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Environmental assessment of viticulture waste valorisation through composting as a biofertilisation strategy for cereal and fruit crops

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Abstract

Composting is a solid waste management alternative that avoids the emission of methane associated with its disposal in landfill and reduces or eliminates the need for chemical fertilisers if compost is applied. The main objective of this study was to analyse the environmental burdens of composting as a way to achieve a more circular valorisation of wine waste. To do so, with the purpose of identifying optimal operational conditions and determining the “hotspots” of the process, the life cycle assessment (LCA) methodology was used. The consumption of diesel fuel in machinery was determined to be the main critical point in the environmental effects of the system, followed by the transport and distribution of the compost. After the application of compost instead of mineral fertilisers, corn, tomato and strawberry crops would have a better environmental performance in most impact categories. In this sense, a maximum improvement of 65% in terrestrial ecotoxicity is achieved in strawberry cultivation. In light of the results obtained, it is demonstrated that composting is a suitable way of organic waste valorisation according to Circular Economy principles.

Keywords

Life Cycle Assessment; Viticulture waste; Composting; Valorisation; Mineral fertilisers

1. Introduction

The concept of the Circular Economy is based on the valorisation of waste flows, while ensuring efficient consumption of energy and resources. This approach is considered the new growth paradigm and must reconcile the preservation of resources and the environment, foster the dynamics of economic prosperity and ensure social welfare (Murray et al., 2017). The food industry, which is responsible for high consumption of natural resources and emissions to soil, air and water (Garcia-Herrero et al., 2018), has emerged as an important sector in the application of the principles of the circular economy. Moreover, when almost one third of the world food production is wasted along the supply chain (Principato et al., 2019). Food waste management ranks high in social agendas, as evidenced by the strategies defined in Agenda 2030 and the Sustainable Development Goals (SDGs), in particular SDG 12. SDG 12 is entitled “Ensure sustainable consumption and production patterns” and aims to take urgent action to improve resource efficiency, reduce waste and mainstream sustainability practice in all sectors of the economy (United Nations, 2015). Beyond food waste, by-products of food processing represent a large amount of wasted resources that could be valued for the recovery of value-added products (Manara et al., 2015). Examples of waste valorisation for chestnut leaves, burs and shells (Vella et al., 2019), raspberry pomace (Saad et al., 2019), pumpkin seeds and peels (Lalnunthari et al., 2019) or cocoa by-products (Vásquez et al., 2019) have been reported.

This paper takes as a reference the Brazilian wine sector. Brazil is one of the largest wine producers in the world, with a total production of 1.65 million hL and 1.1 million tonnes of grapes (OIV, 2018). The winemaking process is characterized by a sequence of numerous activities, from the cultivation and harvesting of the grapes, the fermentation and maturation of the wine in the cellar, to the management of waste (Escribano-Viana et al., 2018). The valorization of the by-products of winemaking has involved numerous approaches, focusing on each type of waste. Kopsahelis et al. (2018) analysed the recovery of phenolic extracts, rich in antioxidants, and tartrate salt from wine lees. Gullón et al. (2017) evaluated the antioxidant activity of extracts from the autohydrolysis liquors of vine shoots. Nair and Taherzadeh (2016) studied the possibility of using vinasse as a fermentation substrate for the production of enzymes, organic acids, ethanol and protein-rich fungal biomass. Many studies whose main objective is to obtain polyphenols from grape marc can be found in the literature (Brezoiu et al., 2019; Goula et al., 2016; Valls et al., 2017). Previous studies have demonstrated the potential of grape seeds as a source of high quality unsaturated fatty acids (Fiori et al., 2014), by means of full-scale supercritical CO_2 extraction (Duba and Fiori, 2019). A less complex alternative is composting, which allows the recovery of organic matter and nutrients that are added as a fertiliser or soil amendment, replacing mineral fertilisers in agricultural activities (Oldfield et al., 2016). In contrast to the environmental benefits derived from replacing peat or mineral fertilisers, there are environmental impacts related to composting that need to be quantified. Most of them are related to potential GHG emissions (Andersen et al., 2010). Although CO_2 emitted during composting is usually accounted for as neutral (IPCC, 2006), ammonia (NH_3) emissions are also considerable.

The main objective of this study was to determine the environmental impacts and benefits of the valorisation of wine growing waste through composting on an industrial scale from a life cycle perspective, identifying the critical points of the system. An evaluation of the use of compost as a bio-fertilizer for cereal, vegetable and fruit crops was also carried out to determine the environmental consequences of fertiliser substitution from a circular perspective.

2. Materials and methods

Life Cycle Assessment (LCA) is a methodology used to analyse the potential environmental impacts related to the entire life cycle of a system, product or activity. LCA consists of a systematic set of procedures included in the ISO 14040 and 14044 standards to convert inputs and outputs of the system into its related environmental impacts. According to these standards, LCA comprises four phases: (i) Goal and scope definition, (ii) Life cycle inventory, (iii) Life cycle impact assessment and (iv) Interpretation of results.

2.1. Goal and scope definition

The function of the system under study was the valorisation of waste from the wine industry to produce a high-quality compost with marketable value. The production scheme was assessed from a cradle-to-grave perspective since all activities involved from the extraction of raw materials up to the final use of compost were considered. At this end-of-life stage, the compost was applied to agricultural land and the direct emissions from the application of the compost were taken into account. It is also necessary to go beyond this classical description of the system boundaries and to emphasize that in this system a waste was converted into resource.

According to ISO standards, the Functional Unit (FU) is the calculation basis to which all study results must refer. Bearing in mind that the main objective of the composting system is to achieve full waste valorisation, the selection of a feedstock-based FU ensures consistency throughout the study. One tonne of feedstock mixture fed to the composting facilities was chosen as FU.

2.2. Description of the system under study

The composting system consisted of different processes that were aggregated into three main subsystems: composting (SS1), packaging and distribution (SS2) and compost use (SS3). **Figure 1** shows the sub-systems and process steps included within the system boundaries. The feedstock flow is composed of grape pomace (82.6%), organic waste from aviaries (13.1%) and ash from eucalyptus and acacia wood (4.3%). This composition is of great interest for the composting system, since the organic waste of aviaries provides a large amount of organic matter and the ash provides microelements such as calcium, potassium, magnesium, phosphorous, etc. The production processes of the feedstock were excluded from the system boundaries since the environmental impacts were entirely assigned to the products.

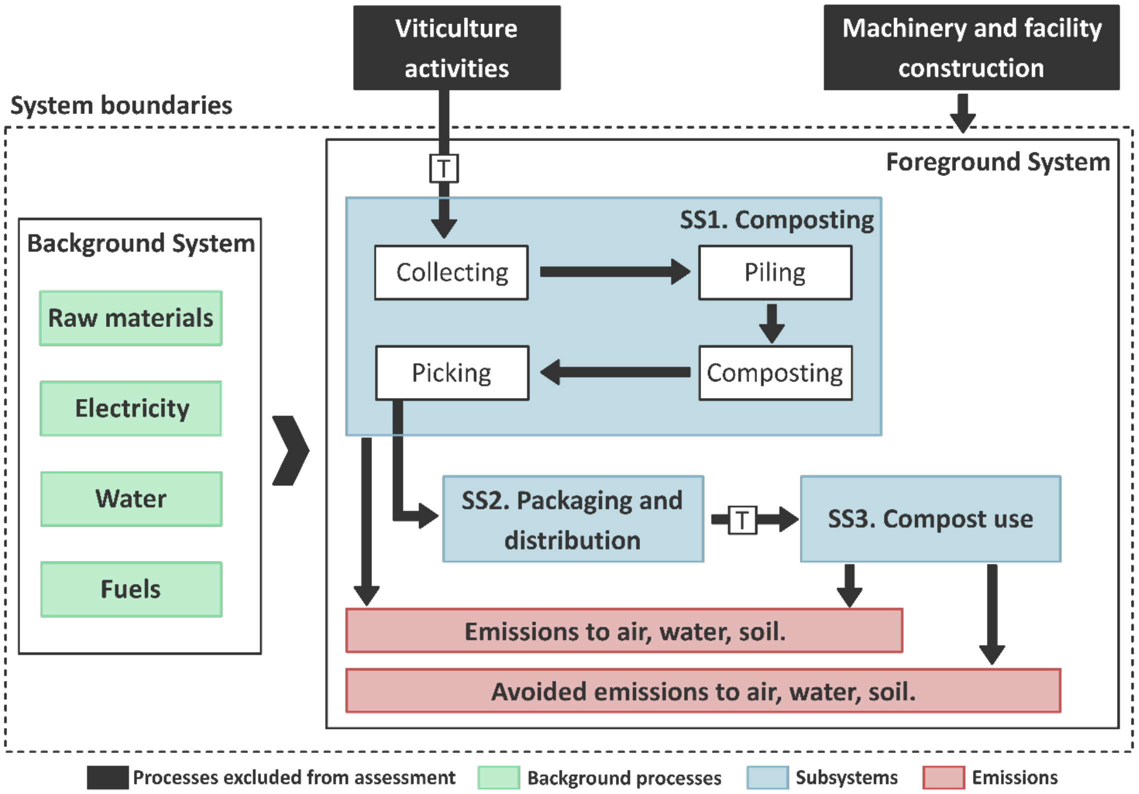

Figure 1. Flowchart and system boundaries of the composting system under study. Legend: T: Transport

The composting plant evaluated is located in the state of Rio Grande do Sul. This region of southern Brazil is characterized by its agricultural nature and the most important crops are soy, wheat, corn, rice and grapes. In fact, grape production in this region accounted for 90% of the total Brazilian production.

The composting process is similar in some general points to the windrow system, and in addition, it requires low material and energy consumption. The feedstock is collected within a maximum radius of 6 km and transported by truck. When this feedstock is received at the composting plant it is placed on electric conveyor belts that take it to the composting area. Once in the composting area, the feedstock is mechanically stacked in piles, which are continuously turned over to avoid anaerobic conditions and a significant amount of water is added (almost 300 L per tonne feedstock). At the same time, the liquid leachate is collected and treated in another parallel line not considered in this study, which generates other value-added products. During the composting process there is no consumption of materials, apart from diesel for machinery and water.

Additionally, direct emissions produced during the composting process have been estimated. For the estimation of the emission factors, a literature review of other studies on composting food or agricultural waste has been carried out. Specifically, five major gases were identified as emissions from composting: Carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), dinitrogen monoxide (N_2O) and ammonia (NH_3).

The description of the plant operation was based on the information reported by Ferrari et al. (2019). Once the first phases of the composting process are completed, the compost is taken to the maturation zone where it can be stored for up to 3 years When the maturation time is over, the compost piles are collected and taken to the packaging and distribution area. The compost is packed in individual high-density polyethylene (HDPE) bags and several bags are placed together in wooden pallets and rolled up with packaging film. This subsystem considers the transport from the composting plant to the sales points, which are located within a maximum radius of 100 km from the composting plant. The use of machinery for the application of fertiliser and the consumption of fuel within the boundaries of Subsystem 3 were considered. Direct emissions from the application of soil fertilizer as an organic amendment were estimated. In particular, emissions were calculated in terms of CO_2, NH_3 and N_2O to air, nitrate (NO_3^-) and phosphate (PO_4^{3-}) to water.

2.3. Data acquisition and life cycle inventory

The accuracy of the data used is a key aspect of the reliability of any LCA study. A consistent environmental assessment requires the collection of high-quality data that allows the construction of a credible life cycle inventory. This should be done using primary data or, failing that, secondary data from reliable scientific databases or publications. In the present study, the inventory data of the foreground systems, such as the electricity requirements of all equipment (mainly conveyors), the consumption of diesel, tap water and other materials, have been taken directly from a company dedicated to the composting of wine growing waste. This company is the owner and operates the composting plant, so the data used are primary. These data are referred to the year 2018. The background inventories have been obtained from the Ecoinvent 3.5 database, considering the primary data collected in the questionnaire.

All electricity requirements for Subsystem 1 have been directly estimated considering the power of the equipment as well as the duration of its use. Emissions due to the composting processes were calculated using emission factors from a literature review. However, CO_2 emissions were not included in the global warming potential taking into account the recommendation of the Intergovernmental Panel on Climate Change to consider CO_2 emissions from organic matter degradation as biogenic CO_2 (IPCC, 2006). This assumption in in line with other similar studies (Saer et al., 2013; Wu et al., 2019). Infrastructure construction has not been considered in this study, as the environmental impacts of construction, installation and decommissioning of the industrial facilities have been considered negligible over their lifetime (Jeswani et al., 2015). The literature review conducted is summarized in Table S.1 of the Supplementary Material. Given the high variability of the different emission factors reported in the literature, it was considered necessary to perform a sensitivity analysis, in which the minimum and maximum emission factors were compared to the average. Table S.2 of the Supplementary Material overviews these emission factors obtained from the literature review. It is important to note that the emission factors related to slurry composting have not been considered in order to obtain reliable emission factors to the case of wine waste.

As far as the consumption of materials in Subsystem 2 is concerned, the corresponding inventories were obtained from Ecoinvent, considering the primary consumption data. It was determined that 20% of the materials consumed (plastic and wood) during packaging were discarded. The Brazilian profile of plastic and organic waste management was followed to determine the end-of-life treatment of plastic and wood waste.

Compost application to agricultural land has been determined using an Ecoinvent process of organic fertiliser application (Nemecek and Käggi, 2007), which includes the production and consumption of diesel and the use of agricultural machinery. Direct emissions of CO_2, NH_3, N_2O, NO_3^- and PO_4^{3-} produced after the application of compost have also been quantified. The estimation of direct emissions was estimated considering an average content of 45% carbon, 2.4% nitrogen, 1.6% phosphorus and 3% potassium in compost (Ferrari et al., 2019). An average content of 45% carbon, 2.4% nitrogen, 1.6% phosphorus and 3% potassium in compost have been considered. The emission factors used to calculate the direct emissions produced by the application of the compost are shown in Table S.3 of the Supplementary Material.

The application of compost to the soil produces some environmental benefits, such as the addition of organic matter and natural fertilizers, which reduce the need for mineral fertilizers. The environmental impacts of applying compost to the soil and the resulting gaseous emissions were calculated. However, the environmental benefits produced by the substitution of other types of mineral or chemical fertilizers were not included in the baseline scenario but in **Section 3.2.** In order to estimate the total amount of NPK fertiliser that can be avoided, the total content of nitrogen, phosphorus and potassium in the compost was taken into account, along with the limiting nutrient in each case (maize, tomato and strawberry). A summary of the main inventory data for the composting of agricultural waste to produce high quality compost is shown in **Table 1**.

Table 1. Summary of main relevant inventory data for the agricultural waste composting process under assessment per FU (1 tonne feedstock)

Inputs from Technosphere		**Outputs to Environment**	
Materials	**L**	**Air emissions from composting**	**kg**
Water	287	CO	0.11
	kg	CH_4	1.37
Packaging film	0.29	N_2O	0.27
HDPE	2.87	NH_3	0.60
Wood pallet	6.89	**Air emissions from compost application**	**kg**
Diesel	2.55	CO_2	196.66
Energy	**kWh**	NH_3	0.02
Electricity	2.64	N_2O	0.17
Transport	**t·km**	**Water emissions from compost application**	**kg**
Feedstock supply	6	$NO_{3(GW)}$	30.6
Compost distribution	**58.71**	$NO_{3(SW)}$	15.8
Outputs to Technosphere		PO_4^{3-}	0.096
Waste	**kg**		
Packaging film	0.048		
HDPE	0.48		
Wood pallet	1.15		

2.4. Life cycle impact assessment: methodology

The software SimaPro 9.0 (PRé Consultants, 2017) was used for the computational implementation of the inventories. The impact method considered to express the environmental impacts was ReCiPe 2016 v1.1. in a hierarchist perspective with the following impact categories at midpoint level (Huijbregts et al., 2016): Global Warming (GW), Ozone Formation (OF), Terrestrial Acidification (TA), Freshwater Eutrophication (FE), Terrestrial Ecotoxicity (TET), Freshwater Ecotoxicity (FET), Human Toxicity (HT) and Mineral Resource Scarcity (MRS).

3. Results and discussion

The relative distribution per subsystem of the environmental impacts of wine waste composting are presented in **Figure 2**. It is important to note that the background activities involved in the production of the different inputs (e.g. water, fossil fuels, electricity...) have been computed. If the complete set of environmental results is analysed, SS1 can be designated as the most burdensome subsystem, except for the TET and GW categories. The impacts of SS1 are especially relevant in the TA (93%) and MRS (75%) categories, due to ammonia emissions and steel used in machine construction. Regarding the packaging and distribution subsystem (SS2), it presents a relevant environmental impact on TET category, due to transport-related heavy metals emissions. In the other impact categories, this subsystem only presents a significant contribution of around 47% in both FE and FET categories. With respect to SS3, the environmental burdens are concentrated in GW, reaching a relative contribution of 64% due to gaseous emissions associated with the compost application (mainly CO_2 and N_2O). It also presented a considerably uniform distribution of environmental impacts in the other categories, with contributions of around 10% in the OF and MRS categories.

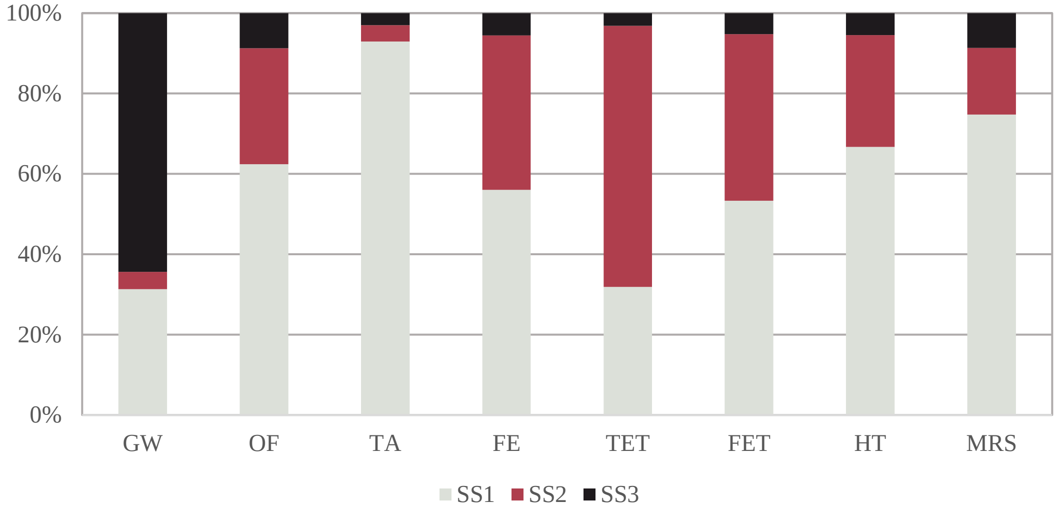

Figure 2. Distribution of environmental impacts per subsystems involved in the valorisation process

In order to highlight the process with the greatest environmental impact in the life cycle of the system, the individual contributions were broken down in **Figure 3**. The item “Compost production” encompasses direct gaseous emissions produced during the decomposition of organic matter and compost formation. While the item “Compost application” includes gaseous emissions produced during compost application on agricultural land.

Diesel production and combustion emerged as the largest contributor in five impact categories, with 82% of the total contribution in MRS and 59% in HT and OF. It is important to note that the application of compost was modelled using the Ecoinvent process "Loading and spreading of solid manure", which considers diesel production and consumption. The inclusion of this element in the "Diesel" category may explain the high contribution of the "Diesel" element in the MRS category. With regards to the high contribution of the element "Diesel" in the categories HT and OF, it can be explained by the direct combustion emissions, either heavy metals (HT) or nitrogen oxides (OF).

According to the results shown in **Figure 3**, diesel consumption was identified as the largest contributor to environmental burdens, although there are three categories with different behaviour. The most important are GW, TA and TET. In GW category, more than 90% of the impact derives from direct gaseous emissions, either in the production or the application of compost. In the TA category, mainly due to ammonia emissions, which have a very high characterisation factor (1.96 kg SO_2eq/kg), most of the impact is from direct emissions during compost production (86%). Also noteworthy is the high contribution of transport in the TET category, mainly due to the use of fossil fuels. Diesel consumption was identified as an environmental hotspot, so special attention and improvements must be made in this activity.

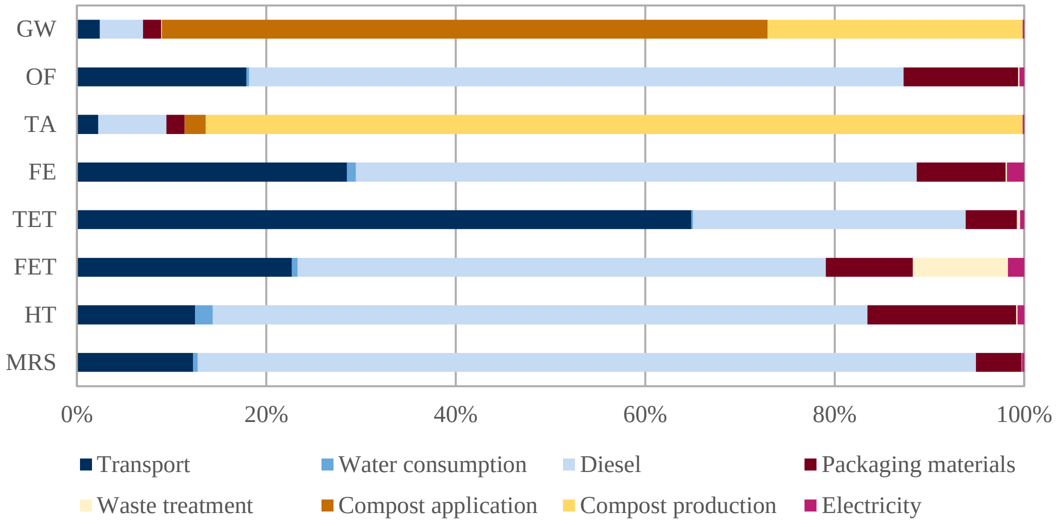

Figure 3. Relative contributions (in %) by component in the environmental profile of the valorisation process

The consumption of packaging materials showed a uniform distribution of environmental loads in all categories, with contributions always below 15% and an average impact of 7.6%. The consumption of electricity and water did not contribute significantly to the total environmental impacts of the system. Electricity consumption caused contributions in all impact categories, ranging from 0.1% to 1.7%. Water consumption showed slightly lower values, ranging from 0.1% to 1.8%. Waste treatment showed negligible contributions always below 0.4% in all impact categories, except for FET, where a maximum contribution of around 10% was achieved. This fact is explained by the fact that the Ecoinvent database considers that 88% of plastic waste in Brazil is taken to landfill, where emissions of leachates rich in heavy metals occur. In general, the contributions of these elements to the environmental profile were not significant.

It is difficult to make a reliable comparison of waste management alternatives through LCA, which is why the results tend to be so specific. This is mainly due to the fact that Functional Units are often not equivalent, in addition to considerations in system boundaries, impact categories, technologies evaluated or waste composition (Thyberg and Tonjes, 2017). The comparison of results must always be done respecting the different modelling assumptions and geographical settings, among other differences.

The study evaluated in Keng et al. (2020) presented system boundaries similar to the current one (collection, preparation, composting, packaging and final waste treatment). However, the results show that the carbon footprint was 3 times smaller (around 130 kg CO_2 eq/tonne) than that obtained in the present study (472.6 kg CO_2 eq/tonne). This suggests that Keng et al. (2020) did not consider the direct gaseous emissions produced by the composting process, nor the application stage. These two stages have been shown to be the main critical points for GHG emissions.

Some research studies sought to harmonize methods for quantifying flows and stocks of materials such as Material Flow Analysis (MFA) and LCA (Padeyanda et al., 2016). This study aimed to evaluate the environmental impacts of food waste management practices in Korea. To this end, the study evaluated different waste treatment facilities that processed 26,103 tonnes/year, of which 906 tonnes were converted into compost. The treated waste is similar to the 1,254.5 tonnes treated at the facilities evaluated in this study in 2018. Again, comparison problems arise from the use of different impact categories from the CML 2002 impact method. For the GW category, 130.4 kg of CO_2 per tonnes of waste were reported. This value is similar to that obtained by Keng et al. (2020). However, this study does not clarify whether direct emissions produced during composting were quantified. Regarding TA category, results around 0.3 kg SO_2 eq per tonne were reported, again influenced by the lack of consideration of direct emissions during the composting stage.

A similar limitation was found when comparing the results obtained by Mondello et al. (2017), which addressed different food waste disposal/treatment scenarios in Italy. Despite the compost yield that they reported was found to be lower: (21% vs. 59%), the results in terms of carbon footprint and acidification potential were better: 100 kg CO_2 eq. per tonne of waste and 0.5 kg SO_2 eq. per tonne, respectively.

If the case study analysed in the present document were to equalize the system boundaries (without considering fertilizer application and direct emissions), the results would improve on all those found in the literature (around 41 kg CO_2 eq and 0.1 kg SO_2 eq per tonne of waste). These results can be explained by the large yield of compost (59%), in addition to the fact that no chemicals or materials are used in the production of compost. Finally, other studies were found that could not be directly compared due to major differences in functional unit, assumptions or process modelling (Catalán et al., 2017; Oliveira et al., 2017; Saer et al., 2013)."

3.1. Sensitivity analysis

In order to investigate the effect of some key parameters and assumptions, as well as to check the robustness of the methodology, a sensitivity analysis was carried out. The following aspects were considered:

- The consideration of different emission factors for the formation of gaseous emissions during compost production. For this analysis the minimum (min EF), maximum (max EF) and maximum* (max EF*) emission factors from **Table S.2** were considered.
- A variation of ±25% in electricity consumption (EC) during the overall process was taken into account. Although it does not play a critical role in the system, electricity is an element that can be controlled by replacing inefficient machinery or by generating energy from renewable sources.
- An identical variation (±25%) in diesel consumption (DC) was considered, excluding transport processes. Diesel was considered due to the fact that is one of the main critical points of the environmental profile of the system.

The results of the sensitivity analysis are reported in **Table 2**. Six of the eight categories remained constant using the average, minimum and maximum emission factors. In the case of GW category, there were significant changes between the different emission factors. In the base scenario, GHG emissions were 472.5 kg CO_2 eq per tonne of feedstock, with 64.4% of the impact from compost application and 31.3% from compost production. In the Low EF scenario, emissions from compost production were responsible for only 3.9%. With respect to the different high-emission scenarios, the contribution of this element varies considerably between 82% in the max EF to 58.6% and in the max EF* scenario. The high percentage of the max EF scenario can be explained by the emission factor of 4.6 kg N_2O per tonne of feedstock. This greenhouse gas has a very high global warming potential (296 kg CO_2 eq/kg) and is the cause of the high environmental impact (1920 kg CO_2 eq per tonne feedstock) in this scenario. However, it seems more consistent with the main objective of the study to exclude emission factors that consider manure composting. In the max EF* scenario, 833.7 kg CO_2 eq emissions per tonne feedstock are obtained. The same analysis can be carried out with respect to the TA category, since 87.4% of the total environmental impact is produced by emissions from composting. Since the min EF scenario reduces ammonia emissions by 90% with respect to the base scenario, the impact on this category is drastically reduced to 79.7%. In the max EF and max EF* scenarios, the opposite effect occurs, increasing the impact of this category by 102%, from 1.3 to 2.7 kg SO_2 eq per tonne of feedstock.

Table 2. Results of the sensitivity analysis: Impact variation (in %) respect to the values reported in "Base scenario" considering the minimum, maximum and maximum* emission factors and 25% variation in electricity and diesel consumption.

Impact category	Unit	Base scenario	Min EF	Max EF	Max EF*	EC ±25%	DC ±25%
GW	kg CO_2 eq	472.59	-24.3%	310.2%	77.4%	±0.04%	±1.0%
OF	kg NO_X eq	0.2	0.0%	0.0%	0.0%	±0.1%	±16.3%
TA	kg SO_2 eq	1.1	-79.7%	102.0%	102.0%	±0.04%	±1.6%
FE	kg P eq	0.01	0.0%	0.0%	0.0%	±0.6%	±17.0%
TET	kg 1,4-DCB	219.9	0.0%	0.0%	0.0%	±0.1%	±6.6%
FET	kg 1,4-DCB	0.9	0.0%	0.0%	0.0%	±0.5%	±14.1%
HT	kg 1,4-DCB	2.1	0.0%	0.0%	0.0%	±0.2%	±17.7%
MRS	kg Cu eq	0.2	0.0%	0.0%	0.0%	±0.06%	±19.1%

The change in electricity consumption in SS1 and SS2 implies a maximum impact variation ranging from -0.58% to +0.58% in the FE category, which is the impact category most affected by electricity and shows the greatest impact variation. In contrast, GW and TA, mainly affected by on-site emissions, are the impact categories least affected by variations in electricity consumption. This change implies a variation in environmental impact of 0.4% in both categories. According to the results, it can be affirmed that electricity consumption is not a key element in the environmental profile of the valorisation process.

The variation in diesel consumption has a more pronounced effect on most impact categories, except those in which the main contributors are on-site emissions (GW and TA). The total variation in environmental impact ranged from 1% in GW to 19.1% in MRS. Despite the fact that on-site emissions are the main contributor in the GW and TA categories, diesel production and consumption stand out as the most harmful element when all impact categories are considered. It seems clear that if improvement actions were implemented that would reduce diesel consumption, the environmental profile of the recovery process would improve considerably.

3.2. Effect of compost application on different crops

Compost is widely recognized as an organic amendment that has a beneficial impact on the physical, chemical and biological properties of the soil (Głąb et al., 2020). It has been shown that compost improves soil structure and causes a decrease in surface runoff and erosion (Głąb et al., 2020). Other benefits derived from compost use as a soil amendment are, among others, an increase in soil porosity, water retention and hydraulic conductivity (Ramos, 2017) and a higher volume of residual and storage pores (Głąb, 2014). It is also important to note the capacity of compost to be used as a substitute for mineral fertilisers. In fact, in this section, the addition of compost was evaluated as the only fertiliser in the agricultural production of maize (Noya et al., 2015), tomato (Ingrao et al., 2019) and strawberry (Valiante et al., 2019), examples of cereals, vegetables and fruits. Taking into account the different stages of cultivation, the modification of the scenarios was considered by replacing mineral fertilisers with compost and quantifying the direct emissions of CO_2, NH_3, N_2O, NO_3^- and PO_4^{3-} produced after the application of compost, following the guidelines of **Section 2.3**. **Figure 4** shows the comparative environmental performance between the crops considered as reference and those in which compost is used as the only fertiliser.

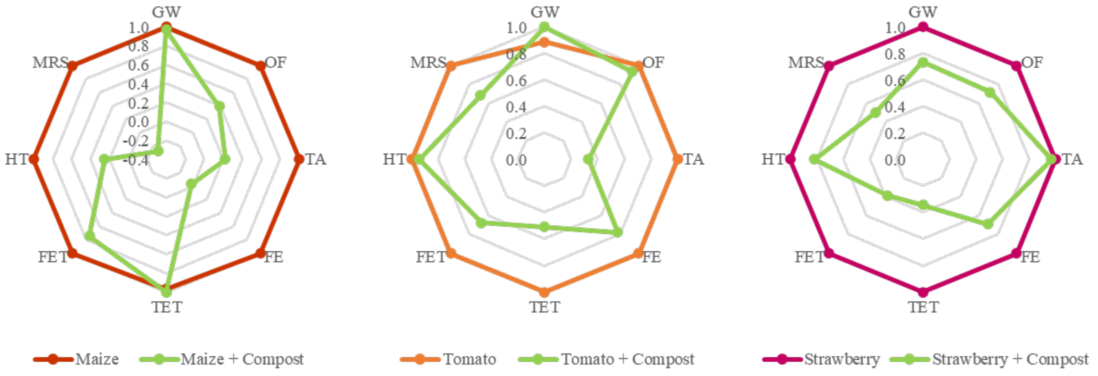

Figure 4. Environmental profiles of maize, tomato and strawberry production when compost is used as fertiliser.

According to the results depicted in **Figure 4**, land application of compost instead of the use of mineral fertilisers would be the most appropriate route for most impact categories. In strawberry cultivation, all impact categories improve their environmental results. A maximum improvement of 65% is reached in the TET category, mainly because the impact of fertilisers is particularly relevant in this category (almost half). On the other hand, the environmental impact of the TA category is only reduced by 3%. Maize cultivation shows reductions between 78% in TA and 3% in GW and a minimum improvement in the TET category. It is notable that in this crop, the FE and MRS categories present negative impacts. This occurs because the environmental credits obtained from the fertilisers avoided exceed the impact of the rest of the inputs consumed during production and application of the compost. Just the opposite is observed in the TET category, in which the impact derived from the use of fertilisers only contributes 25.3%. When mineral fertilisers are replaced by compost, the environmental burdens derived from their production exceed the benefits of their replacement. Tomato cultivation shows slightly worse results in relative terms. Although there are categories that considerably improve their environmental impact (TA and MRS), the GW category increases the environmental impact by 11%. The impact of fertilisers only represents 25.3% for this category and therefore the emissions from production and application of compost are higher than those avoided. It is important to note that these results are in line with other studies, which demonstrate the feasibility of replacing mineral fertilisers with organic and waste-derived fertilisers (Mancini et al., 2019). Substituting mineral fertilisers for the nutrients recovered from waste could be considered a climate change mitigation strategy, since the synthetic production of NPK-based fertilisers is an energy-intensive process (Cobo et al., 2018). Compost also plays an important role as a carbon sink, which allows the long-term storage of organic carbon (Bong et al., 2017).

5. Conclusions

This study focuses on the environmental implications of a wine waste recovery route through composting with the aim of obtaining a high quality biofertiliser. According to the results, special attention should be paid to the diesel consumption of machinery as the main critical point.

Furthermore, the selection of emission factors for direct gaseous emissions during composting is really important, as the results change considerably, especially in the GW and TA categories. The results of the sensitivity analysis showed that the environmental impact can differ by more than 300% in GW and almost 100% in TA.

This study has shown that, if the system boundaries are similar to those of previous studies, the evaluated process has a promising environmental profile. Unlike previous studies, the use of compost as an organic amendment was evaluated, where some environmental burdens related to direct emissions and diesel consumption during the application stage must be taken into account.

The feasibility of using compost as an organic fertiliser in maize, tomato and strawberry crops has been demonstrated, avoiding the use of mineral fertilisers. The results of this analysis showed that the environmental profile of the evaluated crops improved considerably in almost all impact categories. This work shows that composting is an appropriate way to obtain products from waste according to the principles of Circular Economy.

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