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Wine Packaging Waste in Greece: A Preliminary Analysis based on Life Cycle Assessment

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ABSTRACT
The aim of the study is to carry out a screening life cycle assessment (LCA) of PET and Glass wine packaging, to find out which wine packaging has the lowest environmental impact. The current systems for packaging production require large inputs of resources and cause several negative environmental effects. The investigated system includes packaging, transportation, consumption and waste management. Energy use and emissions were quantified and some of the potential environmental effects assessed. Also, a life cycle inventory (LCI) case study from the Greek market is presented. At the end, an environmental impact assessment using the Eco-Indicator '99 method was conducted, which highlights that glass pack of 750ml achieved the worst environmental performance. These results could help policymakers to take more eco-conscious decisions concerning wine packaging.
Keywords: *Life Cycle Assessment (LCA), wine packaging, LCA PET, LCA Glass, Environmental impact, Eco-Indicator '99 method*

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I. INTRODUCTION

Nowadays, consumers and producers are becoming increasingly concerned about the environmental impact of products and services, and demand specific sustainability. Furthermore, consumers want to know how recyclable the products are (Nielsen, 2018). Organizations - more and more often- provide information if their products and services are environmentally friendly and how they plan to deliver their goods and services in a sustainable manner. Life Cycle Thinking (LCT), which is a qualitative concept, Life Cycle Assessment (LCA) and LCA-based tools can provide a way for organizations to achieve their sustainability goals (Curran, 2012; Finkbeiner et al., 2010). Also, Life Cycle Thinking (LCT) and LCA can support European, national and local public authorities and businesses towards Waste Management Decisions, identifying the (environmentally) preferable options (EU, 2012). LCT can help manufacturing industry to understand "the bigger picture", as LCA methodology considers all the environmental impacts that are related to the value chain of a product, and decide the strategy that links design and business strategy towards circular economy (CE) (Lieder et al., 2017; Pajula et al., 2017). Moving towards a CE with improved waste and materials management is a critical issue (OECD, 2020). Today product design is facing a new challenge of eliminating waste (Singh & Ordoñez, 2016) Furthermore, it has to be mentioned that 46% of Europeans (EU28) think that the growing amount of waste is an important environmental issue (EU, 2019a).

Bottle, jars and other containers are the products of hollow glass sector, using silicon dioxide (70-74%), sodium oxide (12-16%) calcium oxide (5-11%), magnesium oxide (1-3%) and aluminium oxide (1-3%) as raw materials (EU, 2017). According to Glass Alliance Europe (GAE), in 2018 21,76 million tonnes of glass containers in EU 28 were produced (GAE, 2019). Furthermore, glass is a major fraction of municipal solid waste (MSW) (Larsen et al., 2009), the management of which has always been a major problem (Bölükbaş & Akıncı, 2018). Moreover, EU produces around 322 million tonnes of plastic per year, about 60 % of which is used in packaging and consumer goods (EU, 2019b). In 2016, 485 polyethylene terephthalate (PET) bottles worldwide were produced and in 2021, 583.3 billion of these plastic bottles will be produced (PET Global Bottle Production 2021, 2019)

The European Union is the world-leading producer of wine. Between 2014 and 2018, the average annual production was 167 million hectoliters. It accounts for 45% of world wine-growing areas, 65% of production, 60% of global consumption and 70% of exports (EU, 2019). According to International Organization of Vine and Wine (OIV), in 2018 Greece had 106,000 hectares under vines, produced 2.2 million hectoliters and consumed 2.1 million hectoliters of wine (OIV, 2019). The wine sector consumes large amounts of energy in the different phases of winemaking: grape growing, vinification, bottling, and distribution (Garcia-Casarejos et al., 2018). On the other hand, climate change has a direct influence on wine quantity and quality, and wine sector is extremely vulnerable to climate variability thus, should adopt strategies and policies to address the harmful consequences. Furthermore sustainability is considered as an important topic for the wine industry (Valero et al., 2019)

The wine production constitutes of seven stages: Vineyard planting, Viticulture, Winemaking, Packaging, Distribution, Storage & Consumption. Waste treatment and the average contribution to carbon footprint (CF) of each stage is 6%, 18%, 11%, 23%, 13%, 18%, 11% respectively, with typical glass bottle having the most carbon footprint (DEG, 2017). An important contributor to the CF of wine production is packaging. Literature regarding CF of one bottle of wine is quite extensive and according to a study CF of red wine is 1.433 kgCO2eq/bottle, and CF of the white wine is 1.377 kgCO2eq/bottle, when the functional unit is a 0.75 L wine bottle (Rinaldi et al., 2016).

The study uses the screening life cycle assessment (LCA)(Gyetvai, 2012) methodology to assess the environmental impacts of plastic (PET) and glass of Greek wine packaging system. Screening LCA is a simplified LCA method used to identify the initial data collection and interpretation of the environmental effects of a product system (Goglio & Owende, 2009; Weidema, 1995), hence a more comprehensive assessment using a complete LCA study is necessary to be conducted in the future. Current systems for packaging production require large inputs of resources and cause several negative environmental effects. The study's goal is to find which wine packaging has the lowest environmental impact. The quantified environmental impacts could be an indicator for wine producers of which wine packaging is more environmentally-friendly practice. Also the findings may prove useful for public policies that aim to improve the eco-profile of wine, the Eco labeling of wine products, waste management or innovation of agricultural products. It has to be mentioned that this is a preliminary research and findings should be confirmed by a more thorough research. Also, to our knowledge, there is a lack of studies that analyses Greek wine packaging system.

II. MATERIAL AND METHODS

2.1 Overview of Life Cycle Assessment methodology

Life cycle Assessment (LCA) is perhaps the most commonly accepted method of assessing the environmental impact caused by product manufacturing systems, as widely used to evaluate potential impacts of products or also services, from extraction of raw materials until the end-of-life of a product (Wowra et al., 2020). In both cases potential environmental impacts associated with the lifecycle of a product/service are assessed based on a life cycle inventory (Garrigues et al., 2012; Turconi et al., 2013). The widespread use of the methodology is due τo quantification of potential environmental impacts over the whole life cycle of a product/service, process or activity (Azapagic & Clift, 1999; Pieragostini et al., 2012; Treyer & Bauer, 2016). LCA is a well-established environmental management tool, useful for sustainable decision making that can be used to assess waste management configurations (Chang & Pires, 2015; Christensen et al., 2020; Vougioukli et al., 2017; Winkler & Bilitewski, 2007). An LCA study can help to better understand systems (e.g. a waste management system) and to improve their performance (García-Gusano et al., 2017; D. A. Georgakellos, 2006; Parkes et al., 2015).

LCA, started as a decision-making tool. It appeared in the 1970s and has been in constant development since then, so as to minimize environmental problems, through all life cycle stages of a product: from extraction and processing of raw materials to manufacturing, transportation and distribution, and finally reuse, maintenance, recycling, and final disposal (Pajula et al., 2017). LCA has been standardised by the ISO 14040 series (ISO, 2006). The LCA framework is developed in four stages and is given in Fig 1. LCA may facilitate private and public sector decision makers to a better informed decision process (Bosso et al., 2012; Dong et al., 2018) and several life cycle inventory (LCI) databases and life cycle impact assessment (LCIA) methods are available (Harder et al., 2015). Furthermore, LCA could be a considerable basis for the identification of Key Performance Indicators (KPIs) for the assessment of a process (Dorn et al., 2016)

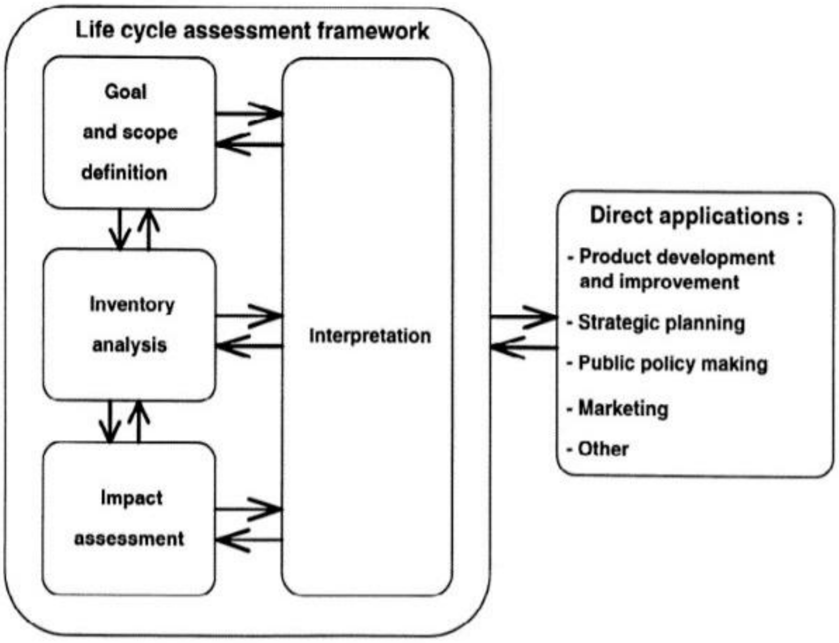

Figure 1: LCA methodology, Adapted by the authors from ISO 14040 (ISO, 1997)

2.2 Case Study: LCI of Glass and PET wine containers

As many people consider glass packaging more sustainable than plastic or multilayer packaging since they do not consider the impacts of production and transportation (Boesen et al., 2019; Ferrara & De Feo, 2020), LCA methodology could be used to assess environmental impact of food packaging systems (Molina-Besch et al., 2019). In this study two wine packaging systems were evaluated a) refill-able glass bottle and b) PET bottle using LCA methodology. The results of previous life cycle inventory analysis concerning the particular packaging materials in Greek market have been used (D. A. Georgakellos, 2005). It has to be pointed out that may be differences from the ideal system boundaries as LCI model with ideal boundaries is practically impossible (Bjørn, Owsianiak, et al., 2018).

Goal and Scope

The first phase of an LCA is the definition of the goal and scope, according to the ISO 14040 standard. In this phase all general decisions for setting up the LCA system are made such as the reason for executing the LCA, a precise definition of the product and its life cycle, and a description of the system boundaries. The goal and scope should be defined clearly and consistently with the intended application. Before deciding the study's objective and context, it is necessary to determine its scope and therefore the modeling criteria to be carried out or implemented. Ideally, all of these choices should be made in the target and scope definition process, and these choices should be accompanied by the methods used in the subsequent research phases.

The goal and scope of the conducted LCA is to assess the environmental impacts of glass and PET bottles for wine packaging. The functional unit is defined as packaging 1l or 750 ml of wine in glass or PET bottle.

System Boundary

The life cycle of wine packaging, whether glass or plastic, includes the supply of raw materials, production of the product, distribution, use and end of life, with all that entails either recycling or destruction. Also is included the production of cap and label, the packaging in boxes, the distribution, the return of the recycled, and their reuse. The LCA developed model of a product, service, or system life cycle is a simplification of a complex reality. The challenge is to develop the model in such a way that the simplifications and distortions do not influence the results in a high level. Life Cycle Assessments allow for analysis at various stages of a product’s life cycle (Fig 2):

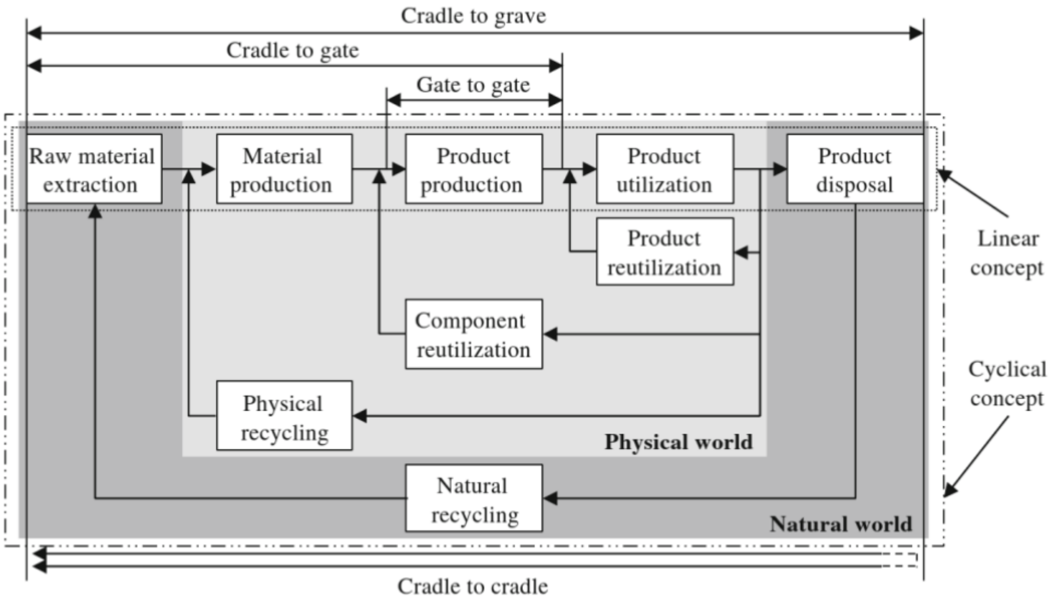

Figure 2: Linear and cyclical product life phase concepts [based on (Herrmann 2010, p. 65)(Winter, 2015)

1. Gate-to-gate — focusing on one particular plant or operation.
2. Cradle-to-gate — gate-to-gate findings with the addition of up-stream providers (mining of raw materials, processing and transportation); and
3. Cradle-to-grave —encompassing the entire linear life cycle of the product from extraction through disposal.
4. Cradle-to-cradle —that includes the entire cradle-to grave life cycle of the product with the addition of recycling the product back to its original purpose.

For this study, a Cradle-to-grave approach is being adopted. In addition, the cap, the label, the packaging in boxes and the distribution up to the return of the recycled, with their reuse are considered.

Transportation of both PET and glass bottles is usually by land. In Greece, land transportation is dominated by trucks. Truck's material is not included in mass and energy balances as it will not affect them. Gas emissions though are included due to the Greenhouse effect.

The system of the life cycle of glass wine packaging consists of 9 subsystems, while the equivalent of plastic bottles consists of 10 subsystems, all of which are shown in Fig 3. The systems were identified based on the principles presented by Georgakellos(D. A. Georgakellos, 2005). Special parameters and assumptions that influence and limit the system are: solid waste refers to the final waste disposal (landfilling), the basis of comparison, the level of technology, the energy system.

The model, which defines numerically the relationships of the individual subsystems to each other in the production of the final product, has been developed and analysed in detail elsewhere (D. Georgakellos, 1998)

Inventory Analysis

The glass container industry is very diverse and covers a variety of different types of technology to produce glass bottles and jars. Container glass begins with melting together several large naturally occurring minerals. The most common raw materials used to produce glass are silica sand (SiO_2) soda ash (Na_2CO_3) and lime ($CaCO_3$) (Rodriguez Vieitez et al., 2011). Furthermore, cullet (waste glass) can be recycled back into glass furnaces, reducing energy consumption (ScienceDirect Topics, 2012). Manufacture of glass bottles, jars and flaconnage produces approximately 518 kg CO_2/t product and approximately 11.6 Mt of CO_2-eq direct emissions (EU, 2009c)

In 2018, 29.1 million tonnes of plastic waste were collected in the EU28 plus Norway and Switzerland and in Greece the waste rate of plastic post-consumer was about 20% (PlasticsEurope, 2019). Bottle grade PET is one of the most important packaging plastics (Shen et al., 2010). PET is formed by step-growth polycondensation from ethylene glycol (EG) and terephthalic acid (TPA). The synthesis requires two steps (prepolymer and polycondensation), the formation of prepolymer can also be achieved by transesterification of dimethyl terephthalate (DMT) with EG (Pudack et al., 2020)

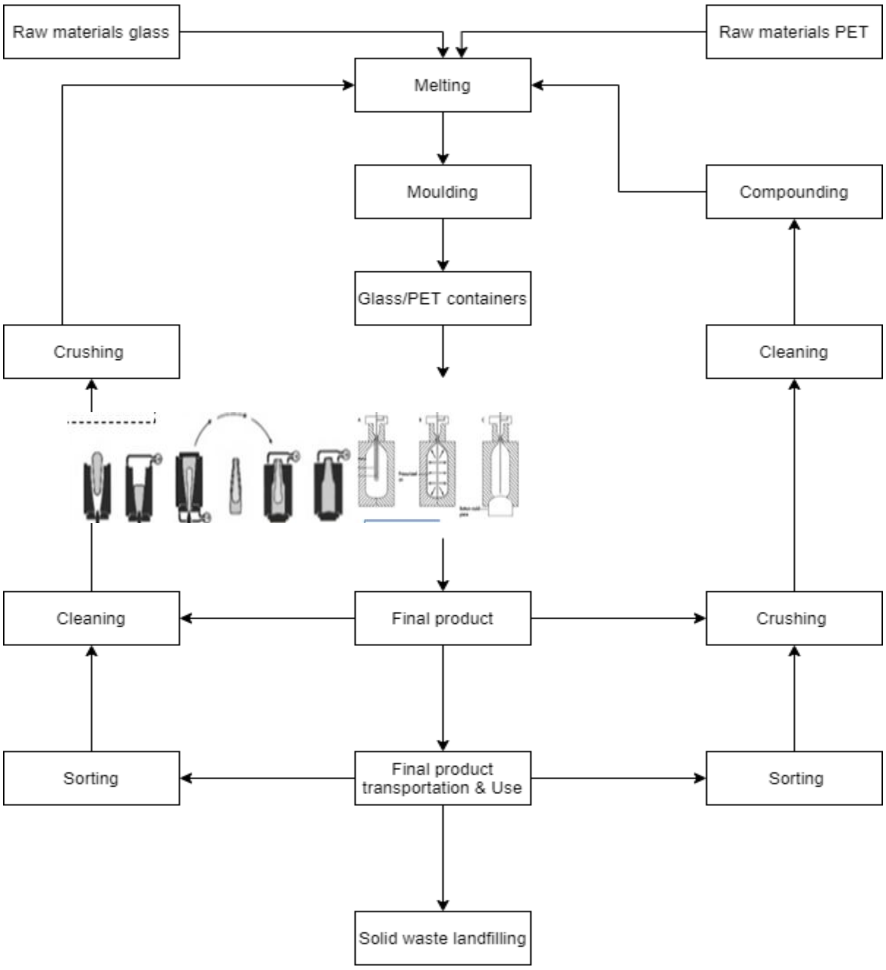

Figure 3: The stages of the system

Mass and Energy Balances: Special conditions, parameters and assumptions

In the system given in Fig. 3, the reference mass is the mass per functional unit and is the required mass of glass and PET containing the packaging of 1000 liters of wine in each case. Whether for plastic or glass, 1000 liters of wine refer to 1000 bottles of 1 liter, while when it comes to 750 ml, refer to 1,333 bottles. The mass of a plastic container of 750ml is 15gr, while that of a glass is 517gr. Regarding the contents of 1L, for plastic the mass is 20gr and for glass it is 689gr (Paschali et al., 2020). In each subsystem, the energy that is consumed is different and the mass remains constant in each subsystem. The energy consumed in each subsystem is Ej (Eq 1) and is calculated as follows (D. Georgakellos, 1998):

$$Ej = ej * mj \quad (1)$$

where,
ej is the energy consumption in each subsystem and
mj is the mass of the subsystem.

The used energy comes from the Greek energy production system and from Greek refineries. Specifically, electricity comes from lignite (coal), oil, gas, in different percentages for each company, for the subsystems that interest us (Fig 4 & Fig 5).

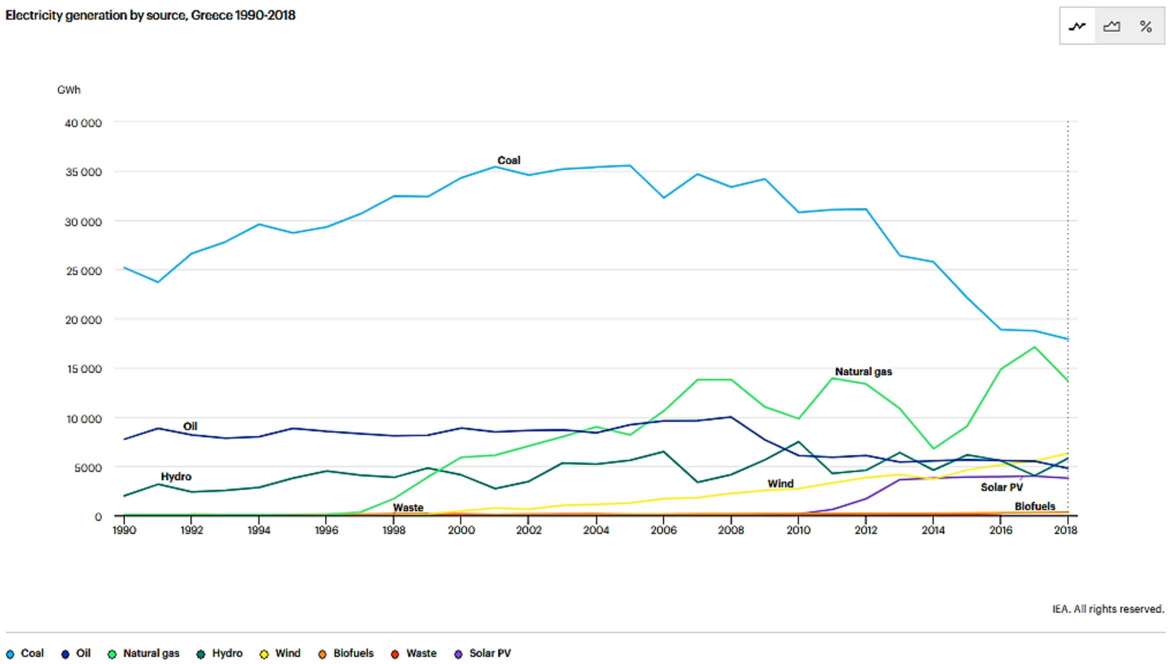

Figure 4: Electricity generation mix of Greece (Data & Statistics, 2019)

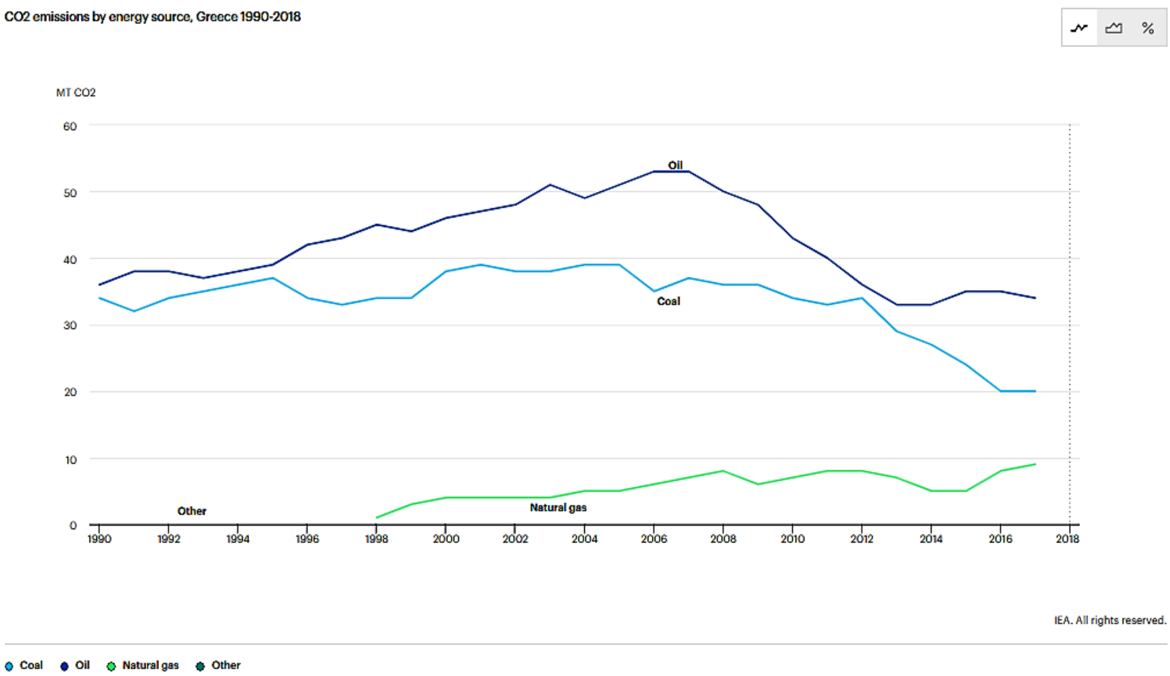

Figure 5: CO2 emissions by source-Greece (Data & Statistics, 2019)

The environmental impact of electricity generation in Greece is (Dei-Anthrakas, 2008)

- 0.9 CO2 Kg/Kwh,
- 0.7 SO2 g/Kwh
- NOX g/Kwh
- 0.3 PM g/Kwh

Energy consumption related to the transport of finished products is also taken into account and in Table 1 the environmental impact through the production of gaseous pollutants consuming of one liter of Diesel (Spielmann et al., 2007) is given.

Table 1: Gaseous emissions from the consumption of one liter of Diesel

Emissions		
CO_2	2.655	Kgr/lt diesel
SO_2	0.017	g/lt diesel
Cd	0.008	mg/lt diesel
Cu	1.423	mg/lt diesel
Cr	0.042	mg/lt diesel
Ni	0.059	mg/ltdiesel
Zn	0.837	mg/ltdiesel

The average number of refilling for glass bottles is 20 times. Due to lack of data, the amount of energy required in this subsystem cannot be estimated at this stage. Also, according to Hellenic Recycling Agency, in 2016, about 100,000 Kg of glass packaging were produced of which 40% is being recycled (HRA, 2017).

III. RESULTS

3.1 Inventory Analysis

The LCI result is a list of quantified elementary flows crossing the system boundary and is the base of assessing the environmental impacts and potential improvements of the studied life cycle (Bjørn, Moltesen, et al., 2018). In this stage environmental outputs associated with glass and PET wine packaging were identified. LCI data, collected from literature or databases (taking account any necessary assumptions and adaptations), are gathered and analyzed. After that, the results of the inventory analysis have been compressed in an eco-profile of three parameters: (1) atmospheric emissions, (2) waterborne waste (3) solid waste

The results of the life cycle inventory analysis of the case study are given in Table 2.

Table 2: Inventory Analysis of Glass and PET Bottles for wine packaging of the Greek Market

	Glass		**PET**	
	0.75 l	**1l**	**0.75 l**	**1 l**
Atmospheric Emissions (gr/1000 lit)				
Particles	5530.603	4149.959	125.405	120.405
Carbon monoxide (CO)	47.541	35.673	1.38	1.035
Hydrocarbons	1118.936	839.608	26.78	24.36
Nitrogen oxides (NOx)	1283.607	963.171	33	27.945
Nitrous oxide (N_2O)	35.828	26.884	0.83	0.78
Sulphur dioxide (SO_2)	2118.675	1589.775	51.038	46.125
Aldehydes	4.134	3.102	0.014	0.009
Organic Compounds	6.201	4.653	0.140	0.135
Ammonia (NH_3)	2.067	1.551	0.050	0.045
Hydrogen chloride (HCl)	24.804	18.612	0.59	0.54
Fluoridea* and hydrogen fluoride (HF)	9.646	7.238	0.26	0.21
Lead (Pb)	6.201	4.653	0.140	0.135
Waterborne Waste (gr/1000 lit)				
Suspended Materials	0.689	0.517	0.020	0.015
Dissolved Materials	1227.798	921.294	31.75	26.73

BOD	0.689	0.517	0.020	0.015
COD	2.067	1.551	0.050	0.045
Oil	16.536	12.432	0.41	0.36
Solid Waste (cm^3 / 1000 l)				
Municipal Waste etc.	10610.6	8111.87	240.35	235.35

* HFC, CFC, HCFC, CF4, F2, etc.

According to these results, PET wine packaging has the lowest environmental impact

3.2 Impact Assessment (LCIA)

At this stage of the life cycle assessment of wine packaging, the environmental emissions reported in the previous stage, are classified into impact categories and characterised per common impact units to make them homogeneous. Most common life cycle impact categories are: e.g. climate change, acidification, human health, aquatic ecotoxicity, resource-depletion, land use, etc(Lorenzo, 2014). A number of LCIA methods are available to the LCA practitioners since the first one appeared in 1984 (e.g. EDIP97, IMPACT 2002+, ReCiPe και EPS CML2001 and Eco-indicator 99) (Dreyer et al., 2003; Rosenbaum et al., 2018; Wu & Su, 2020). The Glass and PET wine packaging, in this study, have been assessed for their potential environmental impact using Eco Indicator 99, and examines 2 types of impacts (PRé Consultants, 2000) which are given in Table 3:

- The impact to human health, measured in Person*Year, defines the expected reduction of average life expectancy.
- The impact to the ecosystem, measured in PDF*m2*yr, defines the percentage of ecosystem that is threatened per m2 per year.

Table 3: Impact Assessment of Glass and PET Bottles for wine packaging of the Greek Market

	Glass		**PET**	
	0.75 l	**1l**	**0.75 l**	**1 l**
Human Health				
Particles (Respiratory effects on humans caused by inorganic substances)	5.53E+00	4.15E+00	1.25E-01	1.20E-01
Factor (DALY/kg)	4.55E-02	4.55E-02	4.55E-02	4.55E-02
ImpactAssessment (DALY)	**2.52E-01**	**1.89E-01**	**5.71E-03**	**5.48E-03**
Nitrogen oxides (NOx) (Respiratory effects on humans caused by inorganic substances)	1.28E+00	9.63E-01	3.30E-02	2.79E-02
Factor (DALY/kg)	5.76E-03	5.76E-03	5.76E-03	5.76E-03
ImpactAssessment (DALY)	**7.39E-03**	**5.55E-03**	**1.90E-04**	**1.61E-04**
Nitrous oxide (N_2O) (Respiratory effects on humans caused by inorganic substances)	3.58E-02	2.69E-02	8.30E-04	7.80E-04
Factor (DALY/kg)	5.76E-03	5.76E-03	5.76E-03	5.76E-03

ImpactAssessment (DALY)	**2.06E-04**	**1.55E-04**	**4.78E-06**	**4.49E-06**
Nitrous oxide (N_2O) (Damages to human health caused by climate change) Factor (DALY/kg)	3.58E-02 4.48E-03	2.69E-02 4.48E-03	8.30E-04 4.48E-03	7.80E-04 4.48E-03
ImpactAssessment (DALY)	**1.61E-04**	**1.20E-04**	**3.72E-06**	**3.49E-06**
Sulphur dioxide (SO2) (Respiratory effects on humans caused by inorganic substances) Factor (DALY/kg)	2.12E+00 3.55E-03	1.59E+00 3.55E-03	5.10E-02 3.55E-03	4.61E-02 3.55E-03
ImpactAssessment (DALY)	**7.52E-03**	**5.64E-03**	**1.81E-04**	**1.64E-04**
Hydrocarbons (Respiratory effects on humans caused by organic substances) Factor (DALY/kg)	1.118936 2.27E-05	0.839608 2.27E-05	0.02678 2.27E-05	0.02436 2.27E-05
ImpactAssessment (DALY)	**2.54E-05**	**1.91E-05**	**6.08E-07**	**5.53E-07**
Total Impact on Human Health	**2.67E-01**	**2.00E-01**	**6.09E-03**	**5.81E-03**
Ecosystem				
Ammonia (Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication)	2.07E-03	1.55E-03	5.00E-05	4.50E-05
Factor (PDF*m^2*yr/kg)	3.04E-03	3.04E-03	3.04E-03	3.04E-03
Impact Assessment (PDF*m^2*yr)	**6.28E-06**	**4.72E-06**	**1.52E-07**	**1.37E-07**
NO_2 (Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication)	3.58E-02	2.69E-02	8.30E-04	7.80E-04
Factor (PDF*m^2*yr/kg)	1.11E-03	1.11E-03	1.11E-03	1.11E-03
Impact Assessment (PDF*m^2*yr)	**3.98E-05**	**2.98E-05**	**9.21E-07**	**8.66E-07**

Nitrogen oxides (NOx)	1.28E+00	9.63E-01	3.30E-02	2.79E-02
(Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication)				
Factor (PDF*m^2*yr/kg)	1.11E-03	1.11E-03	1.11E-03	1.11E-03
Impact Assessment (PDF*m^2*yr)	**1.42E-03**	**1.07E-03**	**3.66E-05**	**3.10E-05**
Sulphur dioxide (SO_2)	2.118675	1.589775	0.051038	0.046125
(Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication)				
Factor (PDF*m^2*yr/kg)	2.03E-04	2.03E-04	2.03E-04	2.03E-04
Impact Assessment (PDF*m^2*yr)	**4.30E-04**	**3.23E-04**	**1.04E-05**	**9.36E-06**
Lead (Pb)	6.20E-03	4.65E-03	1.40E-04	1.35E-04
(Damage to Ecosystem Quality caused by ecotoxic emissions)				
Factor (PDF*m^2*yr/kg)	4.95E-01	4.95E-01	4.95E-01	4.95E-01
Impact Assessment (PDF*m^2*yr)	**3.07E-03**	**2.30E-03**	**6.93E-05**	**6.68E-05**
Total Impact on Ecosystem	**4.97E-03**	**3.73E-03**	**1.17E-04**	**1.08E-04**

In order to be able to compare the impact of the above 2 categories, Eco-Indicator 99 has specific weight factors:

i. Human health = 400 ECO 99 Unit / DALY
ii. Quality of Ecosystem =400 ECO 99 Unit / PDF*m2*yr

The final impact for each container is given in Table 4:

Table 4: Overall environmental footprint in human health and ecosystem quality of glass and PET wine packaging

	Glass		PET	
	0.75 l	**1l**	**0.75 l**	**1 l**
Total Impact on Human Health	2.67E-01	2.00E-01	6.09E-03	5.81E-03
Magnitude factor	400	400	400	400
	1.07E+02	**8.01E+01**	**2.43E+00**	**2.32E+00**
Total Impact on Ecosystem	4.97E-03	3.73E-03	1.17E-04	1.08E-04
Magnitude factor	400	400	400	400

	1.99E+00	**1.49E+00**	**4.69E-02**	**4.33E-02**
Total Impact	**108.77**	**81.61**	**2.48**	**2.37**

This is a fact indicating that the most impactful product is glass 750 ml wine packaging

IV. CONCLUSION

The life cycle of wine consists of many stages that affect the environment. The environmental impacts of wine packaging depend on bottle characteristics and it is always a fundamental question from the environmental analysis point of view. According to the LCIA results, glass and PET wine packaging contribute to the degradation of both categories examined. The LCA profile of Glass and PET wine containers helped us to highlight the areas where negative environmental impacts are expected. Based on the current study, it is shown that glass pack of 750 ml has the worst environmental performance compared to the rest. This is consistent with Navajas et al. study (Navajas et al., 2017) where the overall normalised impact decreases 35.1% when a PET container substitutes a glass container of an industrial product. Further investigation could be carried out using data that totally reflect the average Greek market performance, in order to see in what extent, the current approach can be adapted. To obtain a more comprehensive assessment of the environmental impacts, an application of an LCA method at a more detailed level, and not a screening one, is needed. However, limitations of LCA methodology also exist (e.g. functional unit, weighting) but still is a useful framework for assessing the potential environmental impacts. Furthermore, a methodology based on a statistical approach should be examined so as life cycle inventories to be of much use.

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