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VITICULTURE LIFE CYCLE ANALYSIS FOR THE PRODUCTION OF WHOLE GRAPE JUICE

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Paulo Henrique Franzão Silva[1], Izadora Finco Ribeiro[2], Ana Samily de Oliveira Souza[3], Natalia Ueda Yamaguchi[4] and Francielli Gasparotto[5]

ABSTRACT

Sustainability in agriculture and food processing has attracted great attention from conscious consumers who show a critical and analytical profile focused on environmental practices. Thus, the objective of this research is to evaluate the impacts caused by grape production in the conventional system for the production of whole juice by the approach of the Life Cycle Assessment (LCA). The data from the Life Cycle Inventory (LCI) were collected through a questionnaire in a property located in the municipality of Marialva in the interior of the state of Paraná/BR and the following stages of viticulture production were taken into account – fertilization, protection against diseases and pests, logistics, labor and harvesting. It was found that viticulture is responsible for emitting several greenhouse gases that contribute to the generation of potential environmental impacts and degradation of the quality of natural resources. Among the components of the viticulture inventory in the property under study, synthetic fertilizers in viticulture were responsible for impacts in the largest number of impact categories, followed by fuels and pesticides. In order to achieve sustainability, changes are necessary in the way the crop is managed to reduce the impacts derived from activities such as the use of synthetic fertilizers and pesticides.

[1] Master in Clean Technologies
Ingá University Center – Uningá
E-mail: pa.franzao@gmail.com
LATTES: http://lattes.cnpq.br/3658698268487989
[2] Master's student in Clean Technologies, PROSUP/CAPES scholarship holder
Cesumar University - UNICESUMAR
E-mail: izadorafinco@hotmail.com
LATTES: http://lattes.cnpq.br/6952669123947966
[3] Master's student in Clean Technologies, Scholarship holder at the Cesumar Institute of Science, Technology and Innovation (ICETI)
Cesumar University - UNICESUMAR
E-mail: ana_samily22@outlook.com
LATTES: http://lattes.cnpq.br/5491695132588347
[4] Dr. in Chemical Engineering
Federal University of Santa Catarina – Araranguá Campus
E-mail: natalia.ueda@ufsc.br
LATTES: http://lattes.cnpq.br/3108348607423641
[5] Dr. in Agronomy, Scholarship holder of the Cesumar Institute of Science Technology and innovation
Cesumar University/ UNICESUMAR
E-mail: francielli.gasparotto@unicesumar.edu.br
LATTES: http://lattes.cnpq.br/2673470812353146

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INTRODUCTION

In the last decade, around the world, the population's awareness of the consequences of the environmental impacts caused by human action about their need to meet their demands has been increasing. It is estimated that the world population in 2017 exceeded 7.5 million inhabitants, a number that should reach approximately 11.2 million in 2100 (United Nations, 2018). Parallel to the increase in population, there is also an increase in the question of the possibility of sustainable food production to meet this growing demand.

Intensive agricultural production has been causing negative impacts on the planet, mainly due to the use of synthetic fertilizers, pesticides and the conversion of soil into agricultural land affecting the entire local ecosystem (Meneses et al., 2016). The production of fruits, such as grapes, also contributes to this impact and it is estimated that, in 2016, this crop occupied about 7.6 million hectares in the world (FAOSTAT, 2016). In Brazil, grapes are the fifth fruit with the largest productive area, reaching, in 2017, 75,744 cultivated hectares (IBGE, 2018).

Viticultural activity depends in most cases on the intensive use of pesticides, synthetic fertilizers and energy consumption, and this production pattern has been causing impacts on the environment (Peña, 2018; Ferrara; De Feo, 2018; Santos et al., 2018; Bellon-Maurel, 2015). These impacts need to be correctly estimated in order to be remedied.

An alternative to obtain information on how the exploitation of grape cultivation in the most different regions interferes with the local and global environment is through the use of the Life Cycle Analysis (LCA) methodology. LCA is a tool standardized by the International Organization for Standardization (ISO) capable of quantifying the environmental impacts of a product, process or service throughout its life cycle of all resources consumed and all emissions and waste released. In the grape production chain, it can include analyses in the stages of viticulture, industrialization of wine or juice, distribution of lots, and also processes that include transportation and materials used in agriculture and industrialization of the fruit (Neto et al. 2013; ISO, 2008).

In recent years, there has been an increase in the use of LCA to analyze the impacts generated by the wine production chain, especially in Europe, given the great importance of this crop and wine production on this continent (Neto et al., 2013; Quinteiro et al., 2014;

Villanueva-Rey et al., 2015; Meneses et al., 2016; Ferrara; De Feo, 2018). In Brazil, there are still few studies on LCA and viticulture.

Thus, this study aims to evaluate the impacts caused by grape production in the conventional system for the production of whole juice by the approach of Life Cycle Assessment (LCA). It is expected that the results will help grape producers' decision-making regarding the best management practices in order to benefit the environmental performance and profit of winegrowers in the northwest region of Paraná, Brazil.

METHODOLOGY

The product under study is a whole grape juice produced in a winery located in the northwest region of Paraná, in the municipality of Marialva, Brazil. The juice is produced from grapes of the Bordo variety grown in the vineyards of the rural property in that city. The system practiced on the property is the conventional one, commonly practiced by farmers in Brazil, dependent on the frequent application of pesticides and is based exclusively on the cultivation of the vine in trellis-type vines. The grape is grown on 3 hectares with an average annual production of 35 thousand kg for the summer harvest and 20 thousand kg for the winter harvest.

METHOD

Grape juice was analyzed using the Life Cycle Assessment (LCA) methodology. LCA is used to assess the environmental burden of a product or process throughout its life cycle, i.e., from raw material extraction, manufacturing, distribution, and use to the final disposal of the product or its waste. The procedure is standardized in the BNT NBR ISO 14040:2009 and ABNT NBR ISO 14044:2009 standards, and divided into four phases (ABNT, 2009 a, b): 1. Definition of the objective and scope; 2. Inventory Analysis; 3. Impact assessment; 4. Interpretation.

DEFINITION OF THE OBJECTIVE AND SCOPE

The objective of this study was to evaluate the environmental profile of a whole grape juice, using real field data from a rural property located in the municipality of Marialva, coordinates 23º20'15" to 23º40'27" south latitude and between 51º25'05" and 52º50'59" west longitude with a total area of around 476.4 km² (IBGE, 2010). Identifying at the grape production stage, where the environmental load can be improved.

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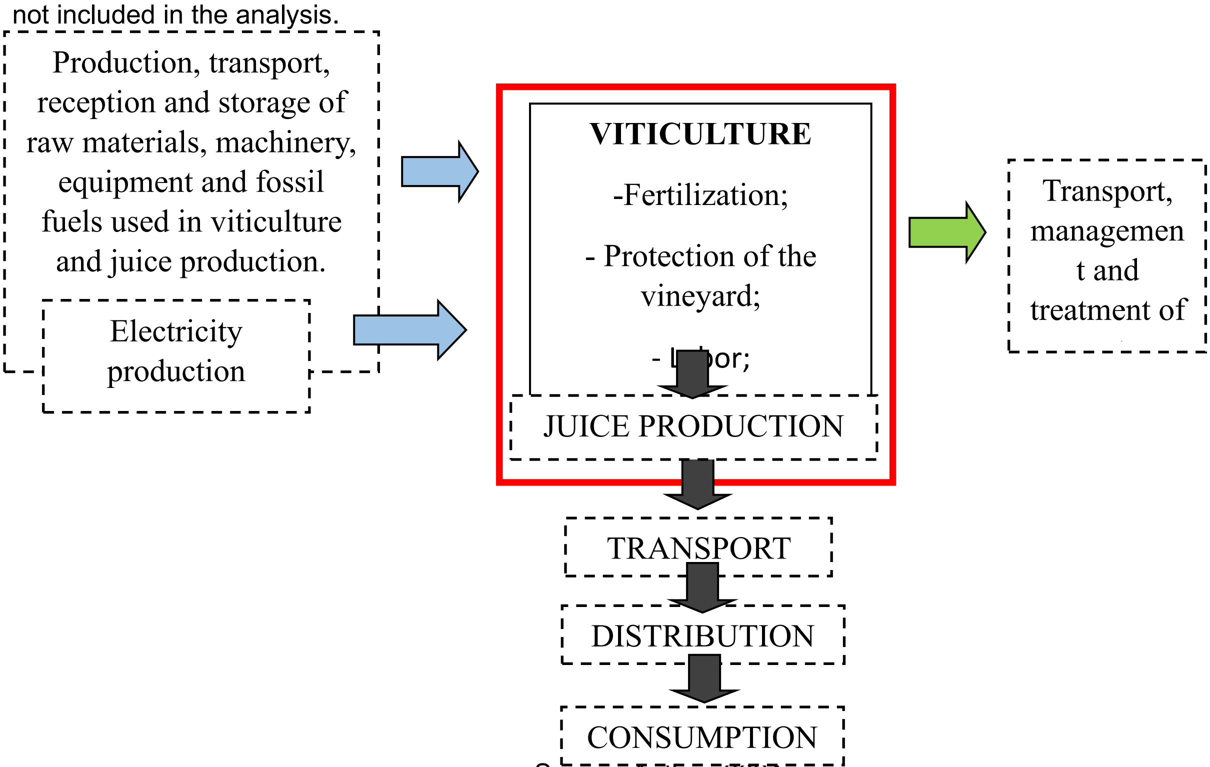
The functional unit (FU) selected was the production of 1.5 L of grape juice, referring to the production of the years 2017 and 2018. The reference flow (RF) adopted was the average productivity of the property and the equivalence of 3 kg of grapes for the production of 1.5 L of juice.

The approach used includes the stages of the life cycle under the influence of the studied site, the system approached focused on all viticulture processes. The treatments carried out by the property in relation to cultivation, cultural treatments of the vines until the harvest phase and delivery of the grapes in natura for processing (Figure 1) were considered.

Figure 1 - Border system of the whole grape juice production process. The dashed line identifies the stages not included in the analysis.



Source: Author, 2024.

In this study, the stages associated with grape juice processing, storage, distribution, consumption and end-of-life options, including transportation, management and treatment of waste, were not considered. All activities associated with the reception and storage of raw materials and equipment used in the viticulture phase, such as agricultural tools and utensils, were also excluded from the study.

Other processes such as administrative and office activities, infrastructure management and maintenance operations, civil and mechanical construction works, use and maintenance of commercial vehicles, laboratory activities, quality processes and

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emergency and exceptional/accidental situations associated with the spillage of juice or products from the process were also excluded. because they are not directly associated with the production of grape juice.

INVENTORY ANALYSIS

The information collected reports the data on grape juice produced from grapes harvested on the property in 2017 and processed in 2018. The information on resources, materials and fuels consumed, emissions to air and water and the production of waste are the result of data considered from the most frequent situations and from appropriate bibliography.

Viticulture activities such as pruning and preparation for grape cultivation began in July 2017 and ended with the grape harvest in December 2017. After harvesting the grapes, they were transported to the agroindustry to start the production of the juice that started simultaneously with the harvest. Then it enters the processing activities phase (January and February 2018), finally, it is moved on to the marketing and distribution phase of the batches until the production cycle starts again (February to June 2018). Table 1 presents the main flows of inputs and outputs, of materials and energy, emissions to air and water and residues from the viticulture phase reported to the UF.

Some considerations were taken in the inventory of the inputs regarding water consumption. The water consumed includes the water necessary for the preparation of the mixtures of the products applied in the cultural treatments, was not accounted for due to the unavailability of information and the difficulty of estimating it, the water consumed in other processes such as machine washes and sprayers.

All cultural treatments carried out on the property, with the exception of pesticide spraying, are manual such as pruning plants and harvesting grapes, with no expenditure of electricity or fuel in their execution. In 2017 and 2018, no herbicides were used on the property, and weed control was carried out via weeding.

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Table 1 - Direct inputs and outputs of viticulture.

Material and energy inputs	Value	Unit referring to UF*
Land occupation	2.51E-04	Ha
Water	5.03E-01	L
Fertiliser		
N-fertilizer (synthetic source)	2.32E-03	Kg
P-fertilizer (synthetic source – P2O5)	8,12E-03	Kg
K-fertilizer (synthetic source - K2O)	4.64E-03	Kg
Boric Acid (H3B03)	8.72E-03	Kg
Pesticide		
Azoxystrobin	7.70E-05	Kg
Metiram + Pyraclostrobin		
They put	1.05E-04	Kg
Pyraclostrobin	9.60E-06	Kg
Thiophanate-methyl	5.44E-05	Kg
Famoxadone + Mancozeb		
Famoxadone	8.00E-06	Kg
Mancozeb	8.00E-05	Kg
Difenoconazole	7.00E-06	L
Imidacloprid	1,28E-05	L
Cyanamide	2.00E-03	Kg
Fuels		
Petrol	2,1E-03	L
Diesel, Tractor	2.5E-02	L
Material and energy output	Value	Unit referring to UF
Fertiliser		
Emissions to air		
CH4	7.6E-06	Kg
N2O	6.38E-06	Kg
NH3	4.50E-05	Kg
Emissions to water		
NO3-	2.78E-04	Kg
Pesticide		
Emissions to the soil		
Azoxystrobin	7.58E-05	Kg
Metiram + Pyraclostrobin		
They put	1.03E-04	Kg
Pyraclostrobin	9.50E-07	Kg
Thiophanate-methyl	5.35E-05	Kg
Famoxadone + Mancozeb		
Famoxadone	7.88E-06	Kg
Mancozeb	7.88E-05	Kg
Difenoconazole	6.90E-06	L
Imidacloprid	1.26E-05	L

*The inventory data corresponds to the functional unit (FU) of 1.5 L of whole grape juice.
Source: Author (2024).

IMPACT ASSESSMENT

SimaPro software (version 8.5.0) was used to model the life cycle of whole grape juice using midpoint indicators of environmental impact (ReCiPe 2016 Midpoint Impact

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Assessment Method (H) V1.01). This method was chosen because it is widely used in viticulture studies in order to allow the comparison of results.

The amount of biogenic CO2 sequestered from the atmosphere during vine and grape growth has been assumed to be equal to the amount of CO2 that is released back into the atmosphere due to oxidation of the carbon contained in pruning residues, as well as due to oxidation of the carbon contained in grapes throughout the life cycle downstream stages. Data taken from Ecoinvent also assumes neutrality for biogenic CO2, so biogenic CO2 was not considered in the global warming impact category.

SENSORY ANALYSIS

Emissions data were estimated based on models in the scientific literature (Greet, 2010; Nemecek; Schnetzer, 2012), suitable for Brazilian conditions. Leaching and phosphorus loss by surface runoff were not accounted for in the inventories due to the low solubility of this element in Brazilian soils (Novais; Smyth, 1999).

The parameters considered include those associated with the emission of nitrogen compounds (NO3, NH3, N2O - direct and indirect) into the air and water caused by the application of fertilizers. The other inventories of the production of agricultural inputs (fertilizers and pesticides) corresponded to those available in the Ecoinvent v. 3.1 database (Wernet et al., 2016).

RESULTS AND DISCUSSION

The data presented in Table 2 highlight the categories of environmental impacts of growing a grape crop of the Bordo variety in the conventional system. The data show that the activity generated environmental impacts related to the use of fertilizers, pesticides and fossil fuels.

Among the components with a tendency to impact the environment, pesticides were responsible for the greatest impacts in four impact categories evaluated, having the greatest influence on freshwater eutrophication, freshwater ecotoxicity, human carcinogenic toxicity and scarcity of fossil resources (Table 2).

Similar to this research, studies have raised the types of environmental impacts caused in the viticulture phase, as in the case of the study to determine the environmental load of the wine production chain in Catalonia/Spain, it was identified that the grape cultivation process had a greater impact when carrying out the management of soil

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preparation and use of pesticides that contain copper and sulfur in their composition to combat pests and fungi, impacts that are harmful when they are drained into the water and by atmospheric emissions (Meneses et al., 2016). Such impacts, however, were related to classes different from those observed in this study, they fit into the action of ozone layer deterioration, ecotoxicity and aquatic eutrophication, only the toxicity to human health was similar to the study in question.

It is important to emphasize that most of the pesticides used in the property under study were used to control diseases incident on the grapevine and that the spraying was carried out in a scheduled manner, that is, without following technical criteria and without monitoring the crop, verifying the incidence and severity of the diseases. In addition to fungicides, the use of hydrogenated cyanamide to break the dormancy of shoots for production in two harvests also negatively impacted the environment and human health.

Also, according to Table 2, the fuels used for the application of pesticides and for the transportation of production were the components that contributed the most to global warming, releasing 0.074899 kg CO2eq, but these among the factors impacting viticulture were the ones that least contributed to the impacts on the ozone layer and ionizing radiation. These were still the most impactful agents in the categories that act on the formation of the ozone layer, impacting both human health and terrestrial ecosystems, with emissions of 0.000834 and 0.000842 kg of NOx eq, respectively. They were the ones that most influenced the impact categories of formation of fine particulate matter, terrestrial acidification and scarcity of fossil resources (Table 2).

Vázquez-Rowe et al. (2013), analyzing the environmental impacts of 9 different types of wines in three European countries Italy, Luxembourg and Spain, found that in conventional agricultural crops the impacts were greater than in organic ones, because they applied pesticides and synthetic fertilizers, associated with the greater use of machines for application, generating diesel combustion and contributing to the emission of greenhouse gases, different from the organic model that uses more labor for agricultural management.

In another study, Vázquez-Rowe et al. (2012) compared the wine production of a winery for 4 years and also found that the viticulture subsystem was the main contributor to all impact categories and, among the viticultural processes, what had an impact on a greater number of categories were the processes aimed at composting and transportation production, in the categories of carbon emissions, climate change, and human toxicity.

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Table 2. Results (expressed in absolute contribution values) of the characterization stage presented for each impact category.

Categories	Pcs.	Fertiliser	Pesticide	Fuels	Emissions to air	Emissions for Water
Global warming	kg CO2 eq	0,031672	0,023571	0,074899	0,019286	0,031672
Stratospheric ozone depletion	kg CFC11 eq	8.92E-08	8.57E-08	4.61E-08	7.02E-07	8.92E-08
Ionizing radiation	kBq Co-60 eq	0,001837	0,001516	0,000786	0	0,001837
Ozone formation, human health	kg NOx eq	9.95E-05	5.61E-05	0,000834	0	9.95E-05
Particulate matter	kg PM2.5 eq	0,000101	7,3E-05	0,000224	1.08E-05	0,000101
Ozone formation, terrestrial ecosystems	kg NOx eq	0,000101	5.77E-05	0,000842	0	0,000101
Terrestrial acidification	kg SO2 eq	0,000295	0,000202	0,000402	8.82E-05	0,000295
Freshwater eutrophication	kg P eq	9.06E-06	1,11E-05	6.72E-07	0	9.06E-06
Marine eutrophication	kg N eq	1.36E-05	7,19E-06	2.55E-07	0	1.36E-05
Terrestrial ecotoxicity	1,4-DCB kg	0,117669	0,057447	0,077774	0	0,117669
Freshwater ecotoxicity	1,4-DCB kg	0,000844	0,001072	7.4E-05	0	0,000844
Marine ecotoxicity	1,4-DCB kg	0,001205	0,001151	0,000127	0	0,001205
Carcinogenic human toxicity	1,4-DCB kg	0,000498	0,000563	5.57E-05	0	0,000498
Non-carcinogenic human toxicity	1,4-DCB kg	0,031599	0,030716	0,371061	0	0,031599
Land use	m2a crop eq	0,010495	0,000234	0,000117	0	0,010495
Scarcity of mineral resources	kg Cu eq	0,000115	0,000564	8.58E-07	0	0,000115
Scarcity of fossil resources	kg oil eq	0,010307	0,0081	0,026591	0	0,010307
Water consumption	m3	0,001589	0,000546	0,000138	0	0,001589

Source: Author (2024).

Similar to what was observed by the authors cited above, fuel emissions were also relevant in this study. It is verified that they total 10 of the 18 studied, since it once again reinforces the need to reduce the number of pesticide sprays in order to reduce environmental impacts, both by the product itself and by the use of fuels used by the machines during the applications. This fact highlights the need for greater environmental awareness on the part of producers and professionals linked to technical assistance, making changes in the production system that has been used in the region.

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In this sense, when Table 2 is analyzed, it is noted that the emissions that obtained significant results related to the use of fossil fuels emitted by vehicles for spraying and logistics during grape cultivation are linked to global warming with a representation of 50.12% of the impacts, followed by the category of impact of ozone formation and risk to human health with 84.28%, formation of fine particulate matter 54.83%, formation of ozone in terrestrial ecosystems 84.12%, terrestrial acidification 40.73%, non-carcinogenic toxicity or also known as human carcinogen with 85.62% and the scarcity of fossil resources 59.02%.

With the impacts generated by fossil fuels by pesticide application on the crop, this component is also an aggravating factor, as these pest inhibitors with different chemical compositions, contributing significantly to ionizing radiation emissions of 36.63%, freshwater eutrophication representing 53.24%, freshwater ecotoxicity with 53.86%, marine ecotoxicity 46.37%, carcinogenic toxicity or also known as carcinogenic (carcinogenic) human with volume of 50.37% and scarcity of mineral resources 82.97% (graph 1).

Several studies point to pesticide spraying as the main factor of environmental impact of practices related to viticulture. In this sense, Quinteiro et al. (2014) observed that spraying impacts eutrophication, freshwater ecotoxicity and marine aquatic ecotoxicity. Viveiros et al., (2018) developed a study on the spatial variability of the terrestrial ecotoxicity impact of copper-based fungicides applied in European vineyards with a focus on combating downy mildew, specifically copper, and found that it is the main contributor to the ecotoxicity impacts in the wine life cycle.

Copper applied to grapevines reaches groundwater and surface water through different mechanisms, which leads to impacts on terrestrial and aquatic ecosystems (Viveiros et al., 2018). It is noteworthy that in the inventory carried out in this research, on the property under study, no copper-based protective fungicide was used in the grape crop in the 2017-2018 harvests, only systemic fungicides.

In addition to the pesticides used, conventional grapevine cultivation also uses synthetic fertilizers that are applied directly to the soil or sprayed on the aerial part of the plants in order to provide essential nutrients for their growth. In this case, the study detected the main impacts from this process, ionizing radiation of 44.38%, freshwater eutrophication with 43.52%, marine eutrophication of 34.32%, terrestrial ecotoxicity 46.52%, freshwater ecotoxicity 42.41%, marine ecotoxicity 48.51%, human carcinogenic toxicity (carcinogenic) of 44.63%, land use 96.76% and water consumption 69.92%.

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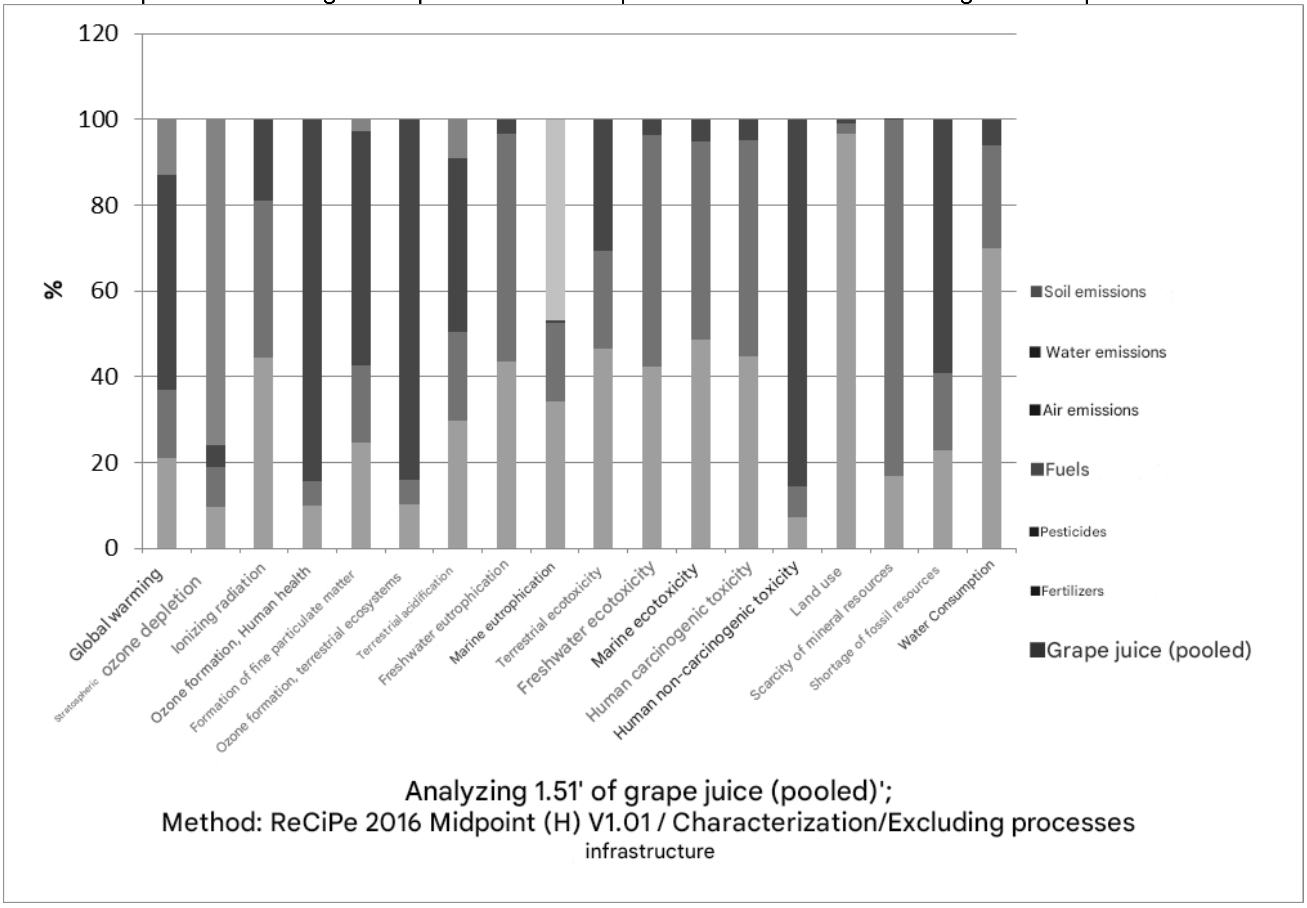
Graph 1 - Percentage of impact of each component of viticulture according to the impact class.



Source: Author (2024).

Analyzing the results of graph 1 individually, it can be seen that the component with the greatest impact was the application of fertilizers, which had the greatest influence in 8 of the 18 classes studied. Also corroborating the results of this research, Vázquez-Rowe (2017) evaluating the wine production associated with 6 wineries, found that the operation that generated the most environmental impact was the use of fertilizers, which provided impacts such as eutrophication, fossil depletion and water depletion with irrigation, in addition to propagating greenhouse gases.

Similarly, in a study with LCA in a Mediterranean vineyard in southern France, Bellon-Maruel et al. (2015) found that the demand for nutrients such as nitrogen, phosphorus, potassium, magnesium and calcium is lower in grapevines than in annual crops, however, the applications that occur are already considered sufficient to cause environmental impacts such as eutrophication and soil acidification, in case of inappropriate applications (Bellon-Maruel et al., 2015).

Concern about the contributions of environmental impacts from viticulture has been growing around the world, and many producers have found in sustainability an opportunity

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to increase their income by adding value to their products influenced by less impactful environmental practices. In this sense, several studies have been developed comparing conventional grapevine cultivation with other cultivation practices that aim to reduce environmental impacts.

Villanueva-Rey (2014) compared three cultivation techniques in Spain: biodynamic, conventional and biodynamic, and found that biodynamic and biodynamic practices implied lower environmental loads, but with a lower production volume compared to the conventional model. The main reasons for the decrease in environmental impact are related to the decrease in the use of diesel, due to the low application of plant protection products and fertilizers, emphasizing manual activities instead of mechanized activities in the vineyards, providing a reduction of up to 80% for the reduction of carbon emissions (Villanueva-Rey et al., 2014).

Similarly, in a study of LCA of wine produced in Nova Scotia/Canada, it was found that the main impacts occur during the viticulture and transport phases, in a comparison made between two cultivation models, conventional and organic, and the conventional model presented higher production, however, it also presented a greater number of impacts caused by the use of synthetic fertilizers and pesticides. The authors verified potential impacts such as eutrophication, global warming potential, ozone layer depletion, aquatic and terrestrial ecotoxicity (Point et al., 2012).

Rouault et al. (2016) also developed LCA studies comparing the environmental performance between organic and conventional viticulture and found that the points that diverge between the types of cultivation are related to phytosanitary treatments and soil management, operations that have greater impacts on global warming, photochemical ozone formation, acidification and demand for fossil resources.

Studies on carbon emissions in the wine production chain have been growing gradually and the research method using LCA has become paramount in this sector, studies have explicitly compared organic and conventional wine productions (Rugani et al., 2013; Aranda et al., 2012; Vázquez-Rowe et al., 2013).

The average value of the difference in CO^2 emissions from the organic model to the conventional model is about 25% lower, however, this data should not be considered unconditionally (Rugani et al., 2013). Future studies will have to address an increasingly complex linkage of the entire winemaking cycle, as currently the methodological themes in

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the concept of life cycle suggest an integrated sustainability assessment that includes economic and social issues, broadening the scope to other pillars of sustainability.

It is verified that an option to significantly reduce the environmental impacts of the viticultural activity on the property under study could be the adoption of integrated pest and disease management aimed at reducing the number of sprays carried out on the crop or even the adoption of an organic or agroecological cultivation model of production. Although an analysis of these models is necessary at the study site, the proposal tends to provide a significant reduction in the use of pesticides, synthetic fertilizers and, consequently, reduce the use of fossil fuels.

The change from conventional cultivation to variants of cultivation that have less impact on the environment comes to meet a market demand, which is increasingly demanding regarding the use of sustainability in production processes. Studies in this sense are necessary to prove or not the reduction of the impacts of the activity after changes in production processes.

CONCLUSION

Conventional viticulture associated with the grape production chain for the production of whole juice in this study provided significant environmental impacts, which contribute to climate change through the emission of greenhouse gases, influence on the formation of the ozone layer and emission of fine particulates. It was also found that the natural resources available such as water and soil for the execution of agricultural activity are also exposed to risks of eutrophication, ecotoxicity, scarcity of resources and risks to human health because they contain carcinogenic chemical compositions. Among the components evaluated, the synthetic fertilizers used in crop fertilization were the ones that impacted the largest number of impact categories evaluated.

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