EVALUATION OF THE ENVIRONMENTAL IMPACT OF PRE- AND POST-HARVEST PRACTICES FOR THE EXAMINATION OF OCHRATOXINS CONTAMINATION THROUGH THE GRAPE TO WINE CHAIN

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ABSTRACT
The risk of mycotoxins is a global issue that represents a serious risk for human and animal health. Ochratoxin A (OTA) is a very toxic mycotoxin that constitutes a severe problem for viticulture and taking into account the extreme climatic events that are frequently faced in recent years, the OTA problem is arising along the vine value chain. In the context of OchraVine Control project, integrated and innovative precision agriculture management strategies will be developed in order to reduce the occurrence of ochratoxins along the vine value chain products, such as grapes, raisins/currants and wine. The evaluation of the sustainability of the technologies and of the approaches that will be used for the examination of OTA contamination will be performed through the Life Cycle Assessment (LCA) methodology. LCA will assess the environmental impact of the approaches developed within the project and compare them to the currently applied practices while LCC analysis will reveal the economic feasibility and cost-effectiveness of the selected case studies.
In the present study, the evaluation of the environmental impact of the current pre- and post-harvest practices for the examination of ochratoxins contamination was performed through the grape to wine chain. The Life Cycle Assessments were performed according to the ISO 14040 and 14044 standards and were implemented using LCA software tools and standards-based methodology for the evaluation of carbon, energy and water footprints taking into account a number of critical factors in the life cycles of products and processes. In a first step, the life cycle inventory (LCI) data were collected by questionnaires and interviews with different stakeholders (e.g. experts, farmers, industries, etc.) in order all data to be actual operating data. Data were then used to determine the environmental profile by the life cycle impact assessment using the GABI software. The results of the analysis were used to determine the main environmental impacts of the overall production processes of the studied products, such as grapes and wine, and to identify what steps have the greatest level of criticality.

INTRODUCTION
Grapes are one of the most widely grown fruit crops throughout the world; vineyards cover a total area of 7.8 million hectares and produce a total yield of about 65 million metric tons. Grapes and their derivatives (grape juice, raisin and wine) are important foodstuff for the human diet, while wine is considered an income commodity. Several diseases can affect grapes during the cultivation, harvest, transport and/or storage, causing quantitative and qualitative yield losses, which mainly associated with fungal contamination. Among fungi species, the genus *Aspergillus* and *Penicillium* constitute a very severe problem for viticulture as they possible produce ochratoxin A (OTA). Ochratoxin A is a fungal metabolite dangerous for human and animal health due to its nephrotoxic, immunotoxic, mutagenic, teratogenic and carcinogenic effects. Among the *Aspergillus* species isolated from grapes, those belonging to *A. niger* and *A. tubingensis* dominate on grapes but only 5-10% from these strains produce OTA. In contrast *A. carbonarius* is considered to be particularly important since almost 100% of the isolated strains produce OTA; therefore, it is confirmed as the main OTA producer in grapes [1,2]. OTA contamination in crops and all along the vine chain is a highly

important and complex issue which may be mitigated by adopting appropriate management strategies in the vineyard. In the context of OchraVine Control project, integrated and innovative precision agriculture management strategies will be developed in order to reduce the occurrence of ochratoxins along the vine value chain products, such as grapes, raisins/currants and wine.

Considering the global warming and climate protection issues, it is important to evaluate the sustainability of the technologies and of the approaches that will be used for the examination of OTA contamination along the vine value chain. Such an evaluation is crucial in order to ensure that the viticulture and wine industry remains not only economically but also environmentally sustainable through the adaption of the approaches developed within the project. The potential environmental impacts of the processes included in the vine value chain will be examined through the Life Cycle Assessment (LCA) methodology. LCA is an internationally recognized and ISO standardized accounting tool to quantify the environmental impacts of a product, a process or a service throughout its life cycle, by identifying, quantifying and evaluating all the resources consumed and all the emissions and wastes released in an analysis over the entire life cycle known as a 'from cradle to grave' [3]. The agricultural sector is considered, after fossil fuels, the main cause of greenhouse gas emissions which is responsible for approximately 20% of greenhouse gas emission. This is due to direct emissions deriving from agricultural operations, for example carbon dioxide (CO_2) emissions from the use of diesel by tractors and irrigation equipment or emissions from agricultural inputs used (e.g. fertiliser, herbicides and pesticides). On the other hand, the wine industry is a productive activity which also imposes environmental loads that cannot be ignored in the framework of an overall assessment of the life cycle of wine [4,5].

In the present study, the evaluation of the environmental impact of the current pre- and post-harvest practices for the examination of ochratoxins contamination was performed through the grape to wine chain. The environmental impacts were calculated for a red wine (FU 750 mL) by LCA analysis. The system boundaries were extended from "cradle-to-gate" in order to identify the environmental impacts occurring along the wine life cycle stages (grape production, wine production, bottling and packaging). The Life Cycle Assessments were performed according to the ISO 14040 and 14044 standards and were implemented using GABI software tool and standards-based methodology for the evaluation of carbon, energy and water footprints taking into account a number of critical factors in the life cycles of products and processes. The results of the analysis were used to determine the main environmental impacts of the overall production processes of the studied products, such as grapes and wine, and to identify what steps have the greatest level of criticality.

MATERIAL AND METHODS

Goal and scope definition

The scope of the LCA study was the assessment of the environmental impacts of the current pre- and post-harvest practices through the grape to wine chain. The selected functional unit (FU) was a bottle (750 ml) of red wine produced by the companies involved in the project. A cradle-to-gate LCA methodology was applied. The studied system includes the grape production, the wine making process and bottling and packaging.

Inventory analysis

The objective of the LCA study of the current situation is to analyse the environmental impacts of the current pre- and post-harvest practices which were performed through the grape to wine chain. The data concerning the processes which were applied though grape production, wine making, and packaging and bottling were obtained by:

- directly measured data by consortium partners through completion of data sheet questionnaires
- specific data from database of GaBi ts, v8.6 such as, Ecoinvent version 2.2.
- literature data.

The data were related to the functional unit of 1 bottle (750 ml) of red wine and implemented in the GaBi software. Each process of the whole system formed a plan or a unit process on GaBi ts v8.6. The whole process line is depicted in the Fig. 1.

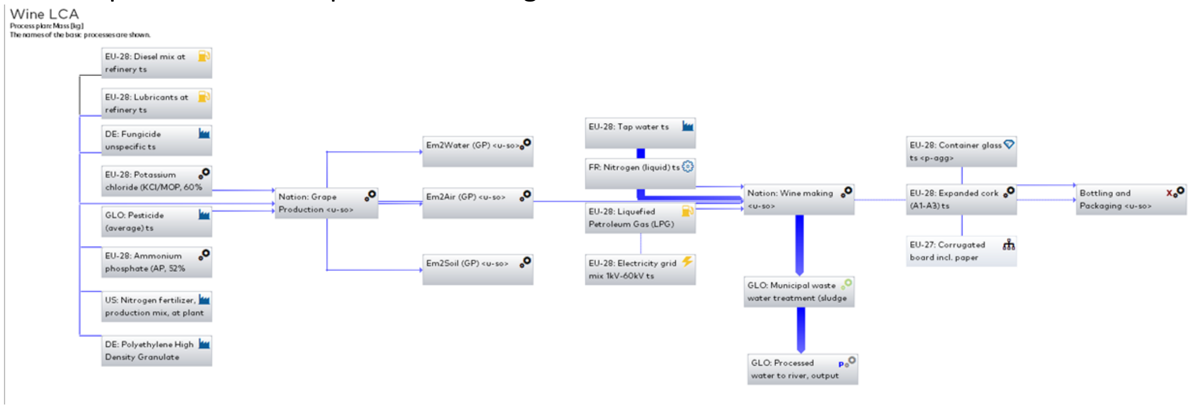

Fig. 1. *The whole process line through the grape to wine chain*

LCI data

The data regarding all inflows/outflows, energy and water consumption, as well as emissions to air, soil and water, for grape production, wine making process, and packaging and bottling were collected and are presented in the following table (Table 1):

Table 1. *Data inventory for grape production, wine making process, and packaging and bottling (data related to FU)*

Grape production

Inputs

Parameter	Flow		Unit
	Ammonium phosphate	8.30E-05	kg
	Diesel	1.21E-02	kg
	Fungicide agent	3.40E-04	kg
	Lubricating oil	3.60E-04	kg
	Pesticide	3.17E-03	kg
	Polyethylene high density	4.63E-05	kg
	Potassium chloride	1.10E-04	kg
	Nitrogen fertilizer	1.35E-05	kg
	Land	1.00E+00	m2*yr
	Water	1.00E+02	kg

Emissions to air

Outputs

Parameter	Flow		Unit
	Ammonia	9.00E-05	kg
	Carbon dioxide	3.80E-02	kg
	Carbon monoxide	2.60E-04	kg
	Carfentrazone-ethyl	3.00E-06	kg
	Dimethomorph	5.75E-06	kg
	Dinitrogen monoxide	8.09E-06	kg
	Glyphosate	2.30E-05	kg
	Hydrocarbons	5.00E-05	kg
	Mancozeb	3.25E-05	kg
	Metalaxyl-M	6.50E-06	kg
	Metiram	3.30E-05	kg
	Morpholine	3.00E-06	kg
	Nitrogen oxides	3.80E-04	kg
	Particulates, > 10 um	4.00E-05	kg

Emissions to soil

Outputs

Parameter	Flow		Unit
	Carfentrazone-ethyl	2.25E-05	kg
	Dimethomorph	4.31E-02	kg
	Glyphosate	1.70E-04	kg
	Mancozeb	2.40E-04	kg
	Metalaxyl-M	4.88E-05	kg
	Metiram	2.40E-04	kg
	Morpholine	2.25E-05	kg
	Pyraclostrobin	1.50E-05	kg

Emissions to water

Outputs

Parameter	Flow		Unit
	Carfentrazone-ethyl	3.00E-06	kg
	Dimethomorph	5.75E-06	kg
	Glyphosate	2.30E-05	kg
	Mancozeb	3.25E-05	kg
	Metalaxyl-M	6.50E-06	kg
	Metiram	3.30E-05	kg

Parameter	Flow	Factor	Unit	Parameter	Flow	Factor	Unit
	Sulphur	1.95E-03	kg		Morpholine	3.00E-06	kg
					Nitrate	4.80E-04	kg
					Phosphate	1.00E-06	kg
					Pyraclostrobin	2.00E-06	kg
					Sulphur	2.60E-04	kg

Wine making process

Inputs				Outputs			
Parameter	Flow	Factor	Unit	Parameter	Flow	Factor	Unit
	Electricity	4.00E-01	MJ		Water	5.34E+00	kg
	Grapes	1.07E+00	kg		Wine	7.50E-04	m3
	Liquefied petroleum gas (LPG)	6.40E-04	kg		Other products from wine making	3.20E-01	kg
	Nitrogen liquid	3.70E-04	kg		Carbon dioxide	1.87E-03	kg
	Water	5.34E+00	kg		Dinitrogen monoxide	3.00E-09	kg
	Bentonite	3.50E-04	kg		Ethanol [Organic emissions to agricultural soil]	3.30E-05	kg
					Ethanol [Group NMVOC to air]	1.32E-04	kg
					Methane	3.00E-08	kg

Packaging and bottling

Inputs				Outputs			
Parameter	Flow	Factor	Unit	Parameter	Flow	Factor	Unit
	Container glass	5.60E-01	kg		Bottle of wine	1	pcs.
	Corrugated board	6.67E-02	kg				
	Expanded cork	4.38E-05	m3				
	Wine	7.50E-04	m3				

Impact assessment (LCIA)

The LCA study was performed in GaBi ts, v8.6 software as a basic tool, while SimaPro was used as a supplementary tool, where needed. The following impact categories were selected to evaluate the environmental impact of the wine under study: global warming potential (GWP 100 years) [kg CO_2 eq.], acidification potential (AP) [kg SO_2 eq.], eutrophication potential (EP) [kg Phosphate eq.], photochemical ozone creation potential (POCP) [kg Ethene eq.], ozone layer depletion (ODP) [kg R11 eq.] and abiotic depletion (ADP fossil) [MJ]. LCIA was carried out using the CML baseline 2001 method.

RESULTS & DISCUSSION

Table 2 reports the total and relative impact values per FU linked to the three processes under study: the agricultural phase (vine planting and grape production), the wine making phase and the bottling and packaging phase. Fig. 2 shows the contribution of each phase to the production of one bottle of wine.

Table 2. *LCIA results for grape production, wine making process, and packaging and bottling for each impact category*

		Agricultural phase		Wine making phase		Bottling and packaging		Total value
Impact categories	**Units**	**Value**	**% over total**	**Value**	**% over total**	**Value**	**% over total**	
Abiotic depletion	MJ	1.95E+00	29.92%	5.43E-01	8.33%	4.02E+00	61.74%	6.52E+00
Acidification	kg SO2 eq.	4.43E-04	21.63%	1.64E-04	8.03%	1.44E-03	70.34%	2.05E-03
Eutrophication	kg PO4-eq.	1.46E-04	35.66%	5.65E-05	13.82%	2.06E-04	50.51%	4.08E-04
Global warming (GWP100)	kg CO2 eq.	7.42E-02	22.21%	7.58E-02	22.71%	1.84E-01	55.09%	3.34E-01
Ozone layer depletion (ODP)	kg R11 eq.	1.62E-12	47.31%	2.00E-13	5.85%	1.60E-12	46.84%	3.42E-12
Photochemical oxidation	kg C2H4 eq.	1.13E-04	24.81%	6.29E-05	13.82%	-3.64E-04	61.37%	4.55E-04

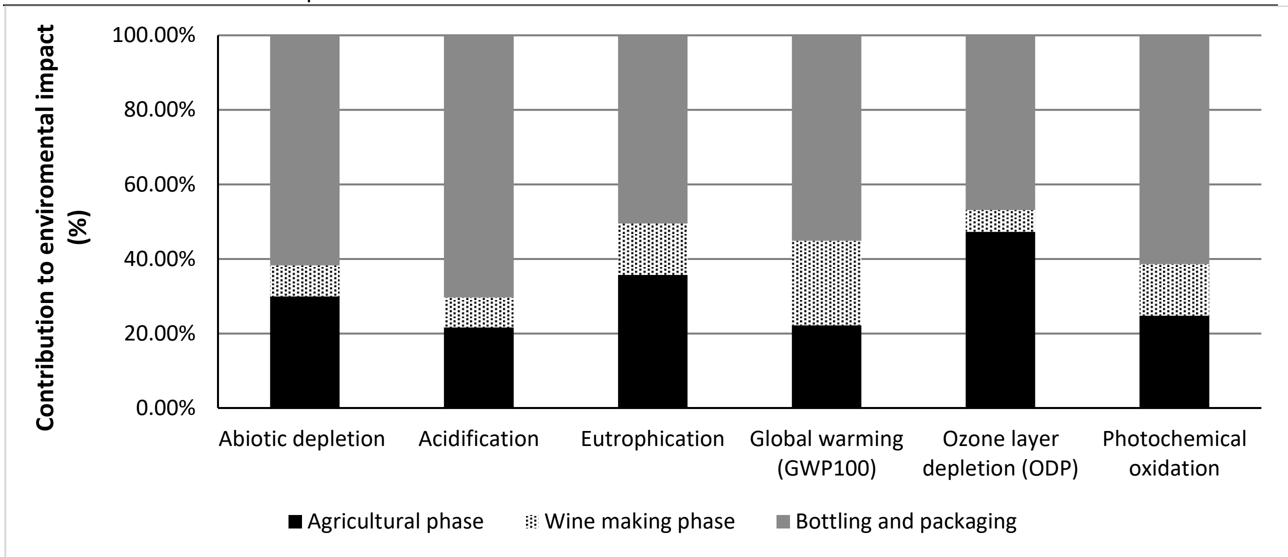

Fig. 2. *Contribution of each phase (agricultural, wine making and bottling and packaging phase) to produce one bottle of wine.*

The bottling and packaging phase represented the main contributor to all impact categories with shares of between 50% and 70%. The principal carrier of environmental impact was glass bottle production, for all impact categories. The impacts on ADP and AP were observed to be higher among the other categories. ADP is mostly due to the use of non renewable energy resources (e. g. crude oil, hard coal, lignite, and natural gas), whereas its highest contribution is indirectly caused by the consumption of natural gas during production of glass bottles. AP has the highest dominance in the bottling phase due to nitrogen oxides and sulfur dioxide emissions during upstream processes of glass bottles and steel productions. The second most important subsystem is viticulture (21% to 47%) followed by wine making phase (5% to 22%).

As for the agricultural phase and the winemaking phase, the following considerations could be made. Abiotic depletion is due to the consumption of fossil-based energy resources, mainly used in the agricultural phase (as diesel fuel) and, secondly, in the wine making phase (as electricity consumption and LPG use). Acidification, which is mostly related to the emission of SO_2 and NO_x to air, was, for the major part, caused by the use of electricity and diesel fuel and by diesel combustion for agricultural operations. Eutrophication was primarily associated with emissions due to fertiliser use in the agricultural phase and with wastewater produced during the wine making process. With regard to GWP, the main contributors were diesel fuel production and consumption (agricultural phase) and electricity consumption (wine making phase). ODP impacts were primarily associated with the emissions related to the production of pesticides used in the agricultural phase. For photochemical oxidation, the contributions of the agricultural phase (due to diesel fuel and pesticide production) and the wine making phase (due to ethanol emissions during the fermentation process) were similar [6].

CONCLUSIONS

The study carried out evaluates the environmental impacts associated with the current pre- and post-harvest practices through the grape to wine chain. Specifically, the studied system included the grape production, the wine making process and bottling and packaging of red wine. The results showed that the environmental performance of a bottle of red wine was mostly determined by glass bottle production. The second most important subsystem was the agricultural process, while the vinification process was generally of little importance. In general, to produce 1 bottle of typical red wine (0.75L) about 0.33 kg CO_2-eq. are emitted. This is mainly a consequence of the production of glass bottles for the wine bottling phase or diesel combustion. Therefore, in order to eliminate the contribution of wine production to environmental impact, new agricultural practices and replacement of glass packaging with another material are possible solutions.

ACKNOWLEDGEMENTS

This study was performed in the context of OchraVine Control project which has received funding from the **EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME** under grant agreement No 778219

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