJ3).

CA2.2. Identify synergistic relationships among different elements of the natural, social and cultural environments and demonstrate an awareness of the relationships among them (OBJ3).

CA2.3. Promote sustainable lifestyles consistent with respect, care, co-responsibility and protection of people and the planet, based on a critical analysis of human impacts on the environment (OBJ4).

CA2.4. Apply an entrepreneurial approach to comparing and evaluating proposals for solving environmental and social problems. Take action to solve them by critically analysing the causes and consequences of human intervention in the environment (OBJ4).

Content: Climate change at local and global scales: causes and consequences; mitigation and adaptation measures; principles of sustainable development; impact of human activities on space and exploitation of resources; economic activities and distribution of wealth: social and regional inequalities globally and within Spain; SDGs; sustainable lifestyles, including limits of the planet and depletion of resources.

Block 4. Lessons from the past

CA4.1. Appreciate, protect and cultivate attitudes of conservation of natural and cultural heritage through proposals and actions that reflect commitment and practices that support sustainability (OBJ3).

Content: Natural and cultural heritage as a common good and resource; its use, conservation and protection.

**3rd cycle. 6th course**

Block 2. The world and sustainable development

CA2.1. Identify and analyse the characteristics, organisation and properties of elements in the natural, social and cultural environment through inquiry, using appropriate tools and methods (OBJ3).

CA2.2. Identify synergistic relationships between different elements of the natural, social and cultural environments and demonstrate an awareness of the relationships between them (OBJ3).

CA2.3. Promote sustainable lifestyles consistent with respect, care, co-responsibility and protection of people and the planet, based on a critical analysis of human impacts on the environment (OBJ4).

CA2.4. Apply an entrepreneurial approach to comparing and evaluating proposals for solving eco-social problems. Take action to solve them through critical analysis of the causes and consequences of human intervention in the environment (OBJ4).

Content: Climate change; eco-social responsibility; eco-dependency, interdependency and interrelationship between people, societies and the natural environment; the urban agenda; sustainable urban development; the city as a space for coexistence; the green economy; the impact of markets (goods, finance and labour) on the lives of citizens; economic agents and labour rights from a gender perspective; the social value of taxation; corporate social and environmental responsibility; advertising, responsible consumption and consumer rights; sustainable lifestyles: ecological footprint.

Block 4. Lessons from the past

CA4.1. Appreciate, protect and cultivate attitudes of conservation of natural and cultural heritage through proposals and actions that reflect commitment and practices that support sustainability (OBJ3).

Content: Natural and cultural heritage as a common good and resource; its use, conservation and protection.

12.4.2.3 Pedagogical orientations and lines of action in the teaching and learning process.

The educational intervention in social sciences progressively establishes different levels of learning that help students to achieve the objectives of the area, while supporting the acquisition of key competences and the overall objectives of the level in conjunction with other subjects. The approach emphasizes the use of local resources and the progression from simple to complex learning experiences, while encouraging individual and collaborative teamwork to increase student participation and engagement in their education.

### 12.4.3 Mathematics

Mathematics plays an essential role in society, is part of our cultural heritage and permeates various human activities. Its instrumental nature connects it to many areas of knowledge, including the natural sciences, engineering, technology, social sciences and the arts.

Mathematics also provides a valuable framework for structuring reality, for analysing information and deriving new knowledge, and for developing reasoning, decision-making and creativity.

Mathematics is also essential for comprehending the complex social and environmental challenges of the future. It serves as a critical tool for analysing both local and global contexts, and for evaluating social, economic, scientific and environmental problems and potential solutions, making it fundamental to achieving the SDGs and creating reflective citizens prepared for the challenges of the 21st century.

12.4.3.1 Objectives of the area

OBJ1. Interpret everyday situations by creating a mathematical representation using relevant concepts, tools and strategies to analyse key information.

Students need to grasp their immediate environment and be equipped with the tools to accurately represent the world around them and to solve problematic situations that arise both in school and in their daily lives.

This approach provides a valuable opportunity to integrate the eight key competencies and address pressing global challenges. By examining issues such as climate change (including deforestation and man-made disasters), sustainability (embodying the 7Rs for the environment, responsible consumption and globalisation), healthy lifestyles and disease prevention through the lens of mathematics, students can increase their interest in mathematics and raise their awareness of the profound impact these issues have on the future of society.

OBJ5. Recognize and use connections between different mathematical concepts and recognize the presence of mathematics in other disciplines and in everyday life, linking concepts and procedures to interpret different situations and contexts.

Recognizing the interconnectedness of mathematics with other disciplines and its practical applications in real-world contexts helps students to appreciate its usefulness. Integrating mathematics with other fields such as music, medicine, physics, art or social sciences stimulates student's interest in the subject area and makes them aware of the need to study it for their future professional and personal development.

12.4.3.2 Evaluation criteria and content

**2nd cycle. 4th course**

Block 1. Numerical sense

CA1.2. Interpret everyday problems, either verbally or graphically, by analysing the questions posed using different strategies or tools, including technological ones (OBJ1).

CA1.8. Interpret situations in different contexts, recognising the links between mathematics and everyday life (OBJ5).

Content: Counting; quantity; understanding operations; relationships; financial education.

Block 2. Measurement Sense

CA2.5. Make connections between different mathematical elements by applying knowledge and personal experience (OBJ5).

CA2.6. Interpret situations in different contexts by recognising connections between mathematics and everyday life (OBJ5).

Content: Magnitude; measurement; estimation; relationships.

Block 6. Socio-Emotional sense

CA6.7. Interpret situations across various contexts by recognizing the links between mathematics and everyday life (OBJ5).

Contents: Beliefs; attitudes; emotions; teamwork (inclusion, respect, and diversity).

**3rd cycle. 5th course.**

Block 1. Numerical sense

CA1.2. Interpret everyday problems by reformulating questions both verbally and graphically (OBJ1).

CA1.8. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Content: Counting; quantity; understanding operations; relationships; proportional reasoning; financial education.

Block 2. Measurement sense

CA2.6. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Content: Magnitude, measurement, estimation and relationships.

Block 6. Socio-emotional sense

CA6.7. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Content: Beliefs; attitudes; emotions; teamwork (inclusion, respect and diversity).

**3rd cycle. 6th course**

Block 1. Numerical sense

CA1.2. Interpret everyday problems by reformulating questions both verbally and graphically (OBJ1).

CA1.8. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Content: Counting; quantity; understanding operations; relationships; proportional reasoning; financial education.

Block 2. Measurement sense

CA2.6. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Content: Magnitude; measurement; estimation; relationships.

Block 6. Socio-emotional sense

CA6.7. Make connections between mathematics, other disciplines and everyday life to solve problems in non-mathematical contexts (OBJ5).

Contents: Beliefs; attitudes; emotions; teamwork (inclusion, respect, and diversity).

#### 12.4.3.3 Pedagogical orientations and lines of action in the teaching and learning process.

Mathematics is both useful and indispensable in everyday life, helping us to grasp reality and contributing to the intellectual development of the individual. It should be integrated with other parts of the curriculum.

To promote deeper learning, mathematical content needs to be contextualized through complex, real-world problems that cut across disciplines. Practical applications and specific mathematical contexts are essential for effective learning and require an integrated and holistic approach.

Interaction plays a critical role in learning mathematics. Cooperative learning structures support collaborative solutions to tasks and problems and promote attention to diversity, inclusion and equity.

### 12.4.4 Physical education

Physical education not only promotes general motor skills, including an active lifestyle, an understanding of one's own body, engagement with cultural expressions of a physical nature and the integration of eco-socially responsible attitudes, but also focuses on responsible attitudes towards the environment. These qualities are fundamental to social competence and should be introduced in primary education.

12.4.4.1 Objectives of the area

OBJ5. Appreciate different natural and urban environments as settings for physical activity, engage with them and recognise the importance of maintaining them from a sustainable perspective. Emphasise the adoption of personal responsibility measures during physical activity and leisure to ensure practices that are both efficient and respectful of the environment.

At this stage, it is crucial to initiate the adoption of sustainable habits and environmental conservation practices, focusing in particular on simple actions and behaviours that individuals can integrate into their daily lives. This approach recognizes that physical and sporting activities provide an excellent context to demonstrate the potential of both natural and urban environments to develop these practices.

The aim is to build the knowledge, skills and attitudes needed to interact with the environment, to participate in its conservation and improvement, and to contribute locally to wider global sustainability efforts.

12.4.4.2 Evaluation criteria and content

**2nd Cycle, 4th Grade**

Block 6. Efficient and sustainable interaction with the environment

CA6.4. Develop safe motoring practices in natural and urban environments by adapting actions to the specific context and implementing environmental protection measures (OBJ5).

Content: Caring for and protecting the environment during physical activity in natural and urban environments.

**3rd cycle. 5th course**

Block 6. Efficient and sustainable interaction with the environment

CA6.5. Adapt physical activities to the inherent uncertainties of natural and urban environments, both terrestrial and aquatic, ensuring efficiency and safety. Evaluate the suitability of these environments for physical activity while maintaining an environmentally sustainable and community-focused approach (OBJ5).

Content: Caring for and preserving the environment during physical activity in natural and urban environments.

**3rd cycle. 6th course**

Block 6. Efficient and sustainable interaction with the environment

CA6.5. Adapt physical activities to the inherent uncertainties of natural and urban environments, both terrestrial and aquatic, ensuring efficiency and safety. Evaluate the suitability of these environments for physical activity while maintaining an environmentally sustainable and community-focused approach (OBJ5).

Content: Caring for and protecting the environment during physical activity in natural and urban environments.

### 12.4.5 Education in Civic and Ethical Values

Education in values is fundamental both to the critical and responsible exercise of citizenship and to the full development of the individual. It provides students with the tools to

engage actively and autonomously with the values, principles and norms essential to democratic coexistence. It also contributes to their intellectual, moral and emotional growth, helping them to formulate their own life projects and to engage in thoughtful and reasoned reflection on the challenges of the 21st century.

In primary education, Education in Civic and Ethical Values focuses on four key objectives: Self-awareness and personal autonomy; comprehension of the social framework of coexistence and commitment to the democratic principles, norms and values that govern it; emotional education; and the adoption of attitudes compatible with environmental sustainability, based on an appreciation of the relationships between interdependence and eco-dependence.

The fourth objective is primarily addressed in the "Sustainable Development and Environmental Ethics" block. Through interdisciplinary and collaborative work, students perceive the complex relationship between human activities and the environment. They explore major eco-social issues on the global agenda and discuss how to address these challenges and our relationship with other living beings.

#### 12.4.5.1 Objectives of the area

**OBJ3.** Understand the system relationships between individuals, society and nature through the study of eco-social issues, and to actively embrace values and practices that promote respect, care and protection for people and the planet.

Life is influenced by social and cultural contexts as well as by complex interdependencies with other living beings and nature. This underlines the importance of grasping the eco-social dimension of our existence, recognising the material limits of the planet and critically assessing the ecological footprint of human activity.

To this end, students must find and analyse reliable information in order to identify and describe the main problems threatening to biodiversity and human life, with a particular focus on climate crisis. The aim is to adopt an ethical and life-affirming perspective on the environment, promoting responsible practices, respectful attitudes towards other living beings, and sensitivity to all forms of injustice.

This can be achieved through activities that promote a sense of responsibility for the planet, encourage reflection on environmental actions and the establishment of healthy and sustainable lifestyles, such as those directed towards the responsible use of land, air, water, energy and waste, and the promotion of safe, healthy and sustainable mobility in everyday life.

#### 12.4.5.2 Evaluation criteria and content

<u>Block 3. Sustainable development and environmental ethics</u>

CA3.2. Evaluate different options for mitigating climate change and achieving the SDGs, identifying causes and eco-social problems, and justifying in an argumentative and critical way the ethical duty to protect and care for nature (OBJ3).

CA3.3. Actively commit to values, practices and affective attitudes consistent with respect, care and protection of people, animals and the planet, through participation in activities that promote responsible consumption and sustainable use of land, air, water, energy, safe, healthy and sustainable mobility and waste prevention and management, recognizing the role of people, groups and entities committed to protecting the environment (OBJ3).

Content: Ecological dependency, empathy, the responsibilities and potential consequences of poor environmental practices (such as climate change and desertification); ethics, politics and justice on a habitable planet; responsible practices for rational and sustainable development such as the role of individuals, groups and organisations committed to environmental

protection, sustainable energy use, rational production of consumer goods, waste management, critical attitudes to pollution, loss of biodiversity and the value of water, air, soil, forests, animals and the overall protection of the planet.

12.4.5.3 Pedagogical orientations and lines of action in the teaching and learning process.

In line with the pedagogical guidelines for this level, the didactic methodology should be communicative, inclusive, active and participatory, focusing on the achievement of curricular objectives and key competences. It involves the integration of curricular elements through problem-based learning in authentic contexts, taking into account the different experiences and learning styles of students. The approach encourages self-directed learning, collaboration, and meaningful learning that fosters autonomy and critical reflection.

Skills such as reading comprehension, oral and written expression, audio-visual communication, digital literacy, creativity, scientific inquiry and entrepreneurship are integrated into all subjects, regardless of their specific focus. Likewise, gender equality, education for peace, responsible consumption, sustainable development and health education, including affective-sexual education, are promoted in all areas. These elements serve as transversal components of the curriculum, together with educational guidance, tutorial support and emotional and values education.

# 13. ECORUSH: THE RACE FOR THE GREEN SHOPPING CART[11]

Sustainable public food procurement can play a key role in the transition to a more ethical and resilient food system that benefits both the environment and public health. Ecorush, a board game aligned with the Sustainable Development Goals, integrates principles of environmental sustainability and promotes healthy lifestyles. This game is particularly relevant during adolescence, a period of profound physical and sociological change that has a direct impact on long-term health and well-being. Players strategically compete to purchase the maximum amount of food products while minimising their carbon footprint and striving for a balanced diet. Using $CO_2$ as currency, players navigate a board representing different food categories. Unforeseen events also influence the game by introducing environmental taxes, green subsidies and other variables that test players' environmental and financial management. The winner will be the player who best demonstrates the ability to balance efficient purchasing with a reduced environmental footprint.

[11] Cambeses-Franco, C., 2024. “Ecorush, a carreira polo carro da compra verde”. EDUGA, revista galega do ensino, 88.

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## 13.1 INTRODUCTION

### 13.1.1 The impact of adolescent development on eating habits

Adolescence is a crucial period in human development, marked by significant physical, biological, psychological, neurodevelopmental and social changes. The changes experienced during adolescence have far-reaching implications for the long-term health of individuals, including the potential health of future offspring (Sisk and Gee, 2022). Furthermore, adolescence is a period of transition, as young people move from being primarily dependent on caregivers to assuming multiple roles and responsibilities related to food acquisition, preparation and consumption. This transition provides a unique opportunity to promote healthy eating habits (Neufeld et al., 2022).

Dietary intake during late childhood and early adolescence plays a critical role in influencing not only immediate growth outcomes such as height, weight and muscle mass, but also cardiorespiratory fitness, neurodevelopment and immune function (Norris et al., 2022). Furthermore, it affects the likelihood of developing NCDs in later life. In many countries, high rates of early adolescent pregnancy pose significant risks to the growth and nutritional status of adolescent females, with consequences that can extend into the next generation (Nguyen et al., 2017).

During adolescence, neurodevelopmental changes, including brain remodelling and rising testosterone levels, significantly influence motivation and behaviour. Increased sensitivity to social judgments promotes a desire for autonomy and risk-taking behaviours aimed at gaining social status (Cardoos et al., 2017; Dahl et al., 2018). Research suggests that the reward-processing systems in the brain become more responsive to energy-dense foods (Cardoos et al., 2017; Galván, 2013). In addition, the development of secondary sexual characteristics and an increased awareness of body image influence eating habits (Tremblay and Lariviere, 2009). Adolescents often become more aware of their eating habits and align them more closely with those of their peer groups or other social circles than with family norms, motivated by the dual drive for belonging and identity (Contento et al., 2006).

### 13.1.2 Adolescent food choices in a transforming world

The current generation of adolescents is living through a period of unprecedented change in the global food environment. Factors such as rapid urbanisation, climate change, shifts in food systems towards increased caloric intake with decreased nutritional value, the COVID-19 pandemic and growing socioeconomic inequality are significantly reshaping food availability and choice. As a result, nutritional challenges such as micronutrient deficiencies and food insecurity persist, while rates of overweight and obesity are increasing (Abarca-Gómez et al., 2017). Despite the critical importance of adolescent nutrition, research in this area has been underfunded compared to other age groups. This lack of investment has hindered the development of nutrition policies that specifically address the needs of adolescents. Much of the focus has remained narrowly focused on single micronutrient supplementation, without adequately addressing the multiple drivers of malnutrition and poor dietary habits. As a result, long-standing nutritional problems such as iron deficiency anaemia remain largely unchanged, particularly affecting adolescent girls due to increased iron requirements for menstruation (Aksu and Unal, 2023).

In this evolving food landscape, young people tend to prioritise taste, enjoyment, price, satiation and health over environmental concerns in their food choices. Their awareness of the environmental impact of food systems is generally limited to issues such as excessive food packaging, food transport, littering, deforestation and factory pollution. Despite being informed about the environmental consequences of meat consumption, young people are reluctant to

reduce their meat intake. This reluctance is driven by health concerns, particularly protein intake, the pleasure and cultural significance of meat, the desire to maintain family or social eating patterns, or the feeling that their current consumption is already low and does not need to be reduced further (Campbell et al., 2016).

Food choices among adolescents are shaped by the complex interactions between their autonomy, agency, and the food environments they inhabit, which can be classified as traditional, mixed, and modern based on the criteria of the High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2017). In traditional food environments, poverty and food insecurity force adolescents to take on adult responsibilities, often prioritising basic needs over health, with limited access to nutritious food. In mixed environments, food choices are influenced by social interactions and the increasing availability of unhealthy, energy-dense foods. Modern food environments, characterised by autonomy and exposure to pervasive advertising, social media and peer influence, promote unhealthy eating habits despite knowledge of healthier choices. In all settings, food serves social functions and youth agency is critical. Policies and programmes need to engage adolescents as active participants in promoting better diets, supported by stronger regulations to curb the marketing of unhealthy foods, especially in modern settings (Neufeld et al., 2022).

### 13.1.3 Tailoring nutrition interventions for adolescents. A multifaceted approach

Nutrition interventions for adolescents vary according to several factors, including age, gender, income, geographic location (rural versus urban), and cultural or national context. Some interventions are designed specifically for adolescents, such as school-based programmes, while others are adapted to meet their social and developmental needs. The focus of these interventions varies from region to region, addressing issues such as undernutrition, micronutrient deficiencies, overweight or a combination of these. There is a strong evidence base for adolescent nutrition interventions across multiple sectors, including education, health care, food systems and the broader community context (Hargreaves et al., 2022).

Health professionals play an important role in promoting good nutrition among adolescents through various interventions, including nutrition counselling, screening programmes, and treatment of eating disorders or obesity-related complications (Salam et al., 2016). Social media and digital health tools also offer promising opportunities to reach adolescents and promote healthy behaviours (Holly et al., 2023).

Supply-side interventions, such as agricultural subsidies, food regulations, and taxes on unhealthy foods and beverages, illustrate the important role of governments in balancing commercial and public health interests (Taillie et al., 2019). Demand-side interventions, including social safety net programs and cash transfers, can effectively improve nutrition and access to education for economically vulnerable families (Dickin et al., 2014; Rivera et al., 2016).

Community-based interventions use local organisations and businesses to improve the food environment and promote healthier food choices (Blum et al., 2022). Policies promoting active transport and regulating fast-food restaurants near schools are examples of how local governments can shape the food environment for adolescents (H. Brown et al., 2021).

Moreover, social media has transformed adolescent interactions, providing opportunities for connection and activism, but also posing challenges such as the normalization of unhealthy body images. Initiatives such as the “Real Food Systems Youth Ambassadors” (Real Food Systems, 2024) and “Eat Well, Live Well” (Balo Khabo Balo Thakbo, 2024) movements demonstrate how adolescents can advocate for systemic change in food production and marketing, thereby harnessing their collective power for positive impact.

### 13.1.4 A Whole-School Approach to nutrition and sustainability

Schools are a central setting for a variety of interventions, with school feeding programs being the most widespread and long-standing initiative (Verguet et al., 2020). In recent times, several countries have introduced new approaches to these programs. For instance, policy measures such as bans on sugar-sweetened beverages (Kamin et al., 2022), changes to menus (e.g. improved foods, inclusion of fortified foods) (Andretti et al., 2021) and modifications to choice architecture (e.g. menu labelling, prompts, item positioning) (Kenney et al., 2020; Olfert et al., 2019) have been implemented.

The school curriculum also provides opportunities to increase dietary diversity, enhance the wider food environment and teach practical skills related to growing and preparing food (Ares et al., 2024). In some settings, initiatives such as school gardens and partnerships with local food producers have shown promise, although evidence suggests that their impact depends largely on the provision of appropriate education and training for teachers and other school staff responsible for managing these projects (Holloway et al., 2023).

There is growing recognition of the need for a "whole school approach" to promoting nutrition through all available means. This approach includes embedding nutrition education in the curriculum, facilitating physical activity and active transport, creating healthy food environments, supporting monitoring, screening and supplementation programs and reinforcing these efforts through the individual commitment of school staff (Sliwa et al., 2023).

In Spain, the LOMLOE (Gobierno de España, 2020b) establishes in a specific additional provision that schools must adopt measures to promote physical activity and healthy eating as integral aspects of children's and adolescents' behaviour. It also promotes sustainable nutrition through the integration of Education for Ecological Transition, which addresses the climate emergency. This approach ensures that students are aware of the impact of their daily actions on the planet and encourages them to develop a sense of responsibility towards their natural and social environment.

Decree 156/2002, of 15 September, which establishes the organisation and curriculum of secondary education in the Autonomous Community of Galicia (Xunta de Galicia, 2022c), aims to promote habits of body care and health through the incorporation of physical education and sport, fostering personal and social development. It also emphasises the critical evaluation of social habits related to health, consumption, care, empathy and respect for living beings, especially animals and the environment.

### 13.1.5 The educational game "Ecorush: the race for the green shopping cart"

The educational game presented in this chapter is in line with the objectives of LOMLOE (Gobierno de España, 2020b) and Decree 156/2022 (Xunta de Galicia, 2022c), the skills of the 21 st-century, the key competences for lifelong learning as set out in the Council Recommendation of May 22, 2018 (European Parliament and Council of the European Union, 2018), the challenges identified in UNESCO's Key Drivers of Curricula Change in the 21st Century (Marope, 2020) and the SDGs of the 2030 Agenda.

Ecorush is an innovative educational game designed to raise environmental awareness and promote healthy eating habits among secondary school students. The game stimulates a shopping experience where students select products based on their CF, measured in $CO_2$ currency. By integrating this game into the physics and chemistry curriculum, students are given a unique opportunity to learn about the links between a balanced diet for physical and mental health and the impact of food choices on the planet.

## 13.2 MATERIALS AND METHODS

### 13.2.1 Context, target audience and duration

The game was implemented in a class of 24 students in the third year of compulsory secondary education (**Fig. 13.1**). The activity was carried out in two 50-minute sessions. The class was divided into groups of four and each group was assigned a game board. The students used the following strategies:

- Conduct a cost-benefit analysis to determine the optimal timing of purchases.
- Use offer cars strategically.
- Effectively manage unforeseen events to ensure a consistent cash flow.

The game is closely aligned with the content, objectives, and competences of subjects within the compulsory secondary education curriculum, including Biology and Geology, Physical Education, Education in Civic and Ethical Values, and Geography and History. Furthermore, the game could be a valuable resource for other disciplines, given that awareness and training on climate change, education for sustainability and responsible consumption are cross-curricular elements outlined in Decree 156/2022 (Xunta de Galicia, 2022c).

**Fig. 13.1. Implementation of the game in a 3rd year of compulsory secondary education class**

### 13.2.2 Key competences

The implementation of the game facilitates the development of key competences for lifelong learning, as outlined in the Council Recommendation of 22 May 2018 on key competences for lifelong learning (European Parliament and Council of the European Union, 2018).

Of the eight key competences, "Ecorush: the race for the green shopping cart" contributes to the acquisition of: (1) Mathematical competence and competence in science, technology and engineering (2) Personal, social and learning competences (3) Citizenship competence (4) Entrepreneurship competence (5) Cultural awareness and expression.

### 13.2.3 Objectives

The objectives proposed are:

- Raise awareness, educate, promote and disseminate the importance of healthy and sustainable diets among teenagers.
- Integrate the SDGs into school education processes.
- Provide students with basic knowledge about sustainable shopping.
- Raise student awareness of the environmental impact of food production, particularly its contribution to climate change using the CF indicator.
- Promote thoughtful discussion and critical thinking on food and the environment.
- Inspire teenagers to adopt healthier eating habits by reflecting on the impact of their daily food choices.
- Promote the Atlantic diet for better health and well-being.

### 13.2.4 Materials

- Game board (**Fig. 13.2**)
- 20 food cards representing foods consumed within the framework of the Atlantic diet, each with its corresponding CF (**Fig. 13.3**). The colour of each card is determined by the food category to which it belongs: meat, fruits, vegetables, fish and seafood, starch-based products, olive oil, dairy products, eggs and nuts.
- 20 offer cars (**Fig. 13.4**)
- 20 event cars, situations that affect the players' finances and purchasing opportunities (**Fig. 13.5**).
- In-game currency: bills denominated in $CO_2$ (eg, 1 kg, 5 kg, 10 kg of $CO_2$)
- Dices and game pieces.

### 13.2.5 Description of the activity

Ecorush is a board game (**Fig. 13.2**) based on the exchange and purchase of food. The budget is based on $CO_2$ and the price of products is taxed according to the GHG emissions they cause. The game board was designed using *Genially* software and features foods that are characteristic of the Atlantic diet. The food, offer and event cards were created using *Canva*.

The food cards (**Fig. 13.3**) were developed using a CF indicator, a metric that has received significant media attention due to its association with global warming. **Table 13.1** shows the CF of the food products that are included in the game. Offer cards provide players with special discounts and promotions that can be used to reduce the CF (cost) of purchased products. **Fig. 13.4** shows examples of offer cards. Event cards add an element of surprise and challenge to the game. Examples of event cards are illustrated in **Fig. 13.5**.

Fig. 13.2. Game board

Fig. 13.3. Examples of food purchase cards

**Table 13.1. Carbon footprint (CF) of food products included in Ecorush**

| Food | CF ($gCO_2eq/kg$) | Reference |
|---|---|---|
| Apples | 120 | (Aguilera et al., 2015a) |
| Oranges | 150 | (Aguilera et al., 2015a) |
| Peach | 120 | (Aguilera et al., 2015a) |
| Hake | 5980 | (Iribarren et al., 2010b) |
| Mussel | 1590 | (Iribarren et al., 2010a) |
| Sardine | 520 | (González-García et al., 2015a) |
| Walnut | 1620 | (Werner et al., 2014) |
| Cheese | 10440 | (González-García et al., 2013c) |
| Milk | 1230 | (González-García et al., 2013b) |
| Olive oil | 2360 | (Sellas Olive Oil, 2013) |
| Eggs | 1800 | (Nielsen et al., 2013) |
| Potatoes | 240 | (Aguilera et al., 2015b) |
| Bread | 880 | (Barilla Center for Food Nutrition, 2016) |
| Pasta | 1280 | (Hess et al., 2016) |
| Onion | 240 | (Aguilera et al., 2015b) |
| Tomato | 220 | (Aguilera et al., 2015b) |
| Pepper | 220 | (Aguilera et al., 2015b) |
| Beef | 24690 | (van Oort and Andrew, 2016) |
| Chicken | 2500 | (González-García et al., 2014) |
| Pork | 4960 | (Noya et al., 2017) |

**Fig. 13.4.** Offer cards

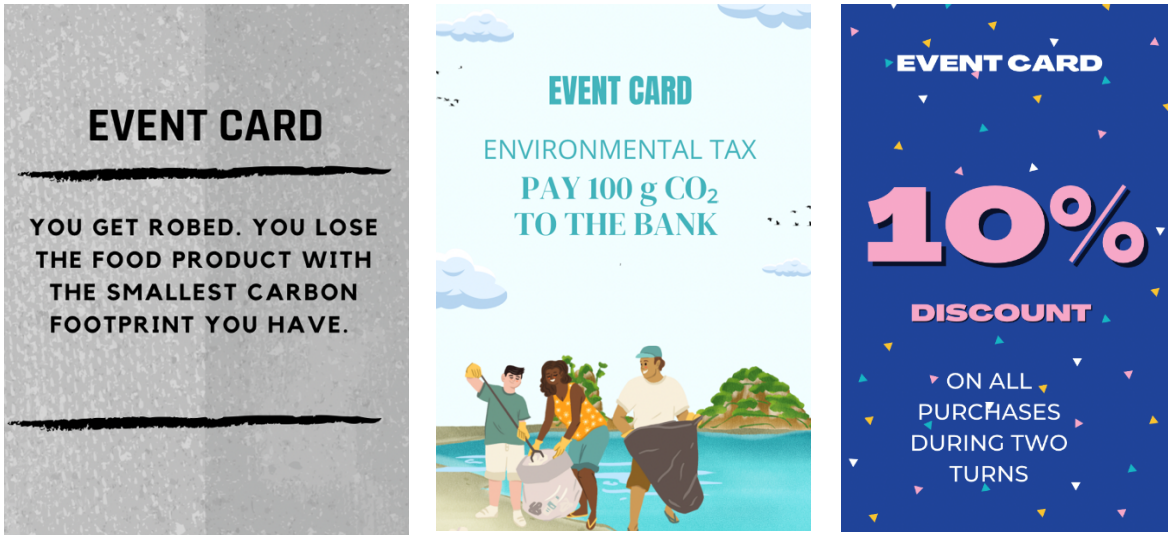


**Fig. 13.5.** Event cards

The goal of the game is to be the player who creates the most balanced complete diet at the lowest $CO_2$ cost.

1) Place the game board on a table.
2) Shuffle the Food cards and stack them in a pile.
3) Shuffle the Offer cards and place them in a separate pile.
4) Shuffle the event cards and form a third group.
5) Choose someone to be the banker, responsible for managing all transactions between players. Players will receive money from the bank when they pass GO square or as specified by Offer and Event cards. Payments to the bank are made when players buy products, pay to get out of jail, or as directed by offer and event cards.
6) Each player chooses a token and places it on the GO square.
7) Distribute an initial amount of money (e.g., 25,000 g $CO_2$) to each player.
8) Each player takes turns to roll the dice. The player with the highest total starts the game.
9) Each player rolls both dice and moves their token clockwise that number of spaces. After the player has completed his turn, the turn passes to the left. The pieces remain on the space they occupied and continue from that point on the player's next turn. Two or more tokens may rest on the same space at the same time.
10) Depending on which space the token reaches, the player may buy the food for the price shown (if it is not already owned by another player). The player receives an ownership card for that food, which should be placed face up. The player may also draw an Offer card or an Event card. If the player lands on one of these spaces, the player takes the top card from the corresponding pile, immediately follows the instructions on the card, and then returns it to the bottom of the pile. If the player draws a "Get Out of Jail Free" card, he/she may keep it until needed or sell it to another player for a mutually agreed price. The third outcome is "Go to Jail". If the player is sent to prison during his turn, the turn ends, and the player does not get to use the speed dice for that turn. The player must move to the prison space and cannot collect the $CO_2$ bonus from the GO space. To get out of jail, the player can use the "Get out of jail free" card, pay a fine of 200 g $CO_2$ before rolling the dice in either of the next two turns, or roll a double. If the player lands on the "just visiting jail" space, there is no penalty.
11) No player may borrow from or lend money to another player.

12) If the player throws double, he/she moves his/her token as usual. If the player throws doubles three times in a row, he/she must immediately move his/her token to the space marked “In Jail”.
13) The game concludes when all products are purchased or after a specified number of rounds. The player with the highest number of products purchased from different categories, at the lowest $CO_2$ cost, wins the game. Each player’s total score is calculated according to the following guidelines. A base score of 3 points is awarded for each food item purchased. Players receive an additional 2 points for each different food category they purchase. There is a penalty of 0.0003 points for each gram of $CO_2$ emitted.

For instance, a player who has acquired 5 food items from 5 different categories with a total CF of 20000 g $CO_2$, receives a final score of 19 points (see **Eq. 13.1**).

$$Score = 5\ food\ products \cdot 3 + 5\ food\ categories \cdot 2 - 0.0003 \cdot 20000 = 19 \quad 13.1$$

### 13.2.6 Methodological strategies

The methodology used in the project was game-based learning. This educational strategy uses elements of a game to achieve specific learning objectives. Pupils become the leaders of their own learning. The teacher's role is that of an educational facilitator. By integrating game dynamics and mechanics into the learning process, active student participation is encouraged, social interaction is promoted and motivation to learn is increased. One of the key benefits of this approach is its ability to provide students with real-world experience in a controlled, risk-free environment. Through a simulated scenario, students can practice decision-making skills related to choosing the most environmentally friendly option in a supermarket. At the same time, they work on their mathematical and citizenship skills through active engagement with sustainability.

### 13.2.7 Content

The game “Ecorush: The race for the green shopping cart” was designed according to the themes established in the Decree 156/2022 that defines the curriculum for secondary education in Galicia (Xunta de Galicia, 2022c): Importance of acquiring sustainable habits; Healthy eating habits; Characteristics of a healthy diet and analysis of its importance; Nutritional value of foods; Responsible living and environmental protection; Responsible consumption for a sustainable life; Food sovereignty; Environmental awareness: Respect, protection and care for living beings and the planet; SDGs: 2030 Agenda for Sustainable Development; Health effects of unhealthy habits linked to social behaviours; Active and healthy living; Climate emergency: Elements and factors that condition the climate and the impact of human activities.

These themes are tightly integrated into the game, creating synergies that emphasise the importance of adopting healthy and sustainable practices as an integral part of daily life. This approach not only promotes improved well-being, but also empowers individuals to take actionable steps towards a healthier and more sustainable future.

### 13.2.8 Assessment

For the evaluation of the game used in the classroom, a questionnaire was proposed to the students, using a scale from 1 (lowest rating) to 5 (highest rating) (**Table 13.2**). This provided detailed feedback on their experience, learning and satisfaction. In addition, another questionnaire was designed to be completed by the teacher (**Table 13.3**).

**Table 13.2. Student questionnaire**

| Indicator | Description | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Understanding game goals | Did you understand "Ecorush" game goals and their relation to sustainability and balanced nutrition? | | | | | |
| Gaming experience | Did you enjoy playing "Ecorush"? | | | | | |
| Learning about sustainability | Did you learn about the importance of sustainability in food purchasing decisions? | | | | | |
| Nutrition knowledge | Did you gain an understanding of balanced nutrition and the Atlantic diet by playing "Ecorush"? | | | | | |
| Decision making | How would you assess your ability to make strategic decisions in the game? | | | | | |
| Environmental impact and public health | Did you become aware of the impact of your decisions on the environment and public health? | | | | | |
| Cooperation and participation | Did you actively participate in the game and collaborate with other players? | | | | | |
| Overall satisfaction | How would you rate your overall experience with "Ecorush"? | | | | | |

**Table 13.3. Teacher questionnaire**

| Indicator | Description | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Space adaptation | The space used for the game is suitable in terms of safety, comfort and capacity. | | | | | |
| Material adequacy | Materials are available and in good condition. | | | | | |
| Motivation of participants | The game's content was captivating, keeping participants engaged and motivated to actively participate. | | | | | |
| Methodology and innovation | The methodology used in the game is innovative and effective in achieving the learning objectives of the game. | | | | | |
| Organisation of the activity | The activity was well-structured with clearly defined roles and a set timeline. | | | | | |
| Climate-environment | The game fostered a positive atmosphere with active engagement and respect among all players. | | | | | |
| Compliance with expectations | The game fulfilled the participants' expectations in terms of objectives and expected outcomes. | | | | | |
| Individual achievement | Students individually benefited from the gaming experience. | | | | | |
| Key competence development | The game contributed to the development of mathematical and citizenship competences. | | | | | |
| Satisfaction with the game | The participants expressed satisfaction with the learning experience provided by the game. | | | | | |
| Promotion of learning | The game facilitated the learning process, promoting reflection and the practical application of the knowledge acquired. | | | | | |
| Review of the previous contents | The game facilitated the consolidation of previously learned content. | | | | | |
| New knowledge acquisition | The game promoted the acquisition of new knowledge | | | | | |
| Alignment with students' daily experiences | The game provided an experience that connected participants to real-life situations and challenges they face as citizens in their daily lives. | | | | | |

## 13.3 REGULATORY FRAMEWORK AND THEMATIC CONTEXT FOR THE TEACHER

The game is in accordance with Decree 156/2002, of 15 September, which establishes the organisation and curriculum of secondary Education in the Autonomous Community of Galicia (Xunta de Galicia, 2022c) and provides further detail on the provisions of Organic Law 3/2020, of 29 December, which amends Organic Law 2/2006, of 3 May, on education (Gobierno de España, 2020b) and Royal Decree 217/2022, of March 29, which establishes the organisation and minimum teaching of secondary education.

The objectives of this stage of secondary education focus on the promotion of responsible citizenship through tolerance, cooperation and gender equality; the development of disciplined study habits and emotional skills for conflict resolution; the promotion of critical information literacy and scientific knowledge; the cultivation of an entrepreneurial spirit along with personal responsibility; the acquisition of proficiency in Galician, Spanish and foreign languages; the promotion of an appreciation of cultural heritage and artistic expression; the appreciation of linguistic and cultural diversity; the understanding of the functions of the body; the development of healthy habits through physical education and sport; and the promotion of empathy and respect for all living beings and the environment in order to preserve it.

Furthermore, according to article 6 of Royal Decree 217/2002, in secondary education, reading comprehension, oral and written expression, audiovisual communication, digital literacy, social and entrepreneurial initiatives, the promotion of critical and scientific thinking, emotional and value education, gender equality and creativity are integrated into all subjects, without compromising their specific treatment. In addition, health education - including affective and sexual education - as well as aesthetic education, education for sustainability and responsible consumption, and mutual respect and cooperation among peers are promoted in a transversal way throughout the curriculum.

The exit profile of students at the end of basic education ensures that all graduates who complete basic education develop a responsible attitude towards the environment, identify aspects related to responsible consumption and adopt a healthy lifestyle, taking personal and social responsibility for self-care, caring for others and promoting public health. Meeting these challenges requires the knowledge, skills and attitudes that underpin the key competences addressed in the different areas, domains and subjects of the curriculum.

“Ecorush: the race for the green shopping cart” is more closely aligned with certain areas of the curriculum than others. An analysis of Decree 156/2022 reveals various links to sustainable and healthy eating, which are detailed below.

### 13.3.1 Biology and geology

This subject aims to develop curiosity and critical thinking while reinforcing the foundations of scientific literacy. Students learn about their own bodies and their environment, which helps them to adopt habits and attitudes that improve their health, such as responsible consumption, environmental protection, respect for other living beings, and an appreciation of active engagement for the common good. Furthermore, it aims to promote scientific careers, particularly among female students, and to develop study habits, teamwork and language skills, which are essential components of scientific methodologies.

The scientific nature of this subject can help students to develop the creative and entrepreneurial spirit that is essential to all sciences. Research methods such as field observation, experimentation and gathering information from different sources can be used to answer questions or test hypotheses, both individually and collaboratively.

The objectives include interpreting, communicating, locating and evaluating scientific information; applying scientific methods to research projects; developing problem-solving strategies; analysing and promoting healthy and sustainable lifestyles; and interpreting the geological features of landscapes.

13.3.1.1 Objectives

**OBJ 2.** Identify, locate, select, check for accuracy, organize and critically evaluate information to answer questions related to the biological and geological sciences.

Scientific research, active civic engagement, and personal and professional growth often require the acquisition of new skills. These skills often begin with the ability to locate, select and synthesise relevant information from multiple sources.

In the current information landscape, individuals are continually exposed to information that may not be accurate. Therefore, developing critical thinking skills, along with the ability to evaluate, categorise, and identify reliable sources, is essential for success in any field.

This objective prepares students for independent decision-making in their personal and professional lives and helps them to become active, contributing members of a democratic society.

**OBJ 4**. Use reasoning and computational thinking by critically analysing answers and solutions, and re-evaluating the approach, if necessary, to solve problems or explain everyday processes related to biology and geology.

Biological and geological sciences are empirical disciplines that rely on logical reasoning and mathematical methods to build models, solve problems and validate results. Formulating hypotheses, interpreting data and designing experiments all require formal reasoning.

Developing these skills in students is important because they can be applied to many aspects of life. For example, critical thinking based on reasoning with available information can help guard against pseudoscience and unfounded popular beliefs.

**OBJ 5**. Evaluate the environmental and health consequences of specific actions based on biological and earth science principles to adopt practices that prevent negative environmental impacts, support SDGs, and contribute to individual and collective well-being.

Human well-being, health and economic development depend on natural resources such as fertile soil, fresh water and diverse living organisms, including pollinating insects, nitrifying bacteria and marine plankton. Without these resources, essential activities such as food production would be severely threatened. Unfortunately, many natural resources are non-renewable or are being used at unsustainable rates. Habitat destruction, climate change and the use of harmful substances are reducing biodiversity. These changes could destabilize human societies. Fortunately, there are actions we can take to improve both the environment and our health in the short and long term.

On the other hand, certain behaviours typical of developed countries, such as consumerism, sedentary lifestyles, diets high in fat and sugar, technological addiction and impulsive behaviour, have serious consequences for the health of the population. Therefore, students need to understand how their bodies work, challenge misconceptions and gender stereotypes, and recognise the importance of sustainable development as a fundamental goal for promoting well-being, health and economic progress.

13.3.1.2 Evaluation criteria and content

**1st course**

Block 6. Ecology and sustainability

CA6.4. Critically analyse the solution to an environmental problem by relating it to biological and geological phenomena (OBJ 4).

CA6.6. Integrate the conservation of biodiversity, environmental protection, the preservation of living organisms, sustainable development and quality of life with scientific principles (OBJ 2)

CA6.7. Develop and implement sustainable practices by critically evaluating personal and external actions based on personal reasoning, acquired knowledge and available information (OBJ 5).

Content: Ecosystems. The importance of conserving ecosystems, biodiversity, and implementing a model of sustainable development; the impacts on ecosystems caused by human activities; and the significance of adopting sustainable habits (responsible consumption, waste prevention and management, and respect for the environment).

**3 st course**

Block 5. Healthy habits

CA5.1 Locate, evaluate and synthetize information from different sources to identify and address common healthy lifestyle habits (OBJ 2)

CA5.2 Differentiate between scientifically based health information and unsubstantiated claims such as pseudoscience, rumours, conspiracy theories and unfounded beliefs, and maintain a sceptical attitude towards them (OBJ 2)

CA5.3 Critically analyse solutions to problems related to healthy eating, drug use, and sexuality. (OBJ 4)

CA5.4 Reflect on the importance of acquiring healthy habits and lifestyles as a method of disease prevention, using situations relevant to the students as examples (OBJ 5)

CA5.5 Analyse the importance of good nutrition and physical activity, recognizing them as healthy habits for both individuals and society. (OBJ 5)

Contents: Healthy eating habits. Characteristics of a healthy diet and an analysis of its importance; habits to maintain physical, mental and social well-being (sleep hygiene, posture habits, responsible use of new technologies, physical activity, emotional self-regulation, care and shared responsibility).

**4 st course**

Block 6. Ecosystems: interactions and changes

CA6.3. Recognize the causes and consequences of human impact and critically analyse solutions to an environmental problem by proposing actions to conserve the environment, locating, selecting, organizing and analysing information form a range of sources (OBJ 4)

CA6.4. Identify and analyse the different environmental problems exacerbated by specific human activities in a geographical area, taking into account its characteristics and socio-economic factors (OBJ 5).

Contents: Ecosystem dynamics: environmental impacts of human activity; environmental problems and possible solutions.

13.3.1.3 Pedagogical orientations and lines of action in the teaching and learning process.

The educational intervention in the subject Biology and Geology develops its curriculum and seeks to progressively establish the necessary learning at different levels. This approach helps

students to achieve the objectives of the subject and, in conjunction with other subjects, to acquire key competences and meet the objectives of the educational stage.
Effective teaching and learning in Biology and Geology involves an emphasis on critical thinking skills such as hypothesis formulation, information gathering, experimentation, data analysis and clear communication. An interdisciplinary approach can improve understanding, while project-based learning, practical laboratory work and inquiry-based activities can make the subject more engaging. In addition, promoting independent learning, embracing diversity and using continuous assessment can further enhance student motivation and progress.

### 13.3.2 Education in Civic and Ethical Values

Education in Civic and Ethical Values is essential both for the active and responsible exercise of citizenship and for the development of students' moral autonomy and personality. Education in Civic and Ethical Values involves the development of knowledge and skills that help students to become aware of their personal and cultural identity, to address fundamental ethical issues, to take responsibility for their interconnected and interdependent lives and to apply the norms and values necessary for a free, diverse, and peaceful society.

A key competence in Education in Civic and Ethical Values is the adoption of attitudes that support environmental sustainability. This is taught both theoretically, to help understand key concepts, and practically, to encourage critical thinking and discussion, as well as behaviours consistent with ethical, civic and eco-social values that promote coexistence.

#### 13.3.2.1 Objectives

**OBJ 3.** Understand the interconnected and interdependent nature of human activities by identifying and analysing relevant eco-social issues in order to promote habits and attitudes that are ethically committed to sustainable lifestyles.

Understanding the systemic relationships of interdependence, eco-dependence and interconnectedness between our lifestyles and the environment is essential to cultivating an ethical commitment to sustainability and care for the planet. Such knowledge can be gained through a critical analysis of the perspectives that individuals hold about their relationship with nature and the implications of these actions for sustainable living. In addition, deeper insights are developed through dialogue on ethical and environmental perspectives that address serious eco-social issues.

To demonstrate their commitment to environmental stewardship, students are required to engage in actions that contribute to the achievement of the SDGs. These actions include waste prevention, sustainable resource management, safe, healthy and sustainable mobility, ethical and civic compliance with environmental laws, promotion of responsible consumption, preservation of cultural heritage, respect for ethno-cultural diversity, community service and animal welfare.

#### 13.3.2.2 Evaluation criteria and content

**3 st course**

<u>Block 3. Sustainability and environmental ethics</u>

CA3.1. Describe the historical relationships of interconnectedness, interdependence, and eco-dependence between our lives and the environment by analysing the causes and consequences of the most serious eco-social problems that affect us (OBJ 3).

CA3.2. Evaluate different scientific, political, and ethical approaches to addressing the climate emergency and environmental crisis through presentations and structured debates on these perspectives (OBJ 3).

CA3.3. Encourage ethically responsible lifestyles that contribute to the achievement of sustainable development by promoting preventive waste management, sustainable resource use, safe, sustainable and healthy mobility, fair trade, responsible consumption, preservation of the natural heritage, respect for ethno-cultural diversity and the care and protection of animals (OBJ 3).

Contents: 1. Living responsibly with and protecting the environment: a) A critical overview of the various ways in which humans have interacted with nature throughout history, and the ecological footprint of human actions on the planet b) Empathy and responsibility towards the environment: independence, interconnectedness and eco-dependence c) Environmental protection and rights: human rights of the third generation; 2. Responsible consumption for a sustainable life on our planet: a) The limits of the planet and resource depletion b) SDGs: the 2030 Agenda for Sustainable Development c) Sustainable and ecological economy in globalization and a new logic of growth: circular economy and blue economy d) Habits for proper resource management and preventive waste management. Safe, healthy and sustainable mobility e) Responsible consumption and food sovereignty; 3. Scientific and ethical-political proposals on eco-social problems: a) ecological justice b) environmental ethics: ecocentrism, biocentrism and extensionism.

13.3.2.3 Pedagogical orientations and lines of action in the teaching and learning process.

The lines of action in the teaching and learning process of Education in Civic and Ethical Values include the use of different methods that take into account different learning paces, promote autonomy and encourage teamwork with a gender perspective. There is an emphasis on meaningful projects and collaborative problem solving, as well as attention to diversity and the prevention of learning difficulties through early support. Strategies are implemented to develop key skills, promote healthy and sustainable lifestyles, and foster respect and assertive emotional management. Active participation, respectful dialogue and the use of civic participation channels in a democratic context are valued. The ultimate goal is to strengthen students' self-esteem, autonomy in decision making, reflection and responsibility.

### 13.3.3 Physical Education

Physical education is designed to help students develop an active lifestyle, understand their bodies, enjoy cultural expressions of movement, develop environmentally and socially responsible attitudes, and improve decision-making skills in movement situations. These elements build important motor skills that are crucial to the overall development of students.

The objectives of Physical Education are to establish an active and healthy lifestyle that students can maintain throughout their lives by promoting autonomous planning and self-regulation of their physical activity and all health-related components.

There is a strong emphasis on the importance of coexisting respectfully with the environment by participating in physical and sporting activities in different contexts and contributing to their organisation with a focus on conservation and sustainability.

13.3.3.1 Objectives

**OBJ 1.** Adopt an active and healthy lifestyle through the conscious selection and integration of physical and sporting activities into daily routines, based on a critical analysis of body models and the rejection of practices without scientific basis.

This objective encompasses the entire physical education curriculum and allows for the exploration of various aspects, such as active participation, healthy eating, postural education,

body care, self-concept, self-esteem and perceived image in the context of physical activity and sport, discriminatory behaviours and unhealthy habits in everyday contexts and those related to sport and physical activity, among others.

There are various contexts for applying these lessons, including personal planning of motor activities, analysing different aspects of maintaining a healthy diet, critically examining movement-related situations, understanding first aid, preventing injury, and participating in a variety of physical and sports activities that connect these concepts to everyday life.

13.3.3.2 Evaluation criteria and content

**1 st course**

Block 1. Active and healthy lifestyle

CA1.2. Incorporate progressively processes of body activation, self-regulation, effort management, healthy eating, postural education, relaxation and hygiene into the practice of motor activities, internalizing the routines associated with healthy and responsible movement practices (OBJ 1).

CA1.4. Recognize and appreciate the impact of certain practices and social behaviours on our health and coexistence, evaluate their effects, and actively work to avoid their reproduction.

Contents: physical health: healthy eating; social health: the impact of unhealthy habits associated with social behaviour.

**3 st course**

Block 1. Active and healthy lifestyle

CA1.2. Incorporate progressively processes of body activation, self-regulation, effort management, healthy eating, postural education, relaxation and hygiene into the practice of motor activities, internalizing the routines associated with healthy and responsible movement practices (OBJ 1).

CA1.3. Adopt attitudes that reject social stereotypes related to the body, gender and sexual diversity, as well as behaviours that threaten health, by evaluating any information based on criteria of scientific validity, reliability and objectivity (OBJ 1).

Contents: physical health: healthy eating and critical analysis of advertising; social health: Dominant body types in society and a critical analysis of their representation in the media and social networks, negative effects of prevailing aesthetic standards and disorders associated with an unhealthy body obsession.

**4 st course**

Block 1. Active and healthy lifestyle

CA1.2. Incorporate progressively processes of body activation, self-regulation, effort management, healthy eating, postural education, relaxation and hygiene into the practice of motor activities, internalizing the routines associated with healthy and responsible movement practices (OBJ 1).

CA1.3. Adopt attitudes that reject social stereotypes related to the body, gender and sexual diversity, as well as behaviours that threaten health, by evaluating any information based on criteria of scientific validity, reliability and objectivity (OBJ 1).

Contents: physical health: healthy eating; social health: Dominant body types in society and a critical analysis of their representation in the media and social networks, negative effects of prevailing aesthetic standards and disorders associated with an unhealthy body obsession.

13.3.3.3 Pedagogical orientations and lines of action in the teaching and learning process.

The Physical Education program at this stage is designed to facilitate active learning through the development of motor skills and practical experiences. Cooperative learning and sports education are employed to facilitate competency development through meaningful projects. Learning situations integrate processes focused on the acquisition of motor skills and key competences from different perspectives, promoting participation, self-esteem, and responsibility. The methodology is adaptable to the content, context and available resources, including the integration of digital technologies. Recognizing the importance of movement in learning, transdisciplinary approaches incorporating physical activity are recommended. Evaluation is continuous and formative, and family involvement is essential to promote healthy and active lifestyles.

### 13.3.4 Geography and history

Geography and history are fundamental to understanding our complex world. By exploring how societies interact with their environment and the lessons of the past, students can develop critical thinking, informed citizenship and a sense of responsibility for the future. This is particularly important during adolescence, when young people are developing their identities and learning to navigate social contexts. By studying the challenges we face today and analysing historical responses, students can be empowered to ensure the sustainability of our planet and the well-being of humanity in the future.

The aims for this subject provide an important framework for key areas of learning. These include working with different sources of information, including digital, linking learning to local and global contexts, promoting interest in the SDGs, fostering solidarity and social cohesion, respecting cultural diversity and different identities, and managing conflict through ethical judgement based on democratic values. It also focuses on valuing and preserving heritage, ensuring genuine equality between women and men, and combating all forms of discrimination. To achieve these aims, it is important to combine the methods of geographical and historical inquiry with critical thinking and awareness.

While each course has a unique historical focus, the progression of the curriculum is guided by the complexity of the subject matter and the intellectual development of the students. We move away from a focus on rote memorisation towards a broader understanding of historical events, the practical application of historical knowledge and the cultivation of critical thinking skills. By adopting more active learning methods, students are able to demonstrate their understanding, increase their motivation and become more actively involved in the learning process.

13.3.4.1 Objectives

**OBJ 2**. Investigate, articulate, and produce original work on geographic, historical, and social issues of contemporary relevance, from local to global contexts, to foster critical thinking that respects difference, contributes to the development of personal identity and enriches our shared heritage.

This objective aims to cultivate independent judgment by contrasting different sources of information and relating them to different schools of thought and ideologies. It promotes reasoned expression through dialogue and debate on important contemporary and historical issues. Moreover, it includes the exchange of ideas, the development of personal identity, respect for others, and the establishment of a civic consciousness that values diverse perspectives.

**OBJ 3**. Acquire knowledge of the main challenges faced by different societies throughout history by developing research projects and using reliable sources to formulate proposals that contribute to sustainable development.

This objective aims to analyse phenomena that are particularly relevant to the world in which students live. The most effective way to achieve this is through project-based learning, assignments or problem solving, both individually and collaboratively.

This approach to learning links students' education to current issues affecting their community, which require analysis, understanding and engagement. Consequently, any issue, past or present, takes on meaning to the extent that it contributes to the understanding of reality and the evaluation of proposals and alternatives to current challenges and the achievement of SDGs.

**OBJ 4**. Identify the elements of the landscape and their integration within complex natural, rural, and urban systems and their evolution over time. Analyse the causes of these changes and assess the degree of balance in various ecosystems in order to promote their conservation and sustainable use.

This objective aims to identify the elements and interrelationships within the environment, as well as their balance and evolution, and to promote efforts to conserve them. It encourages students to recognize the positive contributions of progress, civilization, technology and culture, and to critically evaluate the ethical implications of technological progress and globalization in relation to the degradation of life on Earth.

The environmental quality of our living spaces - whether natural, rural or urban - plays a crucial role in shaping students' present and future. They need to appreciate the opportunities these environments offer for personal growth, while also considering the constraints needed to preserve them. This includes addressing pressing issues such as pollution in large cities and depopulation in rural areas.

To achieve this goal, it is essential to raise awareness of the serious consequences of the climate crisis and the urgent need to adopt behaviours that uphold the dignity of all living beings. This requires promoting sustainable development, encouraging active participation in environmental improvement at both local and global levels, and advocating for a fair, equitable, and compassionate distribution of resources worldwide.

**OBJ 8.** Raise awareness of the role of demographic cycles, the life cycle, lifestyles, intergenerational and interdependent relationships in contemporary society and their evolution over time, while critically analysing these aspects in order to promote healthy, sustainable and enriching alternatives that respect human dignity and encourage commitment to society and the environment.

Students should recognize that life expectancy and quality of life are also closely linked to lifestyles and habits developed both individually and collectively within cultural and family contexts.

**OBJ 9.** Understand and appreciate the importance of comprehensive citizen security in the culture of national and international coexistence, recognizing the contributions of the State, its institutions and other social entities to global citizenship, peace, international cooperation and sustainable development, to promote the achievement of a safer, more supportive, sustainable and just world.

Comprehensive security, provided by institutions and entities, is the basis of coexistence in our society and the exercise of citizenship. This objective aims to engage students with international realities and encourage them to value the formation of international alliances as an essential element in addressing the major challenges facing humanity. It also aims to foster a collective commitment to participate in programs that contribute to security, world peace and

cooperation with countries in need or poverty, supported by states and international organisations that ensure the achievement of the important commitments outlined in the SDGs.

13.3.4.2 Evaluation criteria and content

**1 st course**

Block 1. Contemporary challenges

CA1.5. Identify the major problems and challenges humanity has faced throughout history, their causes and consequences, and current challenges related to SDGs (OBJ 3).

CA1.8. Contribute to a safer, more just, equitable and sustainable world through the analysis of current conflicts and the recognition of state institutions and civil associations that ensure comprehensive security, social coexistence and international commitments to peace, security, cooperation, sustainability, democratic values and SDGs (OBJ 9).

Contents: Climate Emergency: Elements and factors that influence climate and the impact of human activities; Biodiversity: Dynamics and threats to planetary ecosystems. Human influence on the modification of ecosystems in the past and present. Conservation and improvement of the local and global environment; SDGs: Recognition of current global dilemmas as a basis for critical thinking and the development of independent judgment.

Block 3. Global and civic engagement

CA3.3. Argue the need for actions aimed at defending, protecting, preserving and improving the natural, rural and urban environment through proposals and initiatives that reflect commitments and actions in favour of sustainability and the fair and equitable distribution of resources (OBJ 4).

CA3.8. Examine changes in traditional lifestyles and contrast them with healthy and sustainable practices that respect personal health and the health of others, while recognizing the importance of personal development (OBJ 8).

Contents: Environmental Awareness: Respect, protection, and care for living beings and the planet.

**2 st course**

Block 1. Contemporary challenges

CA1.1. Identify, assess and demonstrate interest in the principal issues affecting society, adopting a critical and proactive approach to them (OBJ 2).

CA1.4. Argue the need for actions aimed at defending, protecting, preserving and improving the natural, rural and urban environment through proposals and initiatives that reflect commitments and actions in favour of sustainability and the fair and equitable distribution of resources (OBJ 4).

CA1.7. Interpret the challenges of the contemporary world from the perspective of sustainable development and global citizenship, exploring the importance of seeking and concretizing solutions at the local and global levels. Evaluate the contribution of the state, its institutions, and civil associations in achieving peace, comprehensive security, social coexistence, and cooperation among nations (OBJ 9).

Contents: Lifestyles in the context of globalization

**3 st course**

Block 1. Contemporary challenges

CA1.3. Understand the SDGs by developing proposals that contribute to their achievement, utilizing research methods and projects, with an emphasis on the use of maps and other graphic representations, as well as accessible tools for image interpretation (OBJ 3).

CA1.4. Identify the elements of the environment and understand their functioning as a complex system through a multicausal analysis of their natural and human relationships, both past and present, while assessing the degree of conservation and dynamic equilibrium (OBJ 4).

Contents: SDGs.; Climate Emergency and Sustainability; Relationship between natural and anthropogenic factors; Changes, impacts and threats to the Earth and the local environment in Spain and Galicia; Technological progress and eco-social awareness.

Block 3. Global and civic engagement

CA3.2. Understand the SDGs by developing proposals that contribute to their achievement, utilizing research methods and projects, with an emphasis on the use of maps and other graphic representations, as well as accessible tools for image interpretation (OBJ 3).

CA3.3. Understand and address from an eco-social perspective the past, present and future problems and challenges of contemporary societies, taking into account their interdependence and ecodependence (OBJ 3).

CA3.7. Adopt an active and committed role in the environment, in accordance with personal abilities, aspirations, interests and values, based on a critical analysis of economic realities, the distribution and management of work, the ethical reflection on the use of technology and the management of leisure time, and the adoption of responsible, healthy and sustainable habits that respect human dignity and that of other living beings (OBJ 8).

CA3.8. Contribute to the achievement of a safer, more just, equitable, diverse, intercultural and sustainable world by analysing the main conflicts of the present and recognizing the state institutions and civil associations that ensure comprehensive security, social coexistence, and international commitments to peace, security, cooperation, sustainability, democratic values and SDGs (OBJ 9).

Contents: Commitment to the defence and protection of the environment. Action and position on the climate emergency.

13.3.4.3 Pedagogical orientations and lines of action in the teaching and learning process.

Effective teaching and learning in History and Geography involve organizing content chronologically or thematically, while always considering the historical and geographical context. A practical approach, emphasizing active learning through projects and collaborative problem solving, can help pupils to develop self-esteem and a sense of responsibility. Teachers should act as guides and facilitators, adapting to the individual needs of their students. By integrating different areas of knowledge, an interdisciplinary approach can provide a more holistic understanding. Linking learning to current issues can encourage active participation and community involvement. Group discussions and debates on relevant topics can help students to develop a civic identity and respect for different perspectives.

# SECTION VI

## GENERAL FINDINGS AND CONCLUSIONS

# INDEX

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## 14.1 CONCLUSIONS

### 14.1.1 Detailed findings from the thesis

The future well-being of people and the planet depends on transforming food systems. Despite being the largest producer in Europe and the most concentrated one at a global level, the agri-aqua-food sector is under increasing environmental pressure. To protect jobs and resources, conserve soil, water and biodiversity, and mitigate climate change we need to move towards sustainable economic models and reduce food waste. On the other hand, current food systems and unhealthy consumption patterns lead to the triple burden of malnutrition and are responsible for several NCDs such as diabetes, CVD and cancer.

An unified approach is needed to sustainably balance and optimise the health of people, animals and ecosystems. The current lack of an integrated sustainability strategy hinders the effective management of trade-offs between environmental, social and economic dimensions, and thus the promotion of equitable food systems. Countries need to identify policies, instruments and actions that focus on multi-benefit solutions that address all forms of malnutrition while generating net benefits for people and the planet. In addition, increased financial commitments are essential to ensure that healthy diets are affordable, accessible and desirable.

Therefore, at this pivotal global moment, achieving the necessary transformation of food systems requires making healthy and sustainable diets accessible to all. In recent decades, a growing body of evidence has demonstrated the critical importance of healthy diets in addressing all forms of malnutrition and improving human health and well-being. There is also growing evidence of the environmental and climate impacts of the foods that make up our diets. Global commitment to improving nutrition has increased in recognition of the unique potential of healthy diets to shape the future for both human and planetary well-being, but there is still a long way to go.

This thesis has been developed under the hypothesis of providing both information and inspiration to all those who contribute to the transformation of food systems for accessible sustainable healthy diets, including governments, international organisations and the food industry. This thesis aims to demonstrate the sustainability of different dietary patterns through a trade-off between a multi-criteria approach.

The primary focus was on three key aspects of sustainability: the impact of diet on nutrition and health, the environment and affordability. A methodology was developed to effectively integrate these three aspects into the assessment of FBDGs. This methodology serves as a valuable starting point for achieving the SDGs related to food systems. This methodological approach was applied not only to revise FBDGs in different regions with unique cultural food traditions, but also to evaluate current diets and global dietary trends.

First, the developed methodology was applied to a comprehensive review of different FBDGs at global (EAT-Lancet), regional (NND, MD) and national (DDG, NAOS, IDG) levels. For comparison, all the dietary scenarios studied were adjusted to 2228 $kcal \cdot person^{-1} \cdot day^{-1}$, the recommended daily calorie intake for a middle-aged Spanish woman, and the same scope of LCA was considered (cradle to farm, cradle to factory gate or cradle to port gate).

The IDG, the MD and the EAT-Lancet diet promote a plant-based approach. This is evidenced by the lower recommended daily intake of animal products compared to the American diet. In terms of environmental impact, the EAT-Lancet diet was identified as the most climate-friendly option due to its low CF. Similarly, at the national level, the IDG emerged as the most carbon sustainable. Regionally, the MD outperformed the NND in terms of CF. Adherence to the American dietary guidelines was associated with higher carbon emissions compared to the other dietary approaches examined. This suggests a potential need to revise the

American dietary guidelines to better align them with principles of environmental sustainability.

The dietary guidelines with Spain as the reference location (NAOS and MD) showed higher WFs compared to those from other regions. This discrepancy can be attributed to differences in climatic conditions of production, agricultural factors, and different production systems. Notable differences were identified between the national WFs of the reference countries for milk, beef, pork, chicken and olive oil.

The MD had the highest nutritional quality and the highest Health Gain Score, while other European guidelines from Italy (IDG) and Spain (NAOS) also showed positive results. In contrast, the Dutch and American dietary guidelines scored lower. These differences can be attributed to the limited inclusion of fruits, vegetables, and fiber in the DDG, and the high levels of saturated fat and sodium in the DGA. It is therefore recommended that the Dutch and American FBDGs consider incorporating elements from higher-scoring FBDGs, such as the MD, to improve their nutrient profiles.

The analysis of FBDGs has contributed to the creation of new dietary models in this thesis, including an adaptation of the NND to Southern Europe, where the MD is prevalent. Both diets exceeded recommended nutrient intakes and were similarly affordable. They also offered the potential benefits of weight loss and protection against CVD, T2D and some cancers. However, this adaptation of the NND had a higher environmental footprint, as measured by WF and CF. This highlights the complex interactions between nutrition, affordability and the environment.

The comprehensive analysis of the FBDGs underscored the importance of regional diets, such as the MD, as examples of sustainable dietary patterns. This conclusion was reinforced by an in-depth study of the Atlantic diet, the other regional diet common in Spain. Our findings on the Atlantic diet confirmed the potential of traditional dietary patterns to address the complex relationship between environmental sustainability and health, particularly in relation to the incidence of MetS. The GALIAT study, a cluster randomised clinical trial involving 574 participants, demonstrated a significant reduction in the incidence of MetS following a traditional Atlantic diet intervention. There was no statistically significant difference in the reduction of dietary CF emissions in the intervention group compared with the control group. These findings suggest that traditional diets could serve as valuable tools to promote the convergence of human and planetary health. To fully realise this potential, further research is needed to assess the applicability of our findings to different populations and cultural contexts.

On the other hand, the analysis of the sustainability of Atlantic diet recipes in the context of this thesis provided promising insights for consumers, restaurants and policy makers. Our findings showed that a shift towards plant-based recipes may significantly improve the environmental, economic and energy sustainability of Galician cuisine. Limiting red meat consumption significantly reduces GHG emissions and production costs, while increasing energy efficiency. Alternatives such as poultry, fish or seafood provide additional environmental and economic benefits.

As previously stated, the developed methodology was subsequently employed to analyse real dietary patterns, such as those in Spain. The Spanish case study showed that current dietary patterns are unsustainable. Although Spanish dietary pattern is nutritionally adequate, a shift towards greater sustainability is required. To align with the environmentally conscious EAT-Lancet and other FBDGs, an increase in the consumption of plant-based foods is important.

Section IV of the thesis focused on the socio-cultural dimension of sustainability. Social disruptions, including pandemics, economic crises, and large-scale events, were shown to affect food systems and dietary patterns, potentially exacerbating environmental pressures. The COVID-19 pandemic serves as a stark example of how changing social interactions in Spain

led to dietary shifts and increased consumption, resulting in increased GHG emissions and water use. This underscores the critical need for resilient food systems capable of mitigating the negative consequences of social disruption on both human health and the environment.

Socioeconomic inequality also has a significant impact on the environmental footprint of diets, as shown in this thesis, which analysed the environmental impact, nutritional quality and costs of diets in different socioeconomic subgroups in Chile. Chileans in the highest income quintile have diets with almost twice the GHG emissions and WF of those in the lowest quintile. This discrepancy is mainly due to higher meat consumption among wealthier Chileans. Chileans with a lower socio-economic status consume diets of lower nutritional value. Notably, even high-income diets do not achieve optimal nutritional quality. These findings underscore the need for a multifaceted public health strategy that addresses both affordability for low-income households and overall dietary quality across the entire socioeconomic spectrum. In the context of Chile, a strategy that promotes a gradual shift towards white meat options, combined with an increase in plant-based alternatives, may be an effective approach to achieving a more sustainable food system in the near term.

Nutrition has become a maze of conflicting trends, leaving consumers adrift in a “sea of misinformation”. The growing popularity of the Paleo diet has prompted research into its potential benefits and drawbacks. This dietary approach, which emphasises fat, protein and PUFA with limited carbohydrates, promotes weight loss and muscle development. However, a key concern lies in its environmental impact. The focus on meat, fish and seafood, contributes significantly to GHG emissions and water consumption. These same food groups are also associated with an increased risk of diet-related diseases.

Despite significant progress made on the importance of sustainable diets, sustainability is still perceived as an ambiguous term or buzzword. This is evident in the discourse surrounding policy initiatives over the last decade, including those of the FAO, WHO, the EAT-Lancet Commission on Food, Planet and Health, the United Nations SDGs and the European Farm to Fork strategy. Consumers often have unclear perceptions of sustainability and healthy diets, revealing a gap between their beliefs and the scientific evidence on what constitutes a sustainable healthy diet. School-based approaches can help correct misconceptions and drive positive change. They shape lifelong eating habits, improve food literacy and promote the consumption of locally available, nutritious foods. This not only tackles multiple forms of malnutrition, but also addresses broader challenges such as environmental protection, climate change mitigation and poverty alleviation.

This thesis developed two game-based interventions to promote healthier and more sustainable dietary choices among primary and secondary school children. "Eat Healthy, Eat Sustainably” is a game for primary school children that uses cards of popular Spanish foods. Players calculate the CF and WF of their personal diets, making these abstract concepts more tangible by turning them into relatable measurements. For example, they can learn how many kilometres a car could travel with the same emissions as a particular food, or how many bathtubs could be filled with the water used to produce it. This helps children understand the real-world consequences of their food choices. "Ecorush, the race for the green shopping cart" is a board game that provides a fun and competitive way to learn about sustainability. Players use $CO_2$ as a currency to shop for food, navigating a board filled with different food categories while facing challenges such as environmental taxes and green subsidies. The goal is to be the most efficient and environmentally friendly shopper. Both games contribute to the limited research on offline gamified interventions in schools and highlight the potential of gamification as a motivational tool.

### 14.1.2 Recommendations and future perspectives

The global call for sustainable food systems is essential to achieving the SDGs, as food links the interconnected economic, environmental, and social dimensions of these goals. While food systems contribute to pressing planetary and societal challenges—such as GHG emissions and water use—they also have the potential to address these issues through practices such as carbon capture and water recycling. A food system encompasses all activities related to the production, processing, distribution, and consumption of food, highlighting the complex interactions and feedback loops within it. Four key drivers enable the transformation of food systems.

i) Change the way we eat

The primary objective is to facilitate the transition to sustainable and healthy diets everywhere - changing food environments and consumer behaviour to promote sustainable consumption of safe, healthy, nutritious, affordable, accessible, equitable and culturally acceptable tasty food, while addressing malnutrition in all its forms.

This thesis supports this objective by developing a multi-criteria methodology that integrates sustainability dimensions to assess dietary patterns and provides a comprehensive framework for future research. This methodology was applied to assess the sustainability of food consumption patterns in different countries. Moreover, it allows the inclusion of environmental considerations in the analysis of national FBDGs. These guidelines consider production-consumption, socio-cultural influences, and accessibility, but environmental factors have been overlooked in most of them.

Although this thesis introduces a new methodology, there is still a need for a standardised methodological guide. This guide would help to assess the sustainability of dietary patterns and FBDGs, covering sustainability dimensions and integrating LCA with nutritional considerations. In addition, it should emphasize the development of diets that are not only climate-friendly and water-efficient, but also prioritise other environmental criteria such as biodiversity and animal welfare.

The assessment of the environmental impact of diets in this thesis shows that foods with the highest negative environmental impact, especially red and processed meat, are also correlated with increased health risks. Therefore, research into alternative protein sources such as microalgae, insects and cultured meat, is a promising direction given their considerable potential as future food options. This research will require new methods of risk-benefit analysis that assess aspects such as food safety, nutrient deficiencies, digestibility, and the presence of antinutritional factors and contaminants. In addition, there is an urgent need for better understanding and protocols for novel products and evolving trade practices within food systems.

Future research should also focus on identifying the factors that influence food choices, such as taste, price, and cultural habits, which are essential for designing effective interventions. The use of big data can play a pivotal role in this understanding, enabling the assessment of demand, willingness to pay, and cultural and social barriers, thereby facilitating the implementation of tailored strategies. To influence the consumption choices of different consumer groups, it is important to explore innovative communication methods, such as artificial intelligence-based applications and informative labelling. Moreover, tailored messages that contrast personalised dietary recommendations with general guidelines can be effective.

Education plays a critical role in shaping healthier eating habits and guiding school-aged children, adolescents, and their communities towards more sustainable eating patterns. This thesis uses gamification in education to guide individuals toward healthy and sustainable food

choices throughout their lives. Through these gaming experiences, citizens are encouraged to explore dietary strategies that focus on moderation (achieving energy balance and reducing food waste), diversity, (replacing meat with plant-based options), whole foods, and specific environmental impacts.

ii) Change the way we process and supply food

This change focuses on the post-farming and post-finishing segments of food systems, emphasising efficient and sustainable food processing and supply. The analysis of dietary patterns presented in this thesis showed that, while food production represents the primary source of environmental impact, transport from farm to fork is also a significant contributor. Therefore, it is important to consider the origin of food and to promote diets such as the Atlantic Diet, which is based on the consumption of fresh, seasonal and locally sourced products. This approach reduces transport distances and the associated environmental impact.

Looking ahead, the implementation of efficient agri-food logistics that connect all stakeholders - citizens, retailers and producers - is essential to address vulnerabilities in the food supply chain. Relocation and logistical improvements are key to bringing food production closer to consumers. This will facilitate the flow of fresh and local produce, minimise waste, support local economies, and ensure freshness. In addition, the increasing digitalisation of food supply chains will improve control over material flows and minimise waste. This digitalisation enables flexible production, such as small batch sizes, optimises sourcing and distribution through data analytics, supports local economies and job creation, and promotes transparency in environmental impact and governance.

The analysis of dietary patterns presented in this thesis highlighted the critical issue of food waste along the production chain. To reduce this waste, several initiatives are proposed for future implementation. Innovative processing methods, such as small-scale production techniques, can promote sustainable diets, reduce packaging waste, and enable the reuse of by-products and waste through new collaborations between food system stakeholders. Another focus is circularity, which aims to improve nutrient cycling and resource efficiency in food systems by developing innovative recycling, processing and packaging methods. Other initiatives include waste reduction strategies for different stakeholders, safety measures to prevent contaminants from recycled materials from contaminating food, and improved conservation and hygiene practices. Furthermore, novel food processing methods are being explored to preserve the freshness of raw materials, reduce additives, improve health benefits, and extend shelf life through innovative preservation techniques.

Finally, although this has not been specifically addressed in this thesis, it is important to consider food design as a strategy for creating climate-neutral products that are both healthy and appealing to consumers. This involves using food technology and sensory science to improve texture, taste and nutrition, and reduce waste.

iii) Change the way we connect in food system

A key challenge is to engage citizens, households and stakeholders in changing their food systems, developing alternative systems such as community-supported agriculture, and reassessing food purchases to benefit the entire value chain. Efforts are being made to develop a sustainable labelling system that addresses the nutritional, climate, environmental, and social aspects of food. This thesis has laid the foundation by analysing recipes, diets, and foods from a comprehensive perspective. The next step is to create scientifically based eco-labels to effectively communicate these factors to consumers.

The food environment, which influences the availability, affordability, convenience and desirability of certain foods, is increasingly recognised. For example, creating healthy food environments in schools can support better nutrition and overall well-being. In some countries,

training kitchen staff is helping to promote dietary change. In addition, improving access to convenient food options can help people with little interest in cooking to adopt sustainable and healthy diets.

Rebuilding food systems requires the adoption of democratic principles in food governance. Citizens must be empowered to influence the conventional food system. This involves co-creation, consumer-driven innovation, and community action to transform the dominant food environment through cooperative actions. A growing number of projects are developing solutions in line with food democracy, focusing on short supply chains, community supported agriculture and the possibilities of digitalisation to connect producers and consumers.

iv) Change the way we govern food systems

There is an urgent need to improve the governance of food systems, that face challenges related to climate, sustainability, health and livelihoods. Governance involves social processes that address problems through interactions between different actors with conflicting interests and power struggles. Key challenges include fragmentation, slow change and the difficulty of maintaining political urgency.

Policies across sectors such as agriculture, fisheries, health, food safety and the environment, need to be integrated at global, national, regional and local levels. In the private sector, the food industry has adopted sustainability strategies involving assessment, data collection and appropriate governance patterns, but faces resistance because of the associated costs. Civil society participation in local food systems and cooperative business models promotes systematic change.

There is a need to establish regulatory frameworks for sustainable food systems, prevent food loss and waste, and implement codes of conduct for responsible practices. Transforming these systems is marked by barriers and conflicts of interest and requires research to help policymakers design effective policy tools and encourage participation. Finally, it is crucial to investigate how to better coordinate the involved actors with sustainability goals, and how governance will evolve with the inclusion of new players, such as municipalities, grassroots movements, and digital platforms.

### 14.1.3 General outcome of the thesis

This thesis is a movement call to action to reorient food systems towards healthy and affordable diets that respect planetary boundaries. Developed within an interdisciplinary framework, it provides an evidence base to shift from the current narrative of price, convenience, and taste to one focused on health, sustainability, and equity. The methodological approach used assesses the four dimensions of sustainable diets: (1) nutrition and health, (2) economic, (3) social and cultural, and (4) environmental.

The application of this multidisciplinary methodology revealed that traditional diets, particularly the Atlantic and MD, represent sustainable options that offer dual benefits for human health and the planet through local sourcing. It also identified the need to shift to plant-based diets to mitigate GHG emissions, reduce water consumption, and address diet NCDs. The adoption of national and international FBDGs, such as the IDG and the EAT-Lancet Diet, was recommended as successful sustainability models for other countries to follow.

Moreover, the thesis showed the vulnerability of dietary patterns to external shocks caused by conflict, political instability, and socio-cultural and economic factors. The COVID-19 pandemic exemplified this vulnerability, with changes in consumption patterns in Spain, leading to increased GHG emissions and water use associated with food consumption. This event underlined the need for transformation of food systems to ensure their resilience to such disruptions. A correlation was also found between household income and food choices. In

Chile, higher socio-economic status was associated with better nutritional quality but also with higher meat consumption. The influence of social networks and marketing on eating habits was also analysed, particularly in relation to the Palaeolithic diet, which is popular among athletes. This diet focuses on fats, proteins and PUFA while limiting carbohydrates to promote weight loss and muscle development. However, it raises environmental concerns due to excessive consumption of meat, fish and seafood.

Finally, the importance of educating and raising awareness among consumers, youth and children about nutrition, healthy diets, food choices as drivers of sustainability and food literacy to prevent food waste was emphasised. To achieve this, two gamified educational games for primary and secondary schools were proposed.

The findings of this thesis could serve as a further step in the development and promotion of sustainable diets in the context of the convergence of population growth, economic development, the incidence of NCDs, and environmental pressures stemming from increased globalisation and industrialisation. However, this research must be supported by an appropriate set of policies, regulations, and investments that promote sustainable food systems, as well as institutional mechanisms that facilitate intersectoral coordination and the participation of all stakeholders, including civil society and the private sector. Effective governance is needed to achieve transformational change under the framework of the 2030 Agenda for Sustainable Development.

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# ANNEX I

## LIST OF PUBLICATIONS

# A1. PUBLICATIONS USED IN THIS THESIS

**Driving commitment to sustainable food policies within the framework of American and European dietary guidelines**

**Cambeses-Franco, C.***, González-García, S., Feijoo, G., Moreira, M. T.

CRETUS Centre, Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782 Santiago de Compostela, Spain

**Journal**: Science of The Total Environment, Volume 807, Part 2, 2022, 150894. DOI: https://doi.org/10.1016/j.scitotenv.2021.150894. ISSN: 1879-1026. Amsterdam, Netherlands, Elsevier.
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**Co-benefits of the EAT-Lancet diet for environmental protection in the framework of the Spanish dietary pattern.**

**Cambeses-Franco, C.***, Feijoo, G., Moreira, M. T. , González-García, S.

CRETUS Centre, Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782 Santiago de Compostela, Spain

**Journal**: Science of The Total Environment, Volume 836, 2022, 155683. DOI: https://doi.org/10.1016/j.scitotenv.2022.155683. ISSN: 0048-9697. Amsterdam, Netherlands, Elsevier.
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**Encompassing health and nutrition with the adherence to the environmentally sustainable New Nordic Diet in Southern Europe.**

**Cambeses-Franco, C. *,** González-García, S., Feijoo, G., Moreira, M. T.

CRETUS Centre, Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782 Santiago de Compostela, Spain

**Journal**: Journal of Cleaner Production, Volume 327, 2021, 129470. DOI: https://doi.org/10.1016/j.jclepro.2021.129470. ISSN: 0959-6526. United States.
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**Traditional Atlantic Diet and its impact on health and the environment: A secondary analysis of the GALIAT Cluster Randomised clinical trial.**

**Cambeses-Franco, C.**[a], Gude, F.[b], Benítez-Estévez, A.J.[c], González-García, S.[a], Leis, R.[d], Sánchez-Castro, J.[e,f], Moreira, M.T.[a], Feijoo, G.[a], Calvo-Malvar, M[c,*].

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**Journal**: Jama Network Open, Volume 7, no 2, 2024, e2354473. DOI: 10.1001/jamanetworkopen.2023.54473.ISSN: 2574-3805. United States.
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**Author contribution:** Cristina Cambeses-Franco: Acquisition, analysis, or interpretation of data; drafting of the manuscript; critical review of the manuscript for important intellectual content; administrative, technical, or material support; supervision.
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**A clustering approach to analyse the environmental and energetic impacts of Atlantic recipes-A Galician gastronomy case study.**

**Cambeses-Franco, C.**[a,*], González-García, S.[a], Calvo-Malvar, M.[b], Benítez-Estévez, A. J.[b], Leis, R.[c], Sánchez-Castro, J.[d], Gude, F.[e], Feijoo, G.[a], Moreira, M. T.[a]

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**Journal**: Journal of Cleaner Production, Volume 383, 2023, 135360. DOI: https://doi.org/10.1016/j.jclepro.2022.135360 ISSN: 0959-6526. United States.

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**Climate Change and Water Scarcity at the Focus of Environmental Impacts Associated with the COVID-19 Crisis in Spain.**

**Cambeses-Franco, C.***, Urdaneta, H. J., Feijoo, G., Moreira, M. T., González-García, S. (2023).

CRETUS Centre, Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782 Santiago de Compostela, Spain

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**Book:** In Leal Filho, W., Dinis, M.A.P., Moggi, S., Price, E., Hope, A. (eds) SDGs in the European Region. Implementing the UN Sustainable Development Goals – Regional Perspectives, 2023. Springer, Cham. https://doi.org/10.1007/978-3-031-17461-2_102. ISBN: 978-3-031-17461-2

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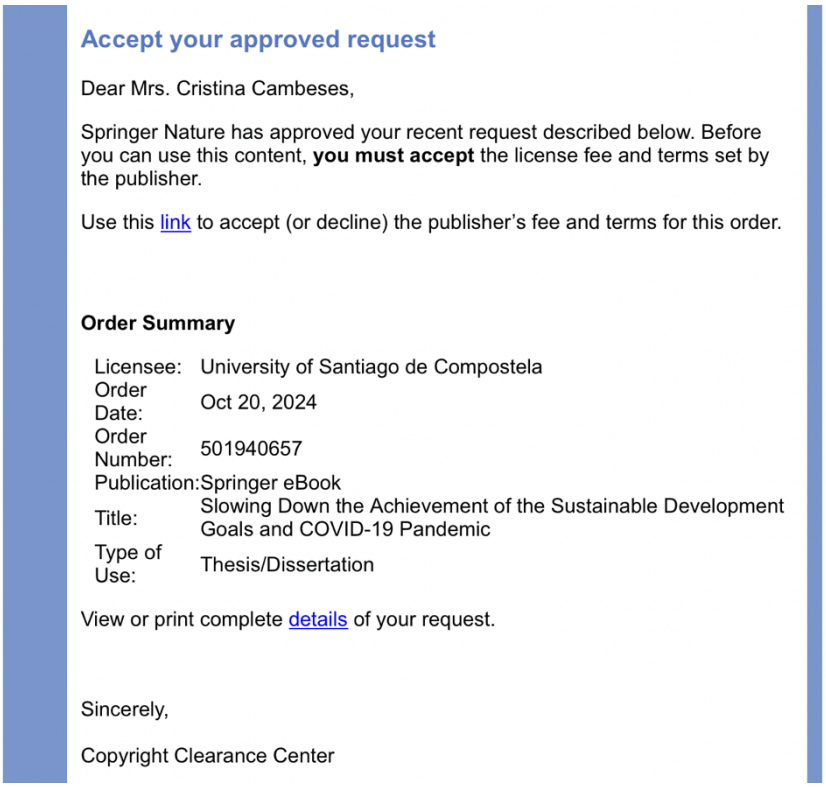

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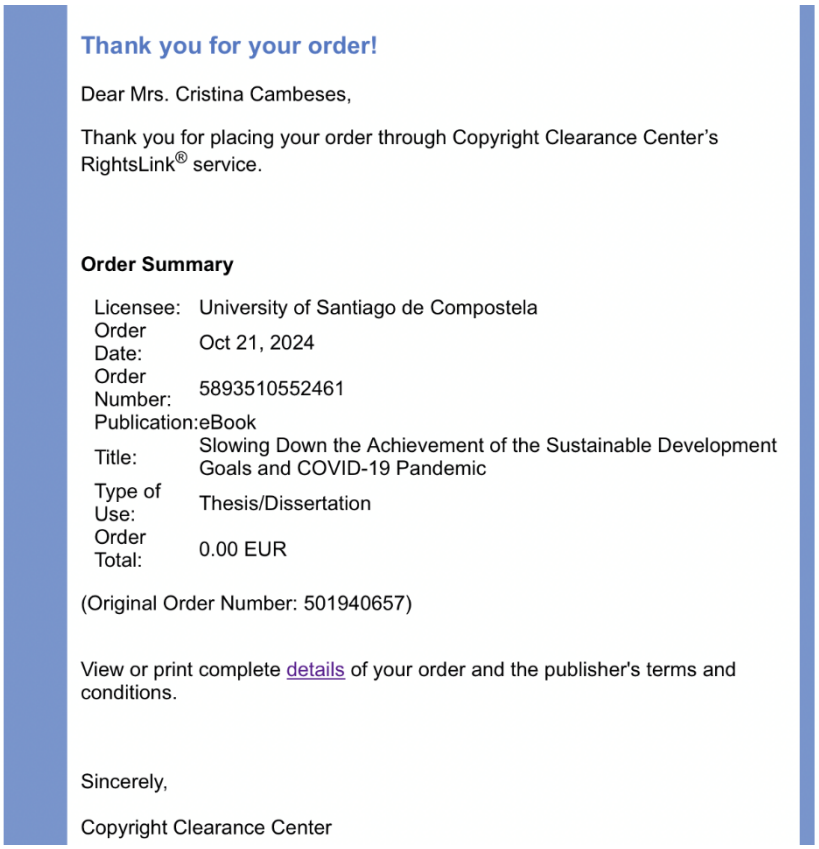

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**Cambeses-Franco, C.***, Rebolledo-Leiva, R., González-García, S., Feijoo, G., Moreira, M. T.

CRETUS Centre. Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782, Santiago de Compostela, Spain

**Journal**: Journal of Cleaner Production, Volume 379, Part 1, 2022, 134723. DOI: https://doi.org/10.1016/j.jclepro.2022.134723. ISSN: 0959-6526. United States.
**Journal quality scores:** The impact factor of this journal is 11.1 (2022 Journal Citation Reports) and a CiteScore of 18.5 (Scopus 2022). Ranking 8 out of 55 in Environmental Engineering (Q1). Ranking 22 out of 275 in Environmental Sciences (Q1, D1). Ranking 8 out of 46 in Green & Sustainable Science & Technology (Q1), based on JCR 2022.
**Author contribution:** Cristina Cambeses-Franco: Conceived and designed the experiments; performed the experiments; formal analysis; writing of the original draft; review & editing.
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CRETUS Centre. Department of Chemical Engineering, School of Engineering, Universidad de Santiago de Compostela, Rúa Lope Gómez de Marzoa s/n, 15782, Santiago de Compostela, Spain

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**Come San... Come Sostible**

Feijoo, G. [a], Moreira, M.T. [a], Arias, A. [a], **Cambeses-Franco, C. [a]**, Lorenzo-Moledo, M.M. [b], Rodríguez-Fernández, J.E. [b], Crespo-Comesaña, J.M. [b], Rico-Díaz, J. [b], García-Álvarez, J. [b]

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Global food systems face significant challenges in providing nutritious food for all due to environmental degradation, unsustainable consumption, resource scarcity, and changing socio-economic conditions. Transforming food systems is essential to promote healthy and sustainable diets that align with global nutrition goals and address non-communicable diseases, as outlined in the Sustainable Development Goals. This thesis provides a comprehensive assessment of dietary pattern sustainability, considering environmental, nutritional, and economic indicators, as well as sociocultural factors influencing food choices. This approach lays a foundation for governments to develop more effective food policies and promote environmental education in schools.