



# 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

Cristina Cambeses Franco<sup>\*</sup>, Ricardo Rebolledo-Leiva, Sara González-García, Gumersindo Feijoo, María Teresa Moreira

CRETUS. 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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## ABSTRACT

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 (NCDs) among Chilean citizens are considered two significant challenges. The 2020 Sustainable Development Goals Report shows that an increasing number of people are suffering 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 found 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<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup> and 1683–3110 L·person<sup>-1</sup>·day<sup>-1</sup> 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 the carbon (56%–59%) and water (40%–43%) footprints and the determining factor in the differences between income quintiles. Although current diets in Chile do not meet nutritional recommendations, diet quality also increased with socioeconomic status. These findings could serve as a reference to implement public policies in Chile, ensuring healthy eating and food security in the context of climate change and water scarcity.

## 1. Introduction

Chronic non-communicable diseases (NCDs) such as cardiovascular diseases, cancer and type II diabetes mellitus are the leading cause of death worldwide and an urgent public health priority (PAHO, 2020). While NCDs tend to manifest later in high-income countries, in the case of underdeveloped countries, such as Latin American countries, they affect working-age population, leading to higher health care expenditures, limited capability for work-related activity and economic instability (CDC, 2020). Addressing NCDs not only encompasses United Nations' Sustainable Development Goals (SDG) but also support global health security and universal health coverage.

In this framework, the World Health Organization (WHO) and the

Pan American Health Organization (PAHO) promote, coordinate and implement technical cooperation activities aimed at preventing of common risk factors such as tobacco or alcohol use, physical inactivity or eating unhealthy diets (Allen et al., 2021; PAHO, 2014; WHO, 2020a). One of the main scientific concerns is the complex interrelationship between diet, disease and health, as well as the lack of updated dietary intake information in Latin American countries (Kovalskys et al., 2019).

With these needs and challenges in mind, Chile recently published the “Radiography of Food in Chile”, a study commissioned by the Chilean government (under the program “Elige Vivir Sano”) and the company EGP Consultants, with the aim of analyzing household food consumption by socio-economic levels. To do this, they considered data from the “VIII Survey of Family Budgets (2017)” performed by the

<sup>\*</sup> Corresponding author.

E-mail address: [cristina.cambeses.franco@usc.es](mailto:cristina.cambeses.franco@usc.es) (C.C. Franco).

Chilean National Statistic Institute with information from above three million of households. The main aim of this survey was to identify the structure and characteristics of the final consumption expenditure of urban households (INE, 2018). Thus, this survey addressed different topics such as expenses, income, and socioeconomic aspects of the home. Moreover, this document defines quintiles determined by ordering all the data according to their observed values in the income variable, from the one with the lowest income to the one with the highest income, and then separating the statistical units into five groups of equal size. The study confirms that Chilean households have an unhealthy eating pattern with a routine intake of sugary drinks and sweets, and insufficient consumption of fruits, vegetables, fish and legumes. Regarding the consumption patterns recommended, the first quintile presented the least compliance in all food groups, while the fifth quintile obtains the highest compliance in fruits and vegetables. Moreover, households of older adults had compliance indicators higher than the average national in all food groups. Food choice criteria prioritize price, freshness, time gaps for their preparation and consumption, and taste over nutritional information and environmental issues (Government of Chile, 2021).

Considering an integrated health and environmental modelling framework creates opportunities to improve the nutritional quality and healthiness of the diet by the Chilean population, reducing the environmental consequences of food systems. The life cycle assessment (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). The main environmental issues arising from food production include climate change (agriculture and land use are the main sources of greenhouse gas emissions - GHG) and the large amounts of water consumed (Clark et al., 2019). Therefore, the carbon footprint (CF) and water footprint (WF) could be used to analyze the environmental consequences of Chilean eating habits and, where possible, the extent to which this approach or exceed the ecological limits set by the SDGs (zero net GHG emissions by mid-century and improving water quality) (United Nations, 2018). Furthermore, to address the interconnected problem described above and to integrate the two dimensions of sustainability, both environmental indicators will be complemented by the nutritional quality score developed by Van Dooren et al. (2014) based on ten metrics for the assessment of diet quality. The 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 nutrition misinformation, malnutrition and hunger (WHO, 2020b).

The integration of nutritional aspects in environmental sustainability studies focusing on complete diets represents a growing concern in the scientific community (Ridout, 2021). Different studies have evaluated the environmental and nutritional nexus of dietary patterns in some developed regions of the world, mainly in North America and European countries. For example, Cambeses-Franco et al. (2021a) evaluated the carbon and water footprints, and nutritional quality of food-based dietary guidelines from Northern and Southern Europe and North America. They found that adherence to the American Dietary Guidelines was associated with higher carbon emissions compared with recommendations from other high-income countries in Northern and Southern Europe. Particularly, the carbon footprint of the American Dietary Guidelines was more than 1.3 times higher compared with the most plant-rich European diets analyzed (e.g., Italian and Mediterranean Dietary Guidelines), due to higher quantities of dairy products and meat. In the European context, Esteve-Llorens et al. (2020b) identified seven regions with the most suitable dietary patterns from all autonomous regions in Spain, integrating nutritional, environmental, and socio-economic criteria. Moreover, Esteve-Llorens et al. (2020a) stated that Portuguese diet can be assimilated to a high meat-eaters, similar to other diets with high caloric intake such as Galician (Esteve-Llorens et al., 2019) and Swedish (Röös et al., 2015) dietary patterns.

In addition, the environmental performance of dietary recommendations was also performed. Scheelbeek et al. (2020) identified the benefits on health and environmental impacts of adherence to national dietary recommendations (the Eatwell Guide, EWG) in the UK. Kesse-Guyot et al. (2020) evaluated the 2017 updated food-based dietary guidelines in France, concluding that they might contribute to the prevention of chronic diseases and decreasing food-related environmental pressures. Concerning water implications, Harris et al. (2020) estimated the global water use of human diets, determining that European and Oceanian dietary patterns have the highest green WFs.

Accordingly, so far, environmental and nutritional assessments of dietary patterns of Latin America populations have not yet been broadly studied in the literature. Only Vázquez-Rowe et al. (2017), and Larrea-Gallegos and Vázquez-Rowe (2020) analyzed environmental impacts of Peruvian food diet profiles, including geographical and socioeconomic aspects. These authors declared a positive correlation between GHG emissions and social expenditure, as well as a low range of diet-related emissions compared with developed nations.

Thus, the aim of this study was to address the correlation between the socio-economic status of households in Chile and related nutrition (diet quality), environmental pressures (climate change and water scarcity), and economic costs derived from food consumption patterns. Moreover, a further objective was to analyze the nutrition and environmental sustainability of the average Chilean diet. It is hoped that the findings of this study will guide decision-making and public health policies in Chile toward new ways of integrating nutrition, environmental sustainability, and socio-economic development.

## 2. Materials and methods

### 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 in order to understand Chilean food consumption patterns in terms of household expenditures and to assess relevant gaps to enforce healthy eating patterns in accordance with WHO recommendations and the 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) (INE, 2018) with information from 3365700 households. This survey includes more than 137 food products, which are divided into 26 food groups according to nutritional composition, based on the frequency of expenditure declaration. The information provided by the survey includes in-home and out-of-home consumption.

### 2.2. Diet scenarios

Based on the data, a set of 6 diet scenarios were designed, as showed in Table 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 by the part of the population with the lowest per capita income and the fifth the food consumption by 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 performed by the National Institute of Statistics) was made based on the average consumption data and on the most updated data of current food consumption by household disaggregation established by the study “Radiography of food in Chile” (Government 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 1. 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., 2020). The BECDA (Spanish food

**Table 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 <sup>-1</sup> day <sup>-1</sup>						kgCO <sub>2</sub> eq·kg <sup>-1</sup>			
<b>Fruits</b>										
Oranges	21.3	14.5	18.8	16.6	26.2	36.9	0.11	Brazil	<a href="#">Knudsen et al. (2011)</a>	
Bananas	29.2	21.3	28.4	27.8	34.3	38.6	0.36	Ecuador	<a href="#">Iriarte et al. (2014)</a>	
Apples	22.0	16.1	21.3	22.4	25.2	28.0	0.06	Chile	<a href="#">Iriarte et al. (2021)</a>	
Pears	7.0	5.1	6.1	6.6	8.7	9.9	0.33	Global	<a href="#">Clune et al. (2017)</a>	
Peaches	11.5	8.7	9.9	13.2	12.8	14.0	0.75	Peru	<a href="#">Bartl et al. (2012)</a>	
Grapes	4.8	3.3	4.3	5.4	5.5	6.1	0.41	Global	<a href="#">Clune et al. (2017)</a>	
Strawberries	5.6	3.5	4.6	5.7	6.5	9.5	0.48	Peru	<a href="#">Bartl et al. (2012)</a>	
Kiwis	3.1	2.1	2.4	3.1	3.7	5.2	0.52	Global	<a href="#">Clune et al. (2017)</a>	
Melon	5.5	4.3	5.9	5.7	6.9	5.0	0.65	Brazil	<a href="#">De Figueirêdo et al. (2013)</a>	
Watermelon	2.9	2.4	3.3	2.7	3.3	2.7	0.32	Global	<a href="#">Clune et al. (2017)</a>	
Avocado	15.3	10.7	13.7	16.3	18.3	20.0	0.66	Peru	<a href="#">Bartl et al. (2012)</a>	
Lemon	10.9	6.9	10.3	11.6	12.1	17.2	0.22	Global	<a href="#">Clune et al. (2017)</a>	
<b>Total</b>	<b>139.1</b>	<b>98.8</b>	<b>128.8</b>	<b>137.2</b>	<b>163.4</b>	<b>193.0</b>				
<b>Vegetables</b>										
Lettuce	23.0	16.7	24.2	23.2	25.5	29.6	0.81	Global	<a href="#">Clune et al. (2017)</a>	
Pepper	10.9	7.3	10.1	12.0	12.8	3.1	1.00	Global	<a href="#">Clune et al. (2017)</a>	
Pumpkin	11.2	8.2	11.1	11.1	11.5	17.4	0.25	Argentina	<a href="#">Blanke and Schaefer (2012)</a>	
Tomato	31.0	23.8	32.2	32.5	33.1	37.8	0.02	Chile	<a href="#">Lam et al. (2018)</a>	
Garlic	9.1	6.7	9.3	10.1	10.5	9.7	0.55	Global	<a href="#">Clune et al. (2017)</a>	
Carrot	9.9	8.7	10.0	10.1	10.0	11.6	0.22	Global	<a href="#">Clune et al. (2017)</a>	
Onion	51.5	39.5	50.5	54.6	57.8	63.0	0.18	Global	<a href="#">Clune et al. (2017)</a>	
<b>Total</b>	<b>146.6</b>	<b>111.0</b>	<b>147.3</b>	<b>153.7</b>	<b>161.2</b>	<b>172.2</b>				
<b>Pulses</b>										
Beans	5.9	6.1	6.2	5.9	6.3	4.2	0.51	Global	<a href="#">Clune et al. (2017)</a>	
Lentils	2.3	2.0	2.6	2.0	2.2	2.7	1.03	Global	<a href="#">Clune et al. (2017)</a>	
<b>Total</b>	<b>8.1</b>	<b>8.1</b>	<b>8.9</b>	<b>7.9</b>	<b>8.5</b>	<b>7.0</b>				
<b>Starch-based products</b>										
Bread	177.0	183.0	197.3	192.3	176.7	119.0	1.15	Europe	<a href="#">(Espinoza-Orias et al., 2011; Kulak et al., 2015; Notarnicola et al., 2017)</a>	
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	<a href="#">Clune et al. (2017)</a>	
Maize	31.4	24.5	26.2	30.9	35.2	33.0	0.48	Global	<a href="#">Clune et al. (2017)</a>	
Breakfast cereals	4.8	1.9	3.4	4.7	6.4	13.3	2.64	Europe	<a href="#">Jeswani et al. (2015)</a>	
Potatoes	76.3	89.7	90.0	78.0	70.7	42.3	0.36	Global	<a href="#">Clune et al. (2017)</a>	
Pasta	20.6	14.8	18.7	20.3	24.4	25.9	1.28	Europe	<a href="#">Hess et al. (2016)</a>	
Rice	28.0	22.4	24.5	27.5	33.2	30.2	2.66	Global		
<b>Total</b>	<b>358.6</b>	<b>352.7</b>	<b>377.3</b>	<b>374.0</b>	<b>369.5</b>	<b>283.8</b>				
<b>Nuts</b>										
Walnuts	0.3	0.1	0.1	0.2	0.4	1.0	1.44	Brazil	<a href="#">De Figueirêdo et al. (2014)</a>	
Hazelnuts	0.3	0.1	0.1	0.2	0.4	1.0	0.23	Europe	<a href="#">Volpe et al. (2015)</a>	
Almonds	0.3	0.1	0.1	0.2	0.4	1.0	1.74	Global	<a href="#">Clune et al. (2017)</a>	
Dried plum	0.7	0.4	0.4	0.6	1.0	1.6	0.41	Chile	<a href="#">Bravo et al. (2017)</a>	
Raisins	0.7	0.4	0.4	0.6	1.0	1.6	0.83	Europe	<a href="#">Scarborough et al. (2014)</a>	
<b>Total</b>	<b>2.2</b>	<b>1.1</b>	<b>1.1</b>	<b>1.8</b>	<b>3.1</b>	<b>6.2</b>				
<b>Dairy products</b>										
Milk	65.3	40.7	51.7	59.6	80.8	117.4	1.52	Mexico	<a href="#">Hagemann et al. (2011)</a>	
Yogurt	25.6	15.8	22.6	24.0	31.8	42.0	1.30	Global	<a href="#">Clune et al. (2017)</a>	
Cheese	17.9	10.0	14.0	16.7	22.1	34.1	8.73	Global	<a href="#">Clune et al. (2017)</a>	
<b>Total</b>	<b>108.9</b>	<b>66.5</b>	<b>88.4</b>	<b>100.3</b>	<b>134.7</b>	<b>193.5</b>				
<b>Eggs</b>										
Eggs	17.1	14.7	17.2	18.3	18.0	17.0	3.26	Global	<a href="#">Clune et al. (2017)</a>	
<b>Meat</b>										
Beef	21.9	14.7	19.4		21.8	28.1	30.5	29.0	Uruguay	<a href="#">González et al. (2011)</a>
Pork	33.7	22.0	31.1		32.0	44.5	46.9	5.72	Global	<a href="#">Clune et al. (2017)</a>
Chicken	38.7	32.3	42.0		44.3	40.3	35.3	1.88	Brazil	<a href="#">Prudencio da Silva et al. (2014)</a>
Processed	54.5	38.1	48.1		57.0	64.4	74.9	14.55	Europe	<a href="#">Noya et al. (2017)</a>
<b>Total</b>	<b>148.8</b>	<b>107.1</b>	<b>140.7</b>		<b>155.2</b>	<b>177.4</b>	<b>187.6</b>			
<b>Fish and seafood</b>										

(continued on next page)

Table 1 (continued)

Foodstuff	Average	Q1	Q2	Q3	Q4	Q5	CF	Country	Source
	g·person <sup>-1</sup> ·day <sup>-1</sup>						kgCO <sub>2</sub> eq·kg <sup>-1</sup>		
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. (2010)
<b>Total</b>	<b>9.7</b>	<b>8.1</b>	<b>9.9</b>	<b>9.4</b>	<b>10.8</b>	<b>11.1</b>			
<b>Sugar</b>									
Sugar	20.4	18.7	23.4	22.0	19.7	16.4	0.44	Global	Werner et al. (2016)
<b>Oils and fats</b>									
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)
<b>Total</b>	<b>24.7</b>	<b>19.1</b>	<b>23.9</b>	<b>26.7</b>	<b>28.3</b>	<b>27.0</b>			
<b>Confectionery</b>									
Biscuits	10.2	6.1	8.3	9.5	13.7	16.5	1.03	UK	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	UK	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)
<b>Total</b>	<b>81.0</b>	<b>43.3</b>	<b>61.4</b>	<b>75.1</b>	<b>104.9</b>	<b>155.3</b>			
<b>Soups and broths</b>									
Soups and broths	3.7	2.5	2.8	3.2	4.3	8.2	4.00	UK	Berners-Lee et al. (2012)
<b>Fast food</b>									
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)
<b>Total</b>	<b>60.6</b>	<b>36.8</b>	<b>44.2</b>	<b>60.6</b>	<b>78.4</b>	<b>104.9</b>			
<b>Total</b>	<b>1129.5</b>	<b>888.3</b>	<b>1075.3</b>	<b>1145.5</b>	<b>1282.2</b>	<b>1383.0</b>			

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.

composition database) was used to calculate the caloric intake linked to each dietary scenario (BEDCA, 2017). The average daily per capita intake was 1130 g·person<sup>-1</sup>·day<sup>-1</sup> with an estimated energy intake of 2300 kcal·person<sup>-1</sup>·day<sup>-1</sup>. The energy supply intake for quintiles ranged from 1765 kcal·person<sup>-1</sup>·day<sup>-1</sup> (quintile 1) to 2913 kcal·person<sup>-1</sup>·day<sup>-1</sup> (quintile 5).

### 2.3. Overview of the system

The scope of this study considered a cradle-to-consumer approach. Fig. 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

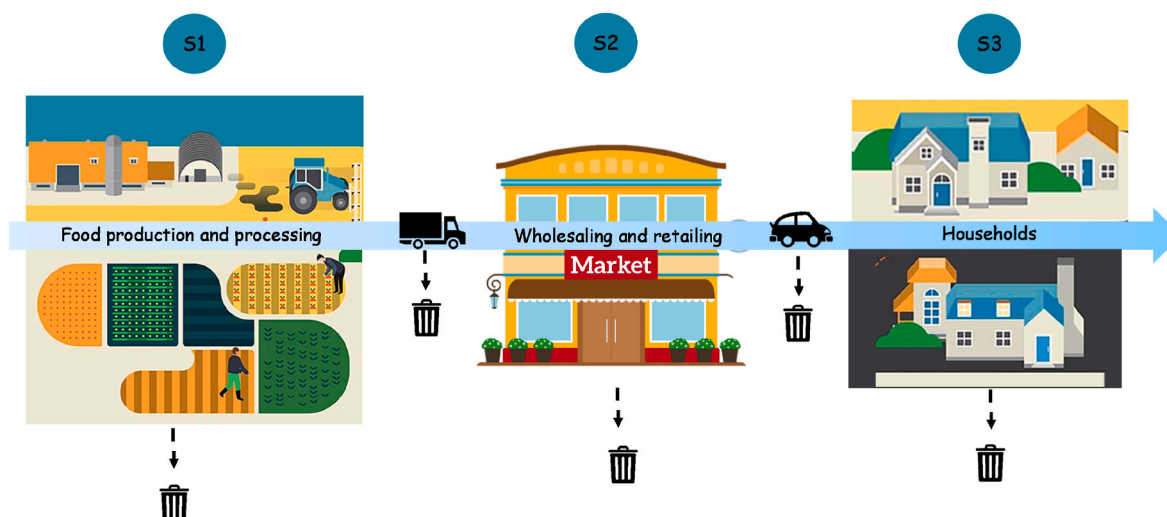


Fig. 1. System boundaries for the carbon footprint calculations.

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 analyzed. 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 taken by food products from the wholesaler and retailer to the end user or final consumer. Household food waste associated with buying more food than necessary, preparing excessively large portions of food or not reusing leftovers was considered. The limits of the system used mean that cooking techniques were not taken into account in accordance with other studies available in the literature (Esteve-Llorens et al., 2019; González-García et al., 2020).

## 2.4. Data acquisition

### 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. (2020). 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, 2019). The most recent pre-COVID data were used, as confinement could have affected global trade. Therefore, the year 2019 was chosen as the baseline.

It was assumed that food items 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., 2020). Considering that most producers do not sell directly over distances greater than 50 km in Chile, this was assumed as an average delivery distance for national 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., 2019). 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 (Werner, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, 2016) was used to compute the CO<sub>2</sub>eq emissions for lorry and transoceanic vessel. Detailed information on trade data and average distribution distances per foodstuff was compiled in **Supplementary Table SM1.1**.

### 2.4.2. 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 **Supplementary Table SM1.2**). Food waste occurring downstream related to consumer behavior was also estimated following the food waste percentages of Gustavsson et al. (2013).

## 2.5. Carbon footprint methodology

The LCA methodology allows determining the environmental impacts of the life-cycle of products or services (ISO, 2006). To perform an LCA study, it is required to apply the four stages of this approach: i) Goal and scope definition; ii) Life cycle inventory; iii) Life cycle impact assessment, and iv) Results interpretation. The results obtained from an

LCA study allow to compare different products, systems, or scenarios analysis; identify critical stages (i.e., hotspots) of the life cycle; identify potential trade-offs and opportunities for implementing improvement strategies. From this tool, the most widely used metric is the CF related to the potential impacts of climate change (Rebolledo-Leiva et al., 2021). In this way, this impact indicator was applied as a holistic tool to quantify the CF of Chilean dietary scenarios. This methodology reports the diet-related greenhouse gas emissions (or CO<sub>2</sub>eq emissions), expressing impacts relative to a functional unit. The selected functional unit that forms the foundation of all impact assessment calculation was defined as the daily food consumption per person (g.person<sup>-1</sup>.day<sup>-1</sup>). 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., 2020).

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), which took Chile 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 1**.

## 2.6. Water footprint methodology

WF plays a key role in monitoring human pressure on freshwater supply. 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 first two phases of the Water Footprint Assessment: i) setting goals and scope and ii) accounting, were undertaken to map the green WF (rainwater), blue WF (surface water and groundwater) and grey WF (water contaminated by the industry) 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. (2020). 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 (Pahlaw et al., 2015).

2.7. 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 (see Eq. (1)): 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 World Health Organization (WHO) and the World Cancer Research Fund International (WCRF) were considered as a reference (Supplementary Table SM1.4.).

$$Nutritional\ Index = \left( \frac{gveg}{200} + \frac{gfruits}{200} + \frac{gfish}{37} + \frac{gfiber}{30} + \frac{5}{gsodium} + \frac{30}{E\% total\ fat} + \frac{10}{E\% free\ sugar} + \frac{10}{E\% sat\ fat} + \frac{52}{E\% carbohydrates} + \frac{2000}{kcal\ energy} \right) \cdot \frac{100}{10} \quad (1)$$

2.8. 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 (ODEPA), INE price publications and the prices reported by the VIII Family Budget Survey 2017 (Government of Chile, 2021).

3. Results and discussion

3.1. Environmental impacts of the average Chilean diet

Concerning CO<sub>2</sub>eq emissions, the diet of an average Chilean citizen had a CF value of 3.42 kgCO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>. 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% and 2% of

total GHG emissions, respectively (see Fig. 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<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>, representing about 12% of total CF associated with food production and processing stage.

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. 2b). Emissions from beef and processed meat represented 37% and 47% of the total CF of meat, respectively (equivalent to 1.60 kg CO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>). The high emission intensities of meat in Chile were explained by the large pro-

portion of meat consumption per capita as well as for the climate impact of beef (29 kg CO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>) (González et al., 2011) and processed meat (14.55 kgCO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>) (Noya et al., 2017). The

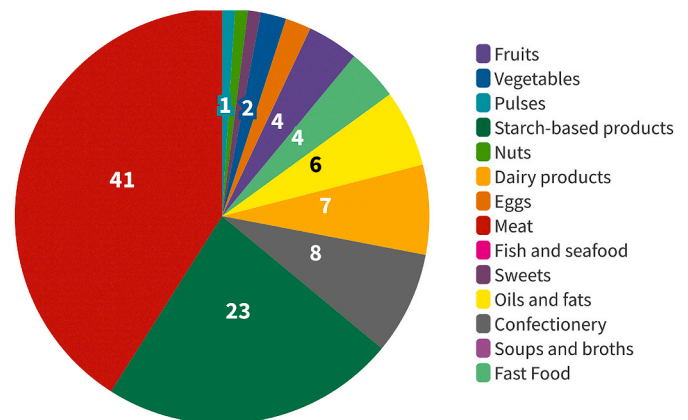


Fig. 3. Breakdown of the water footprint per food categories for the average Chilean diet.

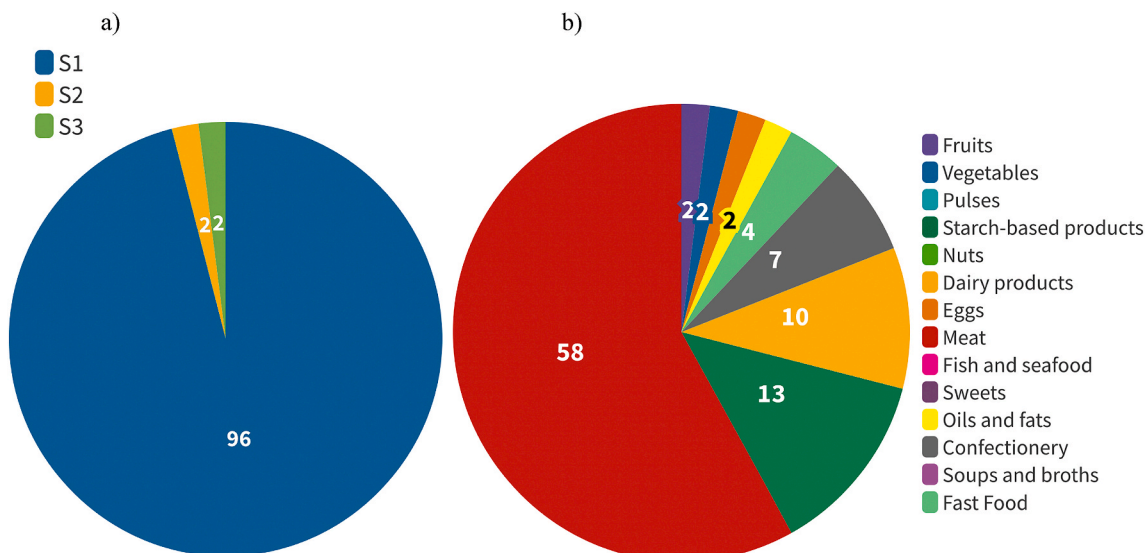


Fig. 2. Breakdown of the greenhouse gases emissions across the life cycle stages (a) and per food categories for the average Chilean diet (b).

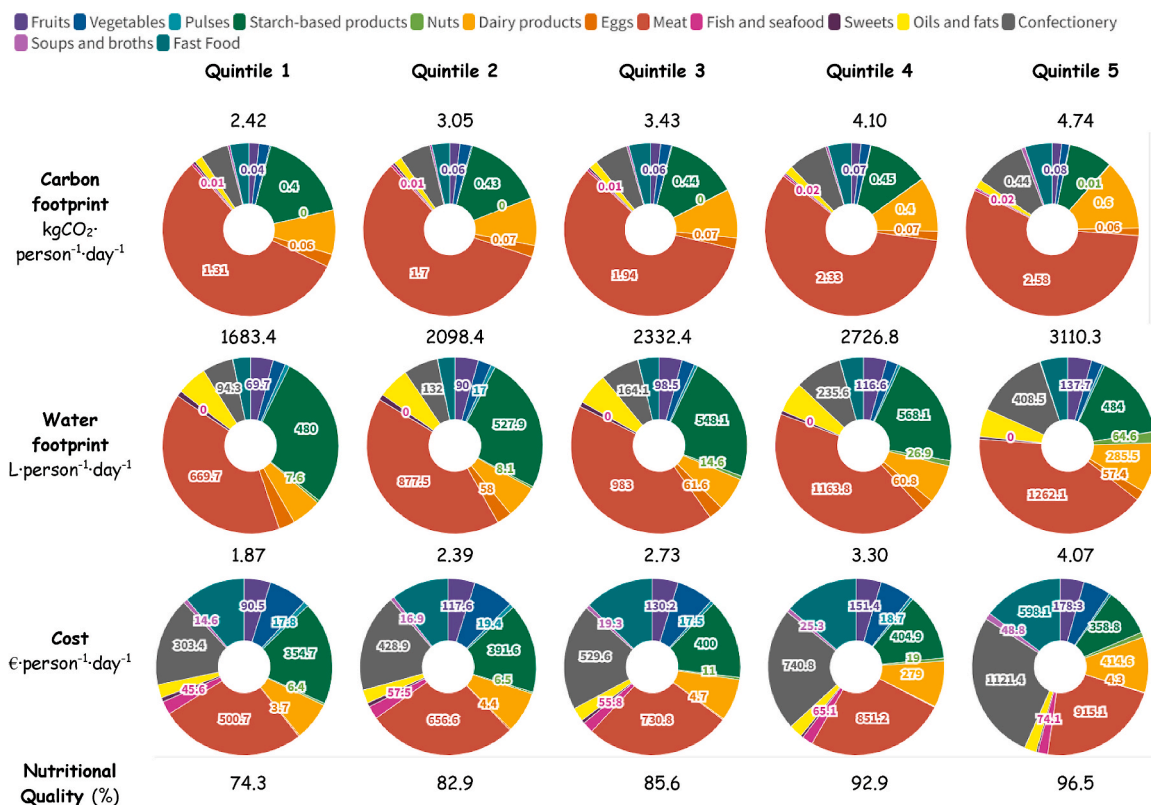


Fig. 4. Daily carbon footprint (considering only the production stage), water footprint, cost per capita and nutritional quality index based in socioeconomic quintiles in Chile.

Fig. 4. Daily carbon footprint (considering only the production stage), water footprint, cost per capita and nutritional quality index based in socioeconomic quintiles in Chile.

CFs for the food production and processing stage per foodstuff for the six dietary scenarios based on socioeconomic status could be seen in **Supplementary Table SM1.3**.

Regarding the WF, the total WF linked to the average Chilean diet represented 2310 L·person<sup>-1</sup>·day<sup>-1</sup>, with a breakdown of green water (1683 L·person<sup>-1</sup>·day<sup>-1</sup>), blue water (339 L·person<sup>-1</sup>·day<sup>-1</sup>) and grey water (265 L·person<sup>-1</sup>·day<sup>-1</sup>). The contribution of food categories to WF are depicted in Fig. 3. The main food category contributing to this environmental indicator was meat, accounting for 41% (956 L·person<sup>-1</sup>·day<sup>-1</sup>), followed by starch-based products, 23% (528 L·person<sup>-1</sup>·day<sup>-1</sup>); confectionery, 8% (187 L·person<sup>-1</sup>·day<sup>-1</sup>); dairy, 7% (157 L·person<sup>-1</sup>·day<sup>-1</sup>) and oils and fats, 6% (129 L·person<sup>-1</sup>·day<sup>-1</sup>).

### 3.2. Correlation of the environmental footprints with the household income level

As shown in Fig. 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 analyzed. In the case of CF, the difference between first and fifth quintile was 2.42 kg CO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>, with the first quintile scoring 2.32 kg CO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup> and the fifth quintile 4.74 kg CO<sub>2</sub>eq·person<sup>-1</sup>·day<sup>-1</sup>. Regarding the WF, this variation was 1427 L·person<sup>-1</sup>·day<sup>-1</sup> with 1683 L·person<sup>-1</sup>·day<sup>-1</sup> for the first quintile to 3110 L·person<sup>-1</sup>·day<sup>-1</sup> for the fifth quintile. Detailed information on total WFs per food category and income quintiles was gathered in the **Supplementary Table SM1.4**.

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. 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 analyzed 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 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.

### 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. 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 **Supplementary Table SM1.5**). 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 World Health Organization and the World Cancer Research Fund International (see **Supplementary Table SM1.4.**) in all quintiles. Thus, the first and fifth quintile ranging from 111 to 172 g·person<sup>-1</sup>·day<sup>-1</sup> for vegetables, 99–193 g·person<sup>-1</sup>·day<sup>-1</sup> for fruits and 8–11 g·person<sup>-1</sup>·day<sup>-1</sup> 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 saturated fatty acids (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 analyzed ranged from 19 g·person<sup>-1</sup>·day<sup>-1</sup> (quintile 1) to 24 g·person<sup>-1</sup>·day<sup>-1</sup> (quintile 5), containing less than the minimum amount of fiber set as a reference by the WHO daily recommendations (30 g·person<sup>-1</sup>·day<sup>-1</sup>).

Concerning cost analysis by income level, the estimated cost for the average Chilean Diet was 2.74 €·person<sup>-1</sup>·day<sup>-1</sup>. 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 €·person<sup>-1</sup>·day<sup>-1</sup> in quintile 1 to 4.07 €·person<sup>-1</sup>·day<sup>-1</sup> in quintile 5 as can be seen in Fig. 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.

### 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. (2017) 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<sub>2</sub>e·person<sup>-1</sup>·day<sup>-1</sup>, whereas in the case of quintile 5, this value was 3.8 kg CO<sub>2</sub>e·person<sup>-1</sup>·day<sup>-1</sup>, 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<sub>2</sub>·person<sup>-1</sup>·year<sup>-1</sup>) doubled the CF of the first quintile (1.98 t CO<sub>2</sub>·person<sup>-1</sup>·year<sup>-1</sup>), when they assessed the environmental impacts of households in Santiago of 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<sup>-1</sup>) and highest income groups (316 L·day<sup>-1</sup>). 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<sup>-1</sup>·day<sup>-1</sup>) with the result reported by Harris et al. (2020) for an average dietary pattern in South America (2932 L·person<sup>-1</sup>·day<sup>-1</sup>). 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).

### 3.5. Contextualizing Chilean results at global scale

Other environmental studies of dietary patterns in different regions of the world presented similar conclusions (see Table 2). In the North American region, Auclair and Burgos (2021) estimated the CF of Canadian self-selected diets, identifying 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<sub>2</sub>e of dietary patterns from individual self-selected diets in the United States from 2003 to 2018, finding that the average GHG emissions fell from 4.02 to 2.45 kg CO<sub>2</sub>-eq per day per capita (i.e., about 39%), despite mean caloric intake remaining relatively stable, because of the reduction of beef consumption.

In the Asian region, Xiong et al. (2020) investigated changes in urban diet and related CF in Beijing, China, identifying that diet-related CF was increased by 41% in the 1980–2017 period, because of the growing consumption of animal-based products. Athare et al. (2020) estimated embodied GHG emissions in Indian diets from 1.36 to 3.62 kg CO<sub>2</sub>e per consumer unit per day. In this country, 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 food products 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. Gökem ÜÇTUĞ et al. (2021) calculated the CF of omnivorous, vegetarian, and vegan

**Table 2**  
Contextualizing Chilean diet at global scale in terms of carbon footprint.

Country	CF (kg CO <sub>2</sub> -eq · person <sup>-1</sup> · day <sup>-1</sup> )	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	Gökem ÜÇTUĞ 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

diets based on traditional Turkish cuisine, observing that lower GHG emissions of vegetarian and vegan diets were mainly attributed 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 impacts of Danish, Czech Republic, French and Italian diets founding that meat products were the main contributor to GHG emissions. As well as Hyland et al. (2017) established that red meat was the highest GHG contributor in the Irish diet. Similarly, Temme et al. (2015) identified that meat, dairy and drinks contribute most to CF of daily diets in The Netherlands.

Concerning the WF, according with Harris et al. (2020) the available evidence suggest that, on average, the consumptive WF of average diets in Europe ( $3227 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ ) and Oceania ( $3226 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ ) were greatest than for the rest of the continents. For instance, Vanham et al. (2018) estimated the consumptive WF in  $2.757 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$  (92% green and 8% blue) for the United Kingdom, in  $2.929 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$  (95% green and 5% blue) for Germany and in  $3.861 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$  (93% green and 7% blue) for France. North America ( $2617 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ ) and Asian dietary patterns ( $2862 \text{ L}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ ) 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.

### 3.6. Sustainable and healthier patterns for Chilean diet

The composition of diets has a relevant influence on CF values, thus, reducing GHG emissions based on changes in food and dietary habits should be analyzed. According to Esteve Llorens et al. (2019), there is a positive relationship between the presence of animal-based products in the food patterns and high diet GHG emissions. As it has been established by several studies, moving from animal to plant products is the best alternative for reducing GHG emissions (Hoolohan et al., 2013; Westhoek et al., 2014). In this sense, González et al. (2011) reported that protein efficiency per unit of GHG is much higher for plant-based foods than for animal-based ones. Furthermore, Esteve-Llorens et al. (2020a) established that changing some component of the Portuguese diet such as meat, fats, sugar, potatoes, among other, by different alternative foodstuffs such as legumes, fruit, non-starchy vegetables, nuts, and olive oil, could increase the nutritional quality of about 67% and reducing the CF of the Portuguese diet by approximately 25%. In addition, legumes represent about 250 times lower GHG emissions per gram of protein than those of ruminant meats (Tilman and Clark, 2014). The replacement of animal-based products with fruits, vegetables, legumes, and cereals, should also be carefully evaluated. For example, among cereal grains, rice generate five times more GHG emissions than wheat in terms of gram of protein (González-García et al., 2018). Finally, as meat has a relevant role in the Chilean diet and could be difficult to be replaced with plant-based products in a short time, the reduction of red meat intake by white meat (chicken and pork) could be an easier alternative to obtain lower impacts (Esteve Llorens et al., 2019).

### 3.7. Sensitivity analysis

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 highly diverse range of drink products difficult the calculation of a detailed CF for the Chilean dietary pattern considering sugar-sweetened and non-sweetened beverages. Moreover, excluding beverages facilitated the comparison with other previous analysis of environmental sustainability of dietary patterns (González-García et al., 2020; Kovacs et al., 2021). However, taking into account that the findings of the "Radiography of Food in Chile" (Government of Chile, 2021) revealed a high consumption of sugary drinks among Chilean citizens, it was calculated both

environmental indicators (CF and WF) considering general values for sugar-sweetened beverages, coffee, tea, and infusions. The diet of an average Chilean would have a CF (including drinks) of  $4.27 \text{ kgCO}_2\cdot\text{person}^{-1}\cdot\text{day}^{-1}$  (an increase of about 25%) in comparison with the value of CF obtained excluding drinks ( $3.42 \text{ kgCO}_2\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ ). On the other hand, the total WF linked to the average Chilean diet (including drinks) would be more than double that calculated without drinks.

### 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 Supplementary Table SM1.6.)

The uncertainty analysis establishes that the CF of the average Chilean diet was  $3.42 \pm 0.77 \text{ kgCO}_2\text{eq}\cdot\text{person}^{-1}\cdot\text{day}^{-1}$ . The uncertainty interval is too wide since CF values have been obtained from the life cycle assessment 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 carbon footprint analysis. Notwithstanding the uncertainty, the CF results guide national programmers and policy makers to develop future food-based dietary 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 Supplementary Table SM1.1.)

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).

## 4. Conclusions

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 carbon and water footprint in the average Chilean diet. Furthermore, impact footprints obtained for Chilean diet patterns were in line with the evidence provided by other studies in the literature and presented similar aspects like the key 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 prioritizing 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.

### CRedit authorship contribution statement

**Cristina Cambeses Franco:** Conceived and designed the experiments, Performed the experiments, Formal analysis, Writing of the original draft, Review & Editing. **Ricardo Rebolledo-Leiva:** Conceived and designed the experiments, Formal analysis, Review & Editing. **Sara González-García:** Conceived and designed the experiments, Contributed materials/analysis tools, Writing – review & editing. **Gumersindo Feijoo:** Contributed materials/analysis tools, Review & Editing. **María Teresa Moreira:** Contributed materials/analysis tools, Writing – review & editing.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

All data are provided in the manuscript

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### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2022.134723>.

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