Environmental impact of tsipouro production by life cycle assessment

P Tsarouhas¹² and I Papachristos¹
¹Department of Supply Chain Management, International Hellenic University, Kanellopoulou 2 str., 60100, Katerini, Greece
²Corresponding author’s e-mail: ptsarouhas@ihu.gr

Abstract. The study of the environmental impact of agricultural products has significantly grown in recent years, as consumers now demand more information about the product's footprint in the environment. The aim of this study is to assess the environmental impact of the life cycle phases of tsipouro production, which is one of the traditional products of Greece produced mainly from viticulture. The environmental analysis was performed through the study of eutrophication, global warming, photochemical oxidation and acidification, using the life cycle assessment methodology. The system was studied through fifteen subsystems and a 250 ml bottle of tsipouro, which was the basis of the calculations, was defined as a functional unit. From the results it appears that the process of tsipouro production is the subsystem with the highest energy consumption and the grape cultivation the one with the highest water consumption. In environmental impact the subsystem with the highest contribution is the cultivation of grapes. Also the subsystems production/transportation and use of fertilizers, bottle production/transportation and the process of tsipouro production have a significant contribution. In addition, some literature-based solutions are suggested. Some of the solutions are the use of clearer energy sources, the use of biodiesel and alternative cultivation methods without synthetic fertilizers. The results of this research can be used by tsipouro or similar industries to minimize the environmental impact and focus on the phases that are most involved in it.

1. Introduction
In recent years, due to serious environmental problems, special attention has been paid to the environmental impact of human activities among them being the processes of food production and by extension the agricultural production. Several studies, using a variety of environmental analysis tools, have shown that the agricultural sector contributes significantly to the environmental impact both locally and globally [1]. The main elements of modern agricultural production are electricity and fossil fuels. They are used either directly with the power supply of the machines or indirectly with their use for the manufacturing of fertilizers, pesticides and various machines [2]. Khanali et al. (2021) in their research showed that a large part of the environmental pollution from agricultural activities comes from diesel consumption.

Researchers and professionals in sustainable supply chain management are increasingly using system approaches such as environmentally extended input output analyzers, life cycle assessment (LCA) and analysis of greenhouse gas emissions (GHG) as part of efforts to improve supply chain
bioavailability [4,5]. In order to achieve a reduction of the environmental impact, resulting from agricultural production, one of the most important steps is to calculate the emissions of a representative functional unit of the product [6]. LCA is a methodology used to assess the environmental impact that may result from a production system and can be used to document the system's resources and emissions [25,26]. The use of the LCA methodology includes all the phases of a product's system life cycle and studies the effects on various environmental categories [7]. For the assessment of the environmental impact in the agricultural production, the use of the LCA methodology has significantly increased in recent years [8].

This research aims at presenting the main environmental problems arising from the production of tsipouro and at highlighting the phases of its lifecycle contributing more to them. Tsipouro is a Greek alcoholic beverage that results from the distillation of grapes and its alcoholic content is 38-45% by volume. Often a second distillation, in which various components such as anise, fennel, cloves, nutmeg and mastic, is carried out in order to make the product clearer and more aromatic. Similar beverages, in other countries, are grappa in Italy and arak in the Middle Eastern. Tsipouro, as well as wine, is produced from the distillation of grapes and this is the reason why these two products have many common stages in their life cycle.

To carry out this research the method used was the partial LCA with ‘cradle to gate’ approach according to ISO-standardized [25,26]. The use of this method achieves the quantification of environmental impact of tsipouro production and highlights the phase most involved in it. The environmental analysis was done through the phenomena of eutrophication, global warming, photochemical oxidation and acidification. The cumulative energy demand and cumulative water demand are also calculated. The study of the system is carried out with the study of fifteen subsystems. Initially, this research aims at highlighting the subsystem that has the largest contribution to environmental pollution and at proposing solutions for the creation of more environmentally friendly production.

There is no research in the literature that studies the impact of tsipouro on the environment. So the literature review will focus mainly on wine, because these two products have a similar life cycle. Wine due to its global availability is one of the most analyzed products [9]. To study the environmental impact of the wine lifecycle, many studies, using the LCA method, have been carried out [10,11]. Some studies used a LCA method with ‘cradle to grave’ approach [12,13] while there are studies that have used a ‘cradle to gate’ approach [14] taking into account the distribution phase. The results of the researches vary according to the phases that burden the environment the most. There are studies that have highlighted the viticulture phase as the one with the highest involvement in the burdening on the environment [6] and others that have highlighted the bottling and packaging phase [15]. In general, most studies, that have analyzed the environmental impact of wine life cycle phases, have highlighted subsystems such as the use of pesticides and fertilizers and the production of bottles as harmful to the environment and highlight the high energy consumption of wine production [13,16]. Similar results emerge from the research of Tsarouhas and Pappachristos (2021) that studied the environmental impact of ouzo production, a product with several common life cycle phases with wine and tsipouro.

2. System description
For the study of the environmental impact of tsipouro production an LCA analysis with ‘cradle to gate’ approach according to ISO-standardized was carried out [25,26] in a production company in Greece. Through the LCA method the total energy and water consumption are calculated as well as the impact that the production of tsipouro has on eutrophication, global warming, photochemical oxidation and acidification. The system is studied through fifteen subsystems that belong to the main production phases that are (i) cultivation of grapes, (ii) production of tsipouro and (iii) packaging. The subsystems are: (i) agricultural machinery production, (ii) pesticides production, (iii) fertilizers production, transportation and use, (iv) grape cultivation, (v) tsipouro production process, (vi) transportation of grapes to the producer, (vii) bottling of tsipouro (viii) bottles production/transportation, (ix) production of stretch film, (x) cartons production and transportation, (xi) adhesive tape production, (xii) lids
production, (xiii) label production, (xiv) production of pallet and (xv) palletizing. In order to have a complete understanding of the production of tsipouro and its subsystems there is a detailed illustration in figure 1.

In this case study there are some subsystems that are not included in the analysis such as the vineyard installation, the raw materials used for energy production etc. This is either because there is lack of data or because their participation in the overall system is small. One phase that is missing, because of lack of data, is the distribution of the final product to the consumers.

2.1. Functional unit
The functional unit chosen is the 250 ml tsipouro bottle containing 42% alcohol by volume, which is the most common on the market. For the production of 250 ml tsipouro, 1.250 kg grapes are needed. The amount of the land needed for the production of the grapes of the functional unit is 0.001097 acre (1.097 m²). These quantities formed the basis of all calculations. All the calculations have been made for the functional unit. The materials of which the final product is composed are presented in table 1.

2.2. Data and assumptions
The data used to perform this research is derived from a tsipouro manufacturer in Greece and some data was obtained from the literature. So the assumptions on which the research was based are a result of this data. The assumptions of this research are:

i. For the production of 250 ml tsipouro, 3.571 kg of grapes are needed. Of the 3.571 kg of grapes only the 1.250 kg of them are used for distillation. This is a result of the double distillation that the product needs.

ii. The transportation of grapes to the producer and to and from the farm is carried out using a pickup truck with engine 3.0 diesel and average consumption 8.9 lt per 100 km. Such vehicles are commonly used in agricultural work in the country (Greece) where the survey is conducted.

iii. The calculations regarding the transportation of the workers and the owner of the farm, were made with the assumption that they lived in a village that is close to the farm and is 3.1 km away from it. Also, the distance between the manufacturer and the farm is 4.2 km and between the manufacturer and the village is 3.4 km.

iv. A tractor with 80HP was used for the tasks at the farm and it is assumed that it remains constantly on the farm. According to the producer depending on the task performed, there is also different fuel consumption. Thus consumption is divided into two categories.
   i. Low consumption; the consumption is 6.1 lt per hour and here tasks that don’t burden the tractor too much, such as fertilizing and pesticiding, belong.
   ii. High consumption; the consumption is 7.2 lt per hour and here tasks that burden the tractor, such as plowing, belong.

v. It is assumed that for the harvesting of grapes for a land of 29.73 acres 8 days were needed. To carry out this task 7 workers who worked 8 hours every day were required.

vi. According to Audsley et al (1997) iron and rubber are the materials from which agricultural tools are made.

vii. The percentages for defective packaging materials and bottles were not taken into account.

viii. The ingredients of the bottles used are the 27.40% from recycled glass and a large part of them come from primary production (72.60%).

ix. A pump 30 HP was used for the irrigation task.

The data was obtained from a tsipouro manufacturer. The emissions and fuel consumptions of each task were calculated based on the above assumptions and data. Most of the tasks were performed with the pickup truck and the tractor. For the calculations the transportation of fertilizers using a truck and the use of the pump for the irrigation task were also taken into account. The calculations for the requirements in total energy, but also the estimation of the liquid waste and gaseous emissions, for the
cultivation of the part of the vineyard (0.001097 acre) that corresponds to the functional unit were made according to the White et al. (1995).

Figure 1. Illustration of the system of tsipouro production.

Table 1. Components of functional unit.

| Component                        | Material                        | Weight (grams) | Percentage % |
|---------------------------------|---------------------------------|----------------|--------------|
| **Product**                     | Tsipouro                        | 240.00         | 53.76        |
| **Main packaging**              |                                 |                |              |
| Bottle                          | Glass                           | 180.00         | 40.32        |
| Sealing disc                    | Polyvinylidene chloride         | 0.15           | 0.03         |
| Lid                             | Aluminium                       | 1.10           | 0.25         |
| Glue                            | Glue                            | 0.15           | 0.03         |
| Label                           | Paper                           | 0.82           | 0.18         |
| **Secondary packaging**         |                                 |                |              |
| Carton                          | Multi-Layer corrugated cardboard| 21.26          | 4.76         |
| **Packaging of**                |                                 |                |              |
| Tape                            | UPVC plastic                     | 0.22           | 0.05         |
| Plastic film                    | LLDPE                            | 0.38           | 0.08         |
3. Results

The Eco-indicator 99 methodology was used to conduct the analysis [19] to evaluate the impact of tsipouro production to eutrophication, global warming, photochemical oxidation and acidification. Also, the total energy and water requirements were calculated. To perform the analysis, a necessary step is the grouping of pollutants according to their impacts. The characterization factors to accomplish this step are given by the research of Tsarouhas et al. (2015).

The production of tsipouro has high requirements in energy and water and these are shown in figure 2 from where the presentation of the results begins. Figure 2 shows the consumption of the four subsystems with the highest consumption in energy and water. The remaining subsystems, due to low consumption, have been grouped and their total consumption has been calculated in both categories. The highest energy consumption is in the subsystem related to the production process and it amounts to 60.74% of the total energy consumption. Then the subsystem of bottle production/transportation with 16.20% follows and the next one is the cultivation of grapes with 7.62%. Regarding water consumption, it is observed that the grape cultivation subsystem has a very high consumption that amounts to 91.31% of the total water consumption. Then, with much lower water consumption, the process of tsipouro production (5.54%) and the production and transportation of cartons (1.23%) follow.

| transportation          | Palette | Wood | Total |
|-------------------------|---------|------|-------|
|                         |         | 2.39 | 0.54  |
|                         |         | 446.47 | 100.00 |

Figure 2. Total energy and water consumption.

Figure 3. Impact of tsipouro production system on Acidification (g SO₂-eq.) and Eutrophication (g PO₄³⁻-eq.).

The Figure 3 includes the results related to the impact of the subsystems on acidification and eutrophication. The cultivation of grapes has the highest impact on both phenomena with its contribution reaching 41.79% and 27.75% respectively. Then, in both phenomena, the highest impact
lies in the subsystem related to the production/transportation and use of fertilizers with a fairly high impact that is 37.61% and 24.90% respectively. Furthermore, the process of tsipouro production and the bottle production/transportation have a significant contribution to acidification (8.35% and 9.65% respectively) and to eutrophication (21.48% and 23.70% respectively).

Figure 4 shows the results for the impact of tsipouro production subsystems on global warming and photochemical oxidation. In the global warming the highest contribution appears to come from the bottle production/transportation and the production process with contributions 42.70% and 38.04%. Also, the production/transportation and use of fertilizers show a contribution to this phenomenon that is worth mentioning and reaches the 11.34%. Concerning the photochemical oxidation phenomenon, the grape cultivation presents the highest contribution to it with a percentage 37.50%. Then the process of tsipouro production and the bottle production/transportation with percentages 28.43% and 22.12% follow.

Figure 4. Impact of tsipouro production system on Global warming (g CO2-eq.) and Photochemical oxidation (g C2H6-eq.).

4. Conclusions

The present research was carried out to study the impact on the environment, through the phenomena of eutrophication, global warming, photochemical oxidation and acidification, of tsipouro production and to calculate its energy and water requirements. The study of the system was carried out through a LCA analysis and fifteen subsystems were studied. A 250 ml bottle of tsipouro was defined as the functional unit, on which all calculations were based.

The results show that the cultivation of grapes has a very high impact on all four phenomena. Quite a high impact, depending on the phenomenon being referred to, have three more subsystems, which are the production/transportation and use of fertilizers, the bottle production/transportation and the production process of tsipouro. Neto et al. (2013) at their research show that the phase of grape cultivation has the highest impact on these four phenomena and the subsequent phase on them is the production of bottles. A result that matches our results, with the only difference that the bottle production does not appear in all phenomena as the second most burdening phase. Another research, that of Meneses et al. (2016), which studied the same environmental phenomena, showed that the production of bottles is the most harmful phase, with grape cultivation and wine production following with lower impact. In our research all these phases have a significant effect on all phenomena but not in this order. Furthermore, Tsarouhas and Papachristos (2021) have shown that the phases with the highest contribution on these four phenomena are the production process, the grape cultivation and the bottle production/transportation, a result that partly coincides with ours. The difference is that the process of tsipouro production is not the most harmful for the environment but in most phenomena is the grape cultivation.
It is understandable that in order to make the tsipouro production system more environmentally friendly, the environmental impact of the subsystems with the highest environmental impact should be reduced. There are researches focusing on finding solutions to reduce these effects of viticulture. In their research, Villanueva-Rey et al. (2014) they have studied different techniques of viticulture in order to find the technique that pollutes the environment the least. They show that the use of a biodynamic and organic technique may result in a reduction of 50% to the impact on the environment. Another solution to reduce gas emissions is the use of clearer energy sources, as well as renewable sources of energy. To reduce gaseous emissions, more environmentally friendly forms of energy should be used, such as solar technology [23].

This research provides useful information on processes that are more harmful to the environment. It also enables industries producing tsipouro or similar beverages to use these results to create a more environmentally friendly product. The limitations of the present study stem from the collection of data from a single manufacturer and from subsystems that were not studied due to lack of data. Therefore, a future research could be done using data from more tsipouro manufacturers and from other regions of Greece.

References
[1] Park Y S, Egilmez G and Kucukvar M 2016 Energy and end-point impact assessment of agricultural and food production in the United States: A supply chain-linked Ecologically-based Life Cycle Assessment Ecol. Indic. 62 117–37
[2] Golasa P, Wysokiński M, Bieńkowska-Golasa W, Gradziuk P, Golonko M, Gradziuk B, Siedlecka A and Gromada A 2021 Sources of Greenhouse Gas Emissions in Agriculture, with Particular Emphasis on Emissions from Energy Used Energies 14 3784
[3] Khanali M, Akram A, Behzadi J, Mostashari-Rad F, Saber Z, Chau K and Nabavi-Pelesaraei A 2021 Multi-objective optimization of energy use and environmental emissions for walnut production using imperialist competitive algorithm Appl. Energy 284 116342
[4] Beylot A, Corrado S and Sala S 2020 Environmental impacts of European trade: interpreting results of process-based LCA and environmentally extended input–output analysis towards hotspot identification Int. J. Life Cycle Assess. 25 2432–50
[5] Blass V and Corbett C J 2018 Same Supply Chain, Different Models: Integrating Perspectives from Life Cycle Assessment and Supply Chain Management: Integrating Perspectives from LCA and SCM J. Ind. Ecol. 22 18–30
[6] Litskas V D, Irakleous T, Tzortzakis N and Stavrinides M C 2017 Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study J. Clean. Prod. 156 418–25
[7] Kramer K J, Moll H C and Nonhebel S 1999 Total greenhouse gas emissions related to the Dutch crop production system Agric. Ecosyst. Environ. 72 9–16
[8] Liang L, Lal R, Ridoutt B G, Du Z, Wang D, Wang L, Wu W and Zhao G 2018 Life Cycle Assessment of China’s agroecosystems Ecol. Indic. 88 341–50
[9] Bonamente E, Scrucia F, Rinaldi S, Merico M C, Asdrubali F and Lamastra L 2016 Environmental impact of an Italian wine bottle: Carbon and water footprint assessment Sci. Total Environ. 560–561 274–83
[10] Falcone G, De Luca A, Stillitano T, Strano A, Romeo G and Gulisano G 2016 Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis Sustainability 8 793
[11] Vázquez-Rowe I, Villanueva-Rey P, Moreira M T and Feijoo G 2012 Environmental analysis of Ribeiro wine from a timeline perspective: Harvest year matters when reporting environmental impacts J. Environ. Manage. 98 73–83
[12] Gazulla C, Raugei M and Fullana-i-Palmer P 2010 Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks? Int. J. Life Cycle Assess. 15 330–7
[13] Point E, Tyedmers P and Naugler C 2012 Life cycle environmental impacts of wine production
and consumption in Nova Scotia, Canada J. Clean. Prod. 27 11–20

[14] Ardente F, Beccali G, Cellura M and Marvuglia A 2006 POEMS: A Case Study of an Italian Wine-Producing Firm Environ. Manage. 38 350–64

[15] Meneses M, Torres C M and Castells F 2016 Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain Sci. Total Environ. 562 571–9

[16] Fusi A, Guidetti R and Benedetto G 2014 Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment Sci. Total Environ. 472 989–1000

[17] Tsarouhas P and Papachristos I 2021 Environmental assessment of ouzo production in Greece: A Life Cycle Assessment approach Clean. Environ. Syst.

[18] White P, Franke M and Hindle P 1995 Integrated Solid Waste Management: A Lifecycle Inventory (Boston, MA: Springer US)

[19] Goedkoop M 2007 The Eco-indicator 99 Methodology J. Life Cycle Assess. Jpn. 3 32–8

[20] Tsarouhas P, Achillas Ch, Aidonis D, Folinas D and Maslis V 2015 Life Cycle Assessment of olive oil production in Greece J. Clean. Prod. 93 75–83

[21] Neto B, Dias A C and Machado M 2013 Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution Int. J. Life Cycle Assess. 18 590–602

[22] Villanueva-Rey P, Vázquez-Rowe I, Moreira M T and Feijoo G 2014 Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain J. Clean. Prod. 65 330–41

[23] Ghasemi-Mobtaker H, Mostashari-Rad F, Saber Z, Chau K and Nabavi-Pelesaraei A 2020 Application of photovoltaic system to modify energy use, environmental damages and cumulative exergy demand of two irrigation systems-A case study: Barley production of Iran Renew. Energy 160 1316–34

[24] Audsley A, Albe S, Clift R, Cowel S, Crettaz R, Gaillard G, Hausheer J, Jolliett O, Kleijn R, Mortensen B, Pearce D, Roger E, Teulon H, Weidema B and van Zeijts H 1997 Harmonisation of Environmental Life Cycle Assessment for Agriculture. Final report, Concerted Action AIR3-CT94-2028 European Commission DG VI Brussels, Belgium

[25] ISO 2006a Environmental Management - Life Cycle Assessment - Principles and Framework. ISO 14040 International Organisation for Standardisation (ISO) Geneve

[26] ISO 2006b Environmental Management - Life Cycle Assessment - Requirements and Guidelines. ISO 14044 International Organisation for Standardisation (ISO) Geneve