Interreg
EUROPEAN UNION
Balkan-Mediterranean
BalkanRoad

Towards farms with zero carbon-, waste- and water-footprint. Roadmap for sustainable management strategies for Balkan agricultural sector

PROJECT DELIVERABLE

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1 Extended Summary

In the line of WP3 of the **BalkanROAD** project, a holistic Life Cycle Analysis (LCA) in terms of raw materials consumption, energy use, transportation and greenhouse gas (GHG) emissions was carried out for all processes considered in the pilot area i.e. Ktima Kyr-Yanni, Naousa, North Greece in order to:

a) analyze the life cycle of the red wine production – Xinomavro variety in Naousa in terms of current grape cultivation practices applied, vinification and wine bottling- packaging processes used along with distribution to main export market port (Thesalloniki port) and

b) identify critical processes that are energy intensive and cause most environmental impacts in the whole life cycle of the agricultural product under study.

LCA was carried out to determine the consumption of raw materials i.e. fertilizers, pesticides, irrigation and processing water, energy and agricultural waste, as well as to calculate emissions of pollutants (CO_2, CH_4, VOCs, NOx, SO_2 etc.) to air, water and soil in relation to the objectives of the study. The study was carried out with open LCA 1.7.0, an LCA software created by GreenDelta, used to model the system and to evaluate its environmental impact according to the guidelines and specific requirements of the International Organization for Standardization (ISO) 14040-14044 standard series.

Based on the system boundaries and the "cradle to winery gate" approach, five mid-point environmental impact categories, defined according to the CML 2001 (April 2013 version) impact assessment method were assessed in the present study: Acidification Potential, Eutrophication Potential, Global Warming Potential, Ozone Layer Depletion, Photochemical Ozone Creation Potential and Cumulative Energy Demand as an energy flow indicator.

LCA identified the existence of two crucial phases that are the most impactful ones for the production of one 0.75 L bottle of red wine from the pilot site of Ktima Kyr-Yianni in all impact categories studied: grape cultivation and bottling. The main reasons to the higher impact associated to these phases were the high energy consumption for the production of fertilisers and glass bottles, respectively. Impacts of critical importance were also ascribed to packaging, mainly attributed to the production of cardboard boxes and pallets.

Overall, the present study showed the viability of the application of LCA to evaluate the environmental impact caused by an agricultural practice and can be extended to other long-term cultivations/agricultural productions in similar environments, in the Balkan region and elsewhere. The LCA results obtained can be also used by several end-users (i.e. farmers, agronomists), policy makers and other stakeholders for developing eco-friendlier and goal-oriented sustainable strategies for similar production systems.

2 Introduction

Briefly, LCA is defined as a method for compiling and evaluating all inputs, outputs and the potential environmental impact of a production system throughout its life cycle. It enables the user to measure and quantify the environmental impacts of a product (ISO, 2006a,b). Furthermore, it helps to identify hot spots where the most significant impacts occur, giving the user the opportunity to develop strategies for improving the product's environmental performance. The use of LCA in environmental management and sustainability has gain considerable attention by researchers and related practitioners in recent years as seen in the steadily increasing number of published research on several case studies.

In respect to agriculture, LCA is a tool that can better place the 'food miles' concept into perspective, and enables farmers and agricultural enterprises to respond to demands and awareness from consumer and environmental groups about the carbon and water footprints of agricultural products. Both environmental demands and awareness influence the way in which legislative bodies such as governments will guide the future development of agricultural and industrial food production systems.

The leading components for standardized LCA are the international standards of ISO 14040 and ISO 14044. The key methodological aspects of an LCA are summarized in the following four steps:

i) "Goal and Scope Definition",

ii) "Inventory analysis",

iii) "Impact Assessment" and

iv) "Interpretation"

A schematic overview of a typical LCA is presented in **Figure 2.1**. However, the detailed methodology proposed, adapted to the specific requirements of the **BalkanROAD** project, is discussed below in detail (materials and methods section).

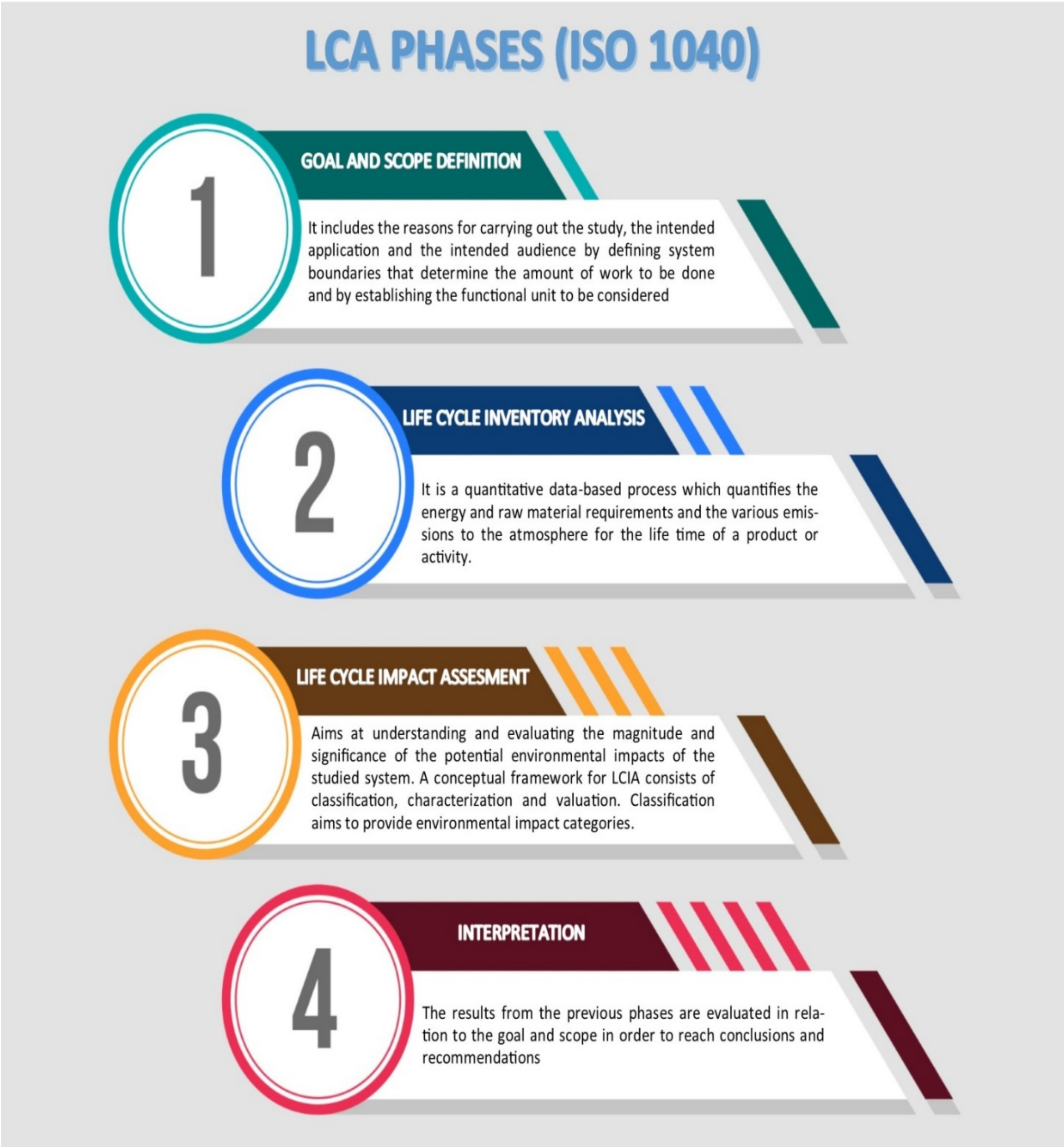

Figure 2.1 LCA steps in standardized methodology according to ISO 1040 standard

3 Material and Methods

3.1 Study Area description – Pilot site

The city of Naousa is located about 22 km north of Veroia i.e. the capital city of the Imathia regional unit in the Central Macedonia and 90 km east of Thessaloniki. It lies on the eastern foothills of Vermio Mountains, one of the biggest mountain ranges in Greece, and west to the plain of Kambania. Within the study area, Chamites (or Chanaktsi), at an elevation of 2062 m, is the highest point (**Fig. 3.1**).

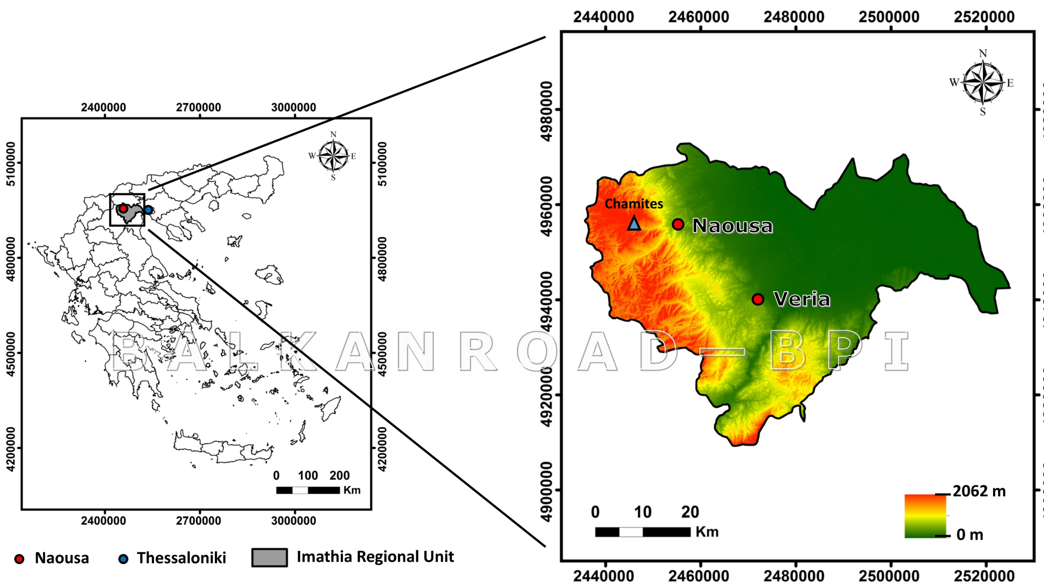

Figure 3.1 Location and altitude map of the study area

Today, Naousa is one of the most prominent wine producing regions of Greece, with approximately 500 ha of cultivated - Protected Designation of Origin (PDO) - wine growing land spreading over an altitude rising from 80 to over 350 meters and about 20 wineries located in the wider area. Apart from vines, it is also surrounded by orchards, producing peaches, apples, cherries and other fruits.

The Greek wine producing pilot site "Ktima Kir-Yianni" is located about 3 km north of Naousa and covers a total surface of 58 hectares, which lies at an altitude of 280 to 330 meters i.e. the highest point of the Naousa PDO zone (**Fig. 3.2**). Ktima Kir-Yianni is planted with Xinomavro (50%), Syrah (15%), Merlot (20%) and Cabernet Sauvignon (10%), while the rest of the area is covered with various experimental varieties, all trained in vertical shoot positioning (**Fig. 3.3**). The mountainous mass of Vermion protects the vines from the cold winds coming from the north in the winter, and sends down a beneficial cool breeze during the summer, which is usually hot and dry.

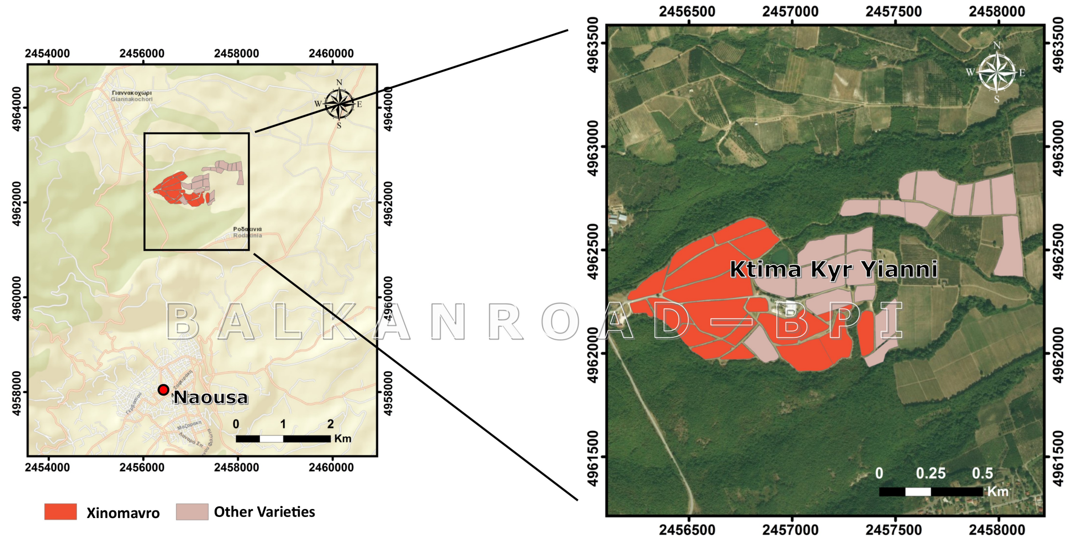

Figure 3.2 Location and wine-variety map of the Greek wine producing pilot site "Ktima Kir-Yianni" near Naousa

Figure 3.3 Vertical shoot positioning of the vineyards in the pilot site "Ktima Kir-Yianni"

3.2 LCA Methodology

The present LCA study was carried out to determine the consumption of raw materials i.e. fertilizers, pesticides, irrigation and processing water, energy and agricultural/processing waste, as well as to calculate emissions of pollutants (CO_2, CH_4, VOCs, NO_x, SO_2 etc.) to air, water and soil. In the frame of BalkanROAD, the "current situation" is analyzed, acting as a basis for undertaking performance tracking, and/or to set improvement environmental targets and monitor progress against them. It includes common farm management and normal mode of field-work processes for agricultural production (both cultivation and processing/post-harvest), by considering data extrapolated from the past 5 years (2013-2017). This "current scenario", based on the actual current cultivation/processing and waste/by-product management practices that take place in the Greek pilot area (Ktima Kyr-Yianni vineyards), will be further used as the basis for comparison with the "build up" scenarios representing alternative sustainable and plausible farm/processing and waste management options followed during BalkanROAD.

3.2.1 Functional Unit

The functional unit (FU) selected in this "cradle to winery gate" LCA study is the production of one 0.75 L bottle of red wine i.e. the common capacity of regular wine bottles. This volume-based FU is adequate in this study since its scope is a marketable product, including packaging of the final product along with its distribution to relative market. It includes the primary packaging (bottle and caps/lids) and secondary packaging (e.g. distribution box). Similar FUs have also been found in the LCA literature related to previous "cradle to winery gate" studies (**Table 3.1**).

Table 3.1 Examples of functional units in published "cradle to winery gate" LCA studies related to wine production

Wine type	Functional Unit	Study area	Reference
Red	One bottle of 0.75 L	Abruzzo/Italy	Arzoumanidis et al., 2014
Red	One bottle of 0.75 L	Central Italy	Bonamente et al., 2016
Red	One bottle of 0.75 L	Australia	Amienyo, et al., 2014
White	One bottle of 0.75 L	Portugal	Neto et al., 2013
White, Red	One bottle of 0.75 L	Italy, Spain, Luxembourg	Vázquez-Rowe et al., 2013
White, Red	One bottle of 0.75 L	Italy	Rinaldi et al., 2016
Red	One bottle of 0.75 L	Catalonia/Spain	Meneses et al., 2016

It is important to note that the selected FU is the most representative marketable wine product of the area under study and in turn of the pilot site. More details concerning the FU used in this study are provided in **Fig. 3.4.** This functional unit was used as reference in order to normalize input and output flows in all cultivation/processing and waste management stages considered.

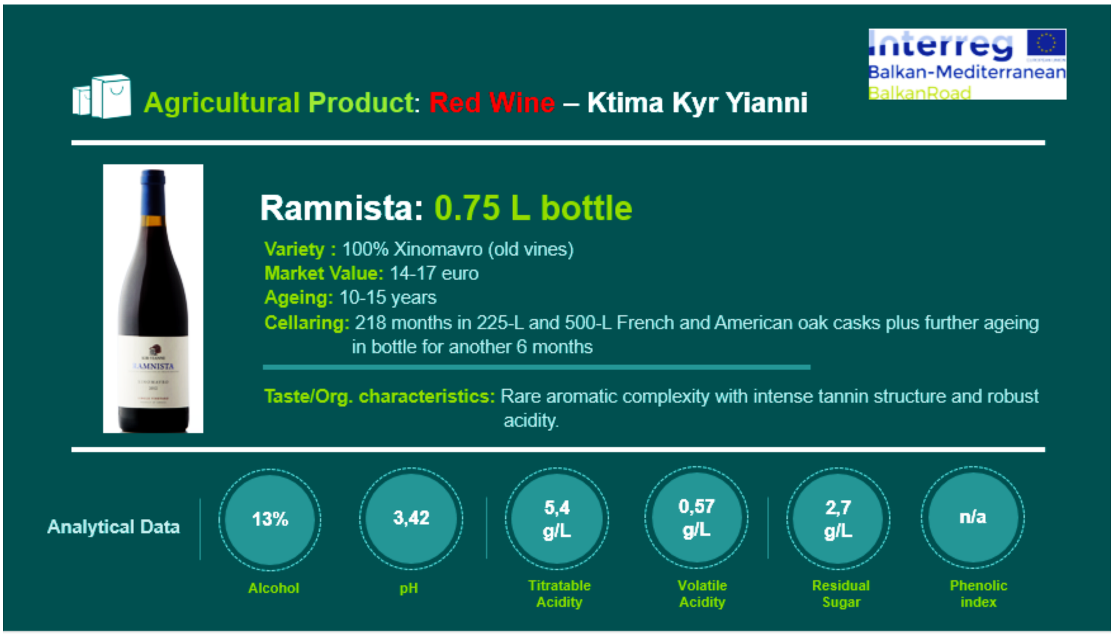

Figure 3.4 Product characteristics of the FU adopted in this LCA study

3.2.2 *System Description*

In the present LCA study, the "cradle-to-winery gate" approach is used, considering all production processes involved from raw materials extraction (i.e. the cradle) to the point where the final product is made available to the market (i.e. the gate after processing) **(Fig. 3.5).** However, aiming to establish a reliable comparison basis of the marketable products under study, an expanding "cradle-to-winery gate" approach is adopted to meet the objectives of the BalkanROAD project, including the stage of distribution (**Fig. 3.6**). In this context, the port of Thessaloniki (94,1 km distance) is used as the final destination of the FU considered.

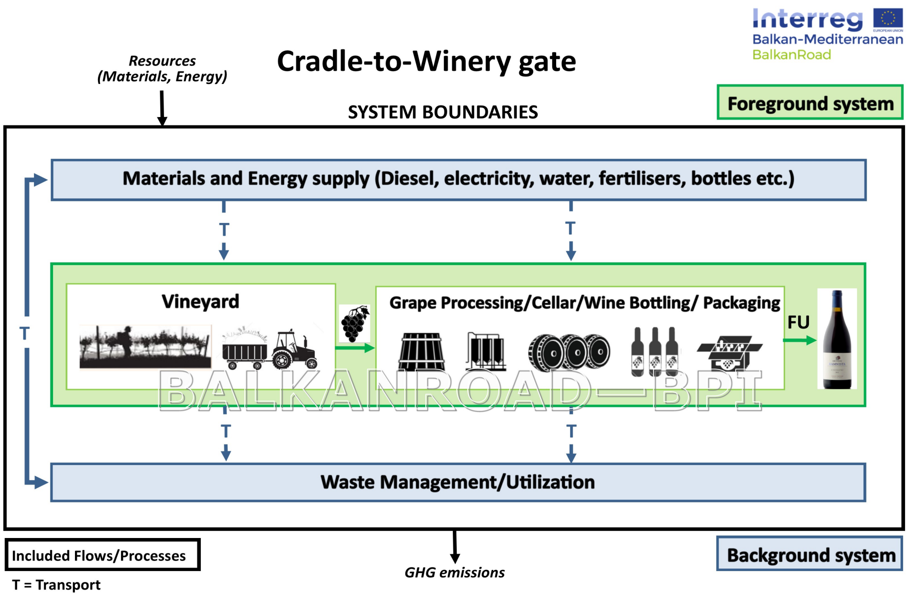

Figure 3.5 System boundaries adopted in the present LCA study

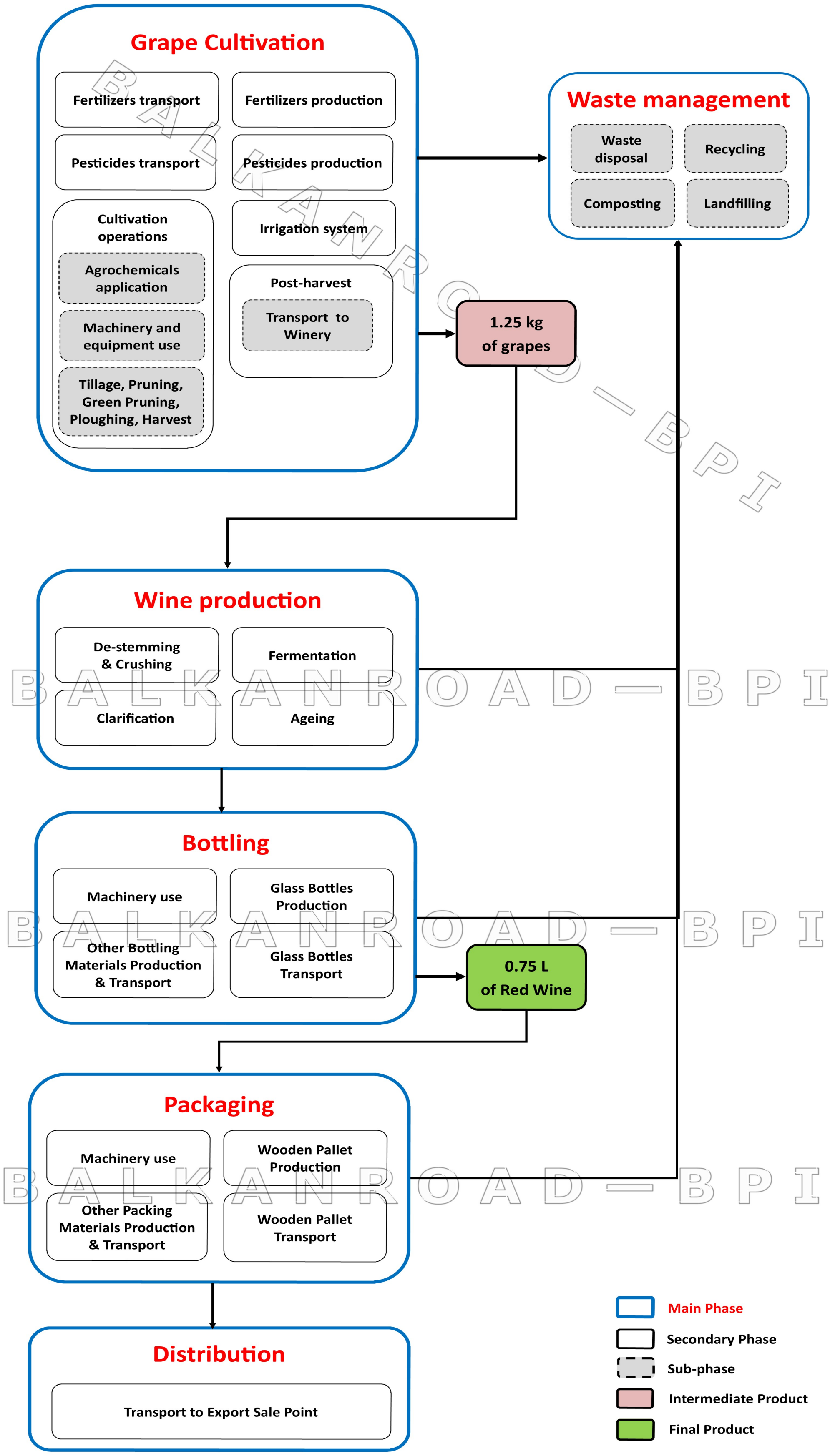

Figure 3.6 Analytical system boundaries adopted in the present LCA study

3.2.3 Data Collection

Data collection regarding wine production was enabled through an in-situ survey conducted in the pilot area. This approach essentially aimed at increasing the credibility of LCA analysis, as well as at drafting conclusions relying on the local agricultural and economic conditions. As a result, primary site-specific data (both cultivation and processing) were used for operations performed at the vineyards and the wine-making, bottling, packaging and distribution stages. To complete the life cycle inventory, data associated with the operations performed in the background system (agro-chemicals production, fertilizers production, bottles production, packaging materials production and transportation) were drawn from literature and well-established LCI databases i.e. Ecoinvent v3.3 and Agribalyse). The data for energy use which were necessary to calculate the cumulative energy demand for each unit process were obtained from the Ecoinvent v.3.3 database.

3.2.4 Modelling approach, Impact categories and Assigned burdens

The openLCA 1.7.0 software, created by GreenDelta, including Ecoinvent v3.3 and Agribalyse databases was used to quantify and compare mid-point impact categories of the wine production (openLCA, 2017). OpenLCA is a free, flexible, modern, fully featured and professional LCA software package that has gained increasing attention in the research community in recent years (Rossi et al., 2016). As a result, almost all free and commercial LCA databases and LCIA methods available, which are now provided by different institutions can be imported in only one integrated software. The latter feature of openLCA has increased considerably its functionality and credibility among all LCA software available on the relative market today.

The LCA flow diagram for the wine production as modelled in the OpenLCA v 1.7.0 software, concerning main phases is given in **Fig. 3.7.**

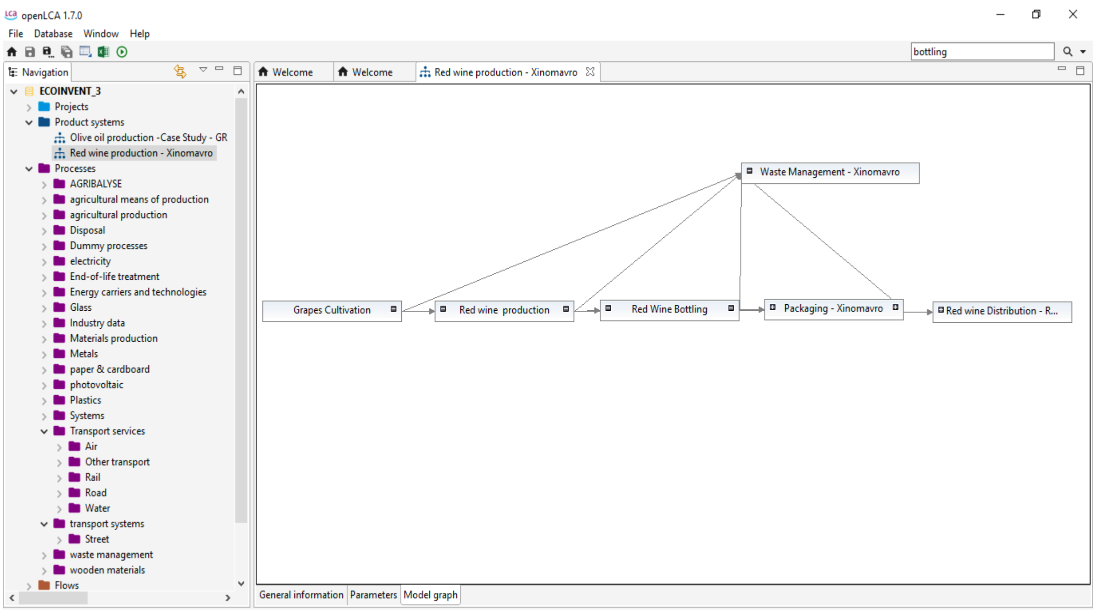

Figure 3.7 Life cycle modeling of the main phases considered for the environmental impact assessment of wine production under study using OpenLCA v 1.7.0 software

By taking into account the phases of classification and characterization defined by the standards of **ISO 14040-14044 series,** the selection of impact categories was chosen according to the goal and scope of the study. During the classification phase, each burden is linked to one or more impact categories, while in the characterization phase the contribution of each burden to each impact category is calculated by multiplying burdens with a characterization factor.

As a result**, five mid-point environmental impact categories**, defined according to the **CML 2001 (April 2013 version)** impact assessment method reported by the Centre of Environmental Science of Leiden University (Guinée et al., 2001; 2002), as well as the impact category of the cumulative energy demand as an energy flow indicator, were considered as shown in **Table 3.2.** The CML method was selected because it is well recognized and widely used in several LCA agricultural studies for allowing clear and precise quantification of a wide range of critical impact categories related to the use of energy and application of fertilizers and pesticides with considerably lower level of uncertainty compared to end-point methods (Cellura et al., 2012b, Perrin et al., 2014; Bartzas et al., 2015; Bartzas and Komnitsas, 2017). In addition, CML 2001 is the only recent impact assessment method that includes a characterization factor for phosphorus. The cumulative energy demand (CED) impact category was also calculated based on the method proposed by Frischknecht et al. (2005), in order to assess the energetic performance of the corresponding agricultural production/processing cycle. Demand for energy as well as waste production was mainly estimated based on primary data (survey).

Table 3.2 Environmental impact categories with their respective units

Impact category	Acronym	Units
Acidification potential	**AP**	kg SO_2-eq·FU^{-1}
Eutrophication potential,	**EP**	kg PO_4-eq·FU^{-1}
Global warming potential (100 years)	**GWP**	kg CO_2-eq·FU^{-1}
Ozone depletion potential	**ODP**	kg CFC-11-eq·FU^{-1}
Photochemical ozone creation potential	**POCP**	kg C_2H_4-eq·FU^{-1}
Cumulative energy demand	**CED**	GJ-eq·FU^{-1}

FU: Functional Unit

In evaluating the environmental impact, consideration is given to the net environmental balance between the environmental benefits and assigned burdens, including waste management and utilization aspects i.e. Waste management phase, associated with the adaptations throughout the various cultivation and processing stages of the products (main and secondary) being considered. To this end, and in accordance with the objectives of the present study, the cut-off method was used for the utilization of the produced waste from all studied cultivation cases, as defined by Ekvall and Tillman (1997). For each main phase, the burdens for which this is directly responsible are assigned. Based on this method, there is no uncertainty in the extraction of raw materials or the related production and transport processes.

3.2.5 Assumptions

The following assumptions were considered in the present LCA study, to ensure integrity and less uncertainty of the obtained results:

1. The share of capital goods such as machinery, buildings (infrastructure) and capital equipment was not included in the whole wine production cycle, because they generally contribute little to LCA results on a long-term basis (Lifetime of production > 50 years).
2. The grid mix of electricity power in Greece, for the year 2016, was taken into account as the main source for irrigation and post-harvest operations (wine-making, bottling, packaging). The energy mix consisted of 49.3% lignite, 16% hydro power, 15.3% oil, 18.5% natural gas and 0.9% renewables (PPC, 2017).
3. The lifetime of the submersible pumps used for irrigation was assumed to be 20 years. Pumping energy requirements refer to a typical well located in the study area with a depth of about 50 m, pumping capacity 40 HP (Horse-Power), pumping efficiency of 75% and water flow rate of 60 $m^3 h^{-1}$.
4. Storage of grapes (in refrigerator for 24h prior to processing) and wine bottles (after production) was excluded from the wine production cycle due to its minimal contribution to all impact categories studied (limited in time).
5. The share of the wine nursery stage was not included in the present LCA study, since little data exist. However, wine planting was included in the stage of grape cultivation since the replacement of dead or damaged vines is a daily task of the pilot site under study.
6. Small to Medium horse power tractors (80 HP) were considered in this study because their use is typical for vineyards farms in Naoussa. Diesel consumption of these tractors was estimated depending on the task used i.e. 5.5 and 7.5 L/h for light tasks (application of fertilizers and pesticides) or heavy tasks (ploughing, transportation), respectively.
7. Transportation of farm materials (e.g. fertilizers, agrochemicals) included a full payload for outgoing transport and empty for return using typical cargo vans of 3.3 t M.A.P . Regarding transport of packed wine bottles on pallets, a distance of 94.1 km from the winery to the shipment point (Thessaloniki port) via heavy-duty trailer trucks – Euro 5 (> 28 t M.A.P) was considered.
8. The contribution of the “Waste Management” stage has been incorporated proportionally in the main stages wherein outputs such as wastes and by-products were generated.

4 Life Cycle Inventory (LCI)

The main agronomic characteristics and the LCI inventory data for grape cultivation and wine production in the Greek pilot site are given in Tables 4.1 and 4.2, respectively. Both Tables also provide information concerning the origin and the quality of the LCA data used. All input data refer to normal operation (cultivation and processing) of the Greek pilot site, excluding unexpected events (that caused operating problems, extreme loss of yield, extreme climate conditions etc.).

Table 4.1 Main agronomic characteristics and LCI data of the grape cultivation

Characteristics	Unit*	Grape	Origin/data quality
Cultivar	-	Xinomavro	Survey
Vine age	years	30	
Density	plants ha^{-1}	400	
Grape Yield**	t ha^{-1}	9.4	
Harvest period	-	August - October	
Irrigation technique	-	Surface/Sub-surface drip irrigation	
Irrigation period	-	June-July (1-2 times per year)	
Fertilizers application rate			
N (as N)	kg ha^{-1}	200	Survey/Ecoinvent
P (as P_2O_5)	kg ha^{-1}	-	
K (as K_2O)	kg ha^{-1}	200	Survey/Ecoinvent
Pesticides application rate			
Fungicides	L ha^{-1}	32	Survey/Ecoinvent
Insecticides	L ha^{-1}	3.2	Survey/Ecoinvent
Other			
Sulfur	kg ha^{-1}	30	Survey/Ecoinvent
Irrigation water	m^3 ha^{-1}	450	Survey/Ecoinvent, Agribalyse
Electricity	MJ ha^{-1}	1,800	Survey/Ecoinvent, (PPC, 2017)
Diesel consumption	L ha^{-1}	210	Survey/Ecoinvent
Lubricants	L ha^{-1}	6.3	Survey/Ecoinvent

*Mean values refer to the period 2013-2017 (Year 2013 was excluded); ** refer to capable grapes for wine-making

Table 4.2 Main characteristics and LCI data of the wine production/Vinification

Characteristics/LCI data	Unit*	PDO Red Wine	Origin/data quality
Grape to Wine Yield	kg / L	1.67 (1.25 for FU)	Survey
Operation (Duration)	days y^{-1}	300	
Density	plants ha^{-1}	400	
Production capacity (Grapes processing)	t y^{-1}	25 Winery 6 Bottling	
Production capacity (FU)	bottles y^{-1}	8,000	
Total power of mechanical equipment	kW	18 Winery 5 Bottling	
Bottling			
Wine	mL	750	Survey/Ecoinvent
Glass	kg	0.57	
Cork	g	4.2	
Capsule	g	1.3	
Sticky label	g	1.1	
Packaging			
Corrugated cardboard box (six-bottle)	g	50	Survey/Ecoinvent
Wooden pallet	kg	0.0160	
Plastic film	g	0.7	
Distibution			
Number of pallets per truck	number	33	Survey/Ecoinvent
Number of boxes per pallet	number	100	
Number of bottles per box	number	6	
Transport to shipment point	km	94.1	
Other			
Water	L	0.25	Survey/Ecoinvent,
Electricity	MJ	0.67	Survey/Ecoinvent, (PPC, 2017)
Diesel consumption	L	0.06	Survey/Ecoinvent
Lubricants	L	0.02	Survey/Ecoinvent

*refers to FU or per year

In this LCA study energy consumption and emissions from each stage have been quantified, while transport between the different stages has been taken into account where needed. Notably, the transport processes of the principal materials (e.g. bottles, fertilisers) were considered while minor material and energy flows accounting for less than 1% of the total were excluded. Therefore, the neglected processes do not exceed 5% of those involved in the entire process based on the system boundaries adopted in this study.

5 LCIA Results and discussion

5.1 Overall results

In the interpretation step, the results were analyzed according to the scope and goal of the study, to identify the most important aspects of the production system under study and determine which activities cause the most significant environmental impacts.

The absolute values of each impact category and the cumulative energy demand for the red wine production under study are shown in Table 5.1 (Results are expressed in units per FU). Under the systems boundaries selected and the relative LCI used, the production of one 0.75 L bottle of red wine from the pilot site of Ktima Kyr-Yianni and distributed to Thessaloniki port consumes 21,31 MJ and releases 1,102 kg CO_2-eq, 1,98E-02 kg SO_2-eq, 5,62E-03 kg PO_4-eq, 2,21E-07 kg CFC-11-eq and 4,48E-04 kg C_2H_4-eq., respectively.

Table 5.1 Impact for each category and cumulative energy demand of the red wine production investigated

Impact Category	Unit	Value
Acidification potential (AP)	kg SO_2-eq·FU^{-1}	1,98E-02
Eutrophication potential (EP)	kg PO_4-eq·FU^{-1}	5,62E-03
Global warming potential (GWP) (100 years)	kg CO_2-eq·FU^{-1}	1,10E+00
Ozone depletion potential (ODP)	kg CFC-11-eq·FU^{-1}	2,21E-07
Photochemical ozone creation potential (POCP)	kg C_2H_4-eq·FU^{-1}	4,48E-04
Cumulative energy demand (CED)	MJ·FU^{-1}	2,13E+01

FU: Functional unit = one 0.75 L bottle of red wine – Xinomavro variety

In order to elucidate the origin of environmental and energy burdens and link them with specific phases of the red wine production, a contribution analysis was carried out and is presented below.

5.2 Contribution analysis

Figure 5.1 presents the results of the impact assessment phase for the production of red wine in the pilot site of Ktima Kyr-Yanni. In this figure, results are given for every impact category and show the percentages for each main phase examined to the cumulative impact (100% corresponds to the values reported in Table 5.1).

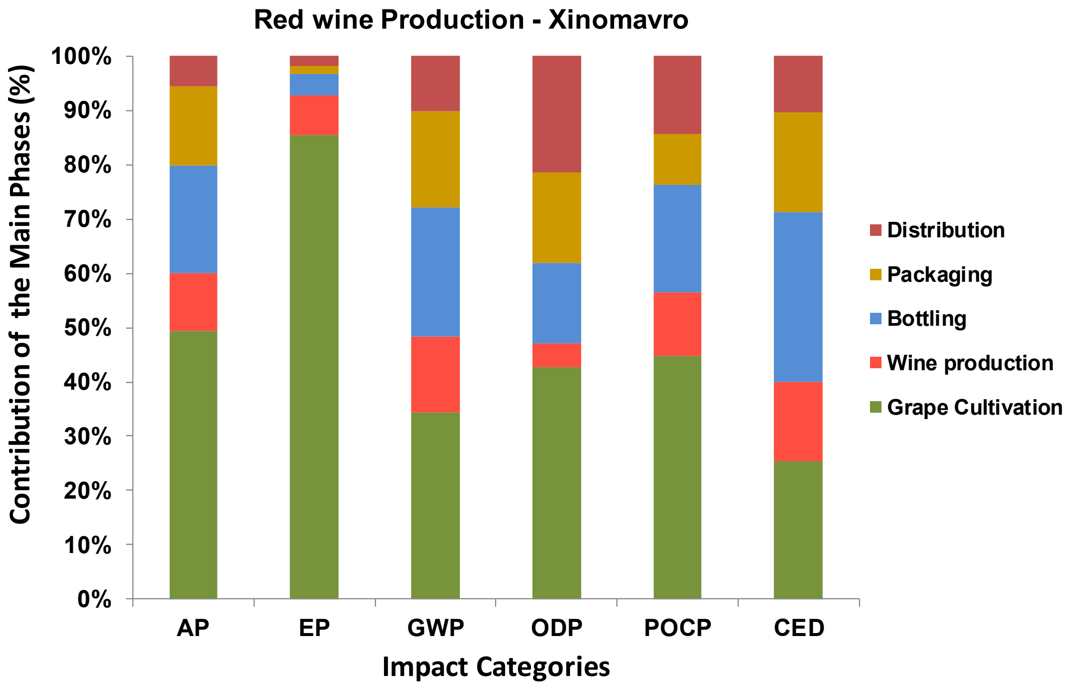

Figure 5.1 Impacts characterization results of Ktima Kyr-Yianni red wine's life-cycle from cradle to winery gate; Relative contribution of impact category indicators (CML 2001 method) among each phase production. (AP: acidification potential; EP: eutrophication potential; GWP: global warming potential (100 years); ODP: ozone depletion potential; POCP: photochemical ozone creation potential and CED: cumulative energy demand).

According to Figure 5.1, several processes are responsible for important contributions, up to 86% depending on the impact category, to the environmental and energy profiles associated with the production of one 0.75 L bottle of red wine. Among studied phases and in agreement with Point et al., 2012 and Neto et al. (2013), the highest contribution impact was assigned for the grape cultivation phase, which represented 25-86% of the cumulative impacts for all the impact categories considered, except for cumulative energy demand (CED). This result is mainly attributed to the high CO_2 and N_2O emissions given off during the fertilizers' manufacture i.e ammonia synthesis and nitric acid production, respectively; however, emissions related to AP, EP, and POCP were caused almost entirely by volatilization and leaching of nitrogenous compounds from N-based fertilizers' application (200 kg ha^{-1}) in the grape cultivation.

The phase of bottling had the second highest contribution to impact categories of AP and GWP, except for CED. Especially for this category, the bottling phase was the first contributor, responsible for approximately 31% of the cumulative impacts. The aforementioned environmental burdens were due to energy consumption for the production of glass bottles, contributing 80% to CED of the single impact score and the production of other bottling accessories (cork stoppers, caps and paper labels), i.e. 10% of the single impact score. Significant environmental impacts were also perceived in the grape cultivation (25%) and packaging (18%) phases in terms of CED, mainly due to emissions derived from raw material extraction and their processing i.e. N/P/K fertilisers and packaging materials (cardboard boxes, pallets etc.), respectively. The bottling phase represents also a significant burden in the GWP, contributing 24%, followed by the packaging (18%) and wine production (14%). Regarding AP, the bottling phase was responsible for approximately 20% of the cumulative impacts due to the emission of nitrogen oxides and sulfur dioxide during upstream processes of glass bottles and caps production.

Moreover, the share of packaging for most impact categories ranged between 9% and 18%, except for EP, which exhibited an almost negligible contribution (1%). Packaging processes prior to distribution showed important contributions for GWP (18%), AP (15%) and POCP (14%). In the case of ODP, the packaging phase was responsible for 17% of the cumulative impact (third contributor) due to emissions of Halon and R114 used for the production of cardboard boxes.

The wine production phase hardly ever contributes more than 11% to the total impact of red wine production, except for GWP (14%) and CED (15%). These impacts were due to the use of electricity in the winery. The impacts related to wine production/vinification were also found to be significant for POCP as a result of emissions created by CO, acetaldehyde and ethanol.

The lowest impacts but of critical importance were ascribed to distribution phase, ranging between 2% and 14% to all impact categories, except for POCP, for which the contribution (9%) was due to nitrogen oxide emissions (NO) derived from fuel combustion (diesel) used in transport to Thessaloniki port via heavy-duty trailer trucks – Euro 5 (> 28 t M.A.P).

6 Conclusions

In the present study, a detailed life cycle assessment analysis of a typical agricultural product in Greece (red wine) has been performed. With the use of five environmental indicators as well as one indicator concerning energy, it was possible to identify the activities causing the highest impacts across and five main life cycle phases (grape cultivation, wine-making/vinification, bottling, packaging and distribution).

According to the LCA results, the production of one 0.75 L bottle of red wine from the pilot site of Ktima Kyr-Yianni and distributed to Thessaloniki port consumes 21,31 MJ and releases 1,102 kg CO_2-eq, 1,98E-02 kg SO_2-eq, 5,62E-03 kg PO_4-eq, 2,21E-07 kg CFC-11-eq and 4,48E-04 kg C_2H_4-eq., respectively. Contribution analysis revealed that the environmental impacts associated with the current production of red wine in the pilot site are mainly due to the life cycle phases of grape cultivation and wine bottling.

Overall, the present study highlighted the importance of the implementation of an LCA study to evaluate environmental impacts caused by agricultural practices and wine-making/bottling/packaging processes in vineyards and processing units, respectively.

7 References

Amienyo, D.; Camilleri, C.; Azapagic, A. **2014**. Environmental impacts of consumption of Australian red wine in the UK. *Journal of Cleaner Production* 72, 110–119.

Arzoumanidis, I.; Raggi, A.; Petti, L. **2014.** Considerations When Applying Simplified LCA Approaches in the Wine Sector. *Sustainability,* 6, 5018–5028.

Bartzas, G. Komnitsas, K. **2017.** Life cycle analysis of pistachio production in Greece. *Science of the Total Environment* 595: 13–24.

Bartzas, G., Zaharaki, D., Komnitsas, K. **2015.** Life cycle assessment of open field and greenhouse cultivation of lettuce and barley. *Information Processing in Agriculture* 2(3-4): 191–207.

Bonamente, E.; Scrucca, F.; Rinaldi, S.; Merico, M.C.; Ardrubali, F.; Lamastra, L. **2016.** Environmental impact of an Italian wine bottle: Carbon and water footprint assessment. *Science of the Total Environment* 560–561, 274–283.

Cellura, M., Ardente, F., Longo, S., **2012a.** From the LCA of food products to the environmental assessment of protected crops districts: a case-study in the south of Italy. *Journal of Environmental Management* 93, 194–208

Cellura, M., Longo, S., Mistretta, M. 2012b. Life cycle assessment (LCA) of protected crops: an Italian case study. *Journal of Cleaner Production* 28: 56–62.

Ekvall T. and A. Tillman, **1997**. Open-loop recycling, criteria for allocation procedures. *International Journal of Life Cycle Assessment* 2 (3), 155–162.

Frischknecht, R., Jungbluth, N., Althaus, H.J., Doka, G., Dones, R., Heck, T. **2005**. The ecoinvent database: overview and methodological framework. *International Journal of Life Cycle Assessment* 10, 3–9.

ISO, **2006a**. Environmental Management – Life Cycle Assessment – Principles and Framework, ISO 14040. ISO, Geneva, Switzerland.

ISO, **2006b**. Environmental Management – Life Cycle Assessment – Requirements and Guidelines, ISO 14044. ISO, Geneva, Switzerland.

Meneses, M.; Torres, C.M.; Castells, F. **2016**. Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain. *Science of the Total Environment* 562, 571–579.

Neto, B.; Dias, A.C.; Machado, M. **2013**. Life cycle assessment of the supply chain of a Portuguese wine: From viticulture to distribution. *International Journal of Life Cycle Assessment* 18, 590–602.

openLCA, **2015**. GreenDelta. http://www.openLCA.org.(accessed 21.12.17).

Point, E., Tyedmers, P., Naugler, C., **2012**. Life Cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. *Journal of Cleaner Production* 27, 11–20.

PPC - Public Power Corporation **2016**. Energy mix of PPC S.A. for the year 2017. https://www.dei.gr/en/i-dei/enimerwsi-ependutwn/etairiki-eikona/tautotita-etaireias (accessed 14.06.18).

Rinaldi, S.; Bonamente, E.; Scrucca, F.; Merico, M.C.; Asdrubali, F.; Cotana, F. **2016.** Water and Carbon Footprint of Wine: Methodology Review and Application to a Case Study. *Sustainability,* 8, 621.

Rossi, M., Germani, M., Zamagni, A., **2016**. Review of eco-design methods and tools, barriers and strategies for an effective implementation in industrial companies. *Journal of Cleaner Production* 129, 361–373.

Vázquez-Rowe, I.; Rugani, B.; Benetto, E. **2013.** Tapping carbon footprint variations in the European wine sector. *Journal of Cleaner Production* 43, 146–155.