Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools

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Please cite as:

Arzoumanidis, I., Salomone, R., Petti, L., Mondello, G. and Raggi, A. (2017), "Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools", Journal of Cleaner Production, Vol. 149, pp. 406-425. https://doi.org/10.1016/j.jclepro.2017.02.059

Words: 10558

Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools

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Abstract

Life Cycle Assessment (LCA) has been increasingly used for the improvement of the environmental performance of goods and services, amongst which products belonging to the agri-food sector. Part of the international scientific literature considers simplification of LCA a relevant approach in order to make LCA easier to perform, especially for Small- and Medium-sized Enterprises (SMEs), which generally lack in resources. Despite a protracted theoretical discussion on the simplification of LCA, few simplification approaches and tools have been developed and proposed in the last decades, in particular as regards the agri-food sector. In the research presented here, the implementation of selected tools was performed for four agri-food products, notably: roasted coffee, lemon juice, olive oil, and wine. The obtained results showed that the use of different modelling (in order to meet the needs of each tool), along with the different databases and different environmental impact categories can lead to contrasting results, for example regarding the most affected impact categories or the most impacting life-cycle phase(s). Finally, the inclusion of agricultural processes within the incorporated databases of simplified LCA tools can be of fundamental importance for the agri-food products case studies. As a general conclusion, the analysed tools demonstrated to be quite suitable for the agri-food industry. Nevertheless, a wider use of the simplified approach in this sector would be strongly related to the existence of food-specific flows and processes in the incorporated databases.

Keywords: simplified LCA, agri-food sector, wine, olive oil, lemon juice, coffee

1. Introduction

The food supply chain has become an important contributor to a number of environmental impacts, due to an increase in food production (Schau and Fet, 2008), to changes in dietary habits (Delgado, 2003; Kearney, 2010) and to the way in which the processes included in the food chain are generally performed (Arzoumanidis et al., 2013a). Life Cycle Assessment (LCA) has been increasingly used for the improvement of the environmental performance of goods and services, amongst which products belonging to the agri-food sector (Gazulla et al., 2010; Peacock et al., 2011; Notarnicola et al., 2012; Notarnicola et al., 2015). Furthermore, simplification of LCA was found to be an important issue, especially for Small- and Medium-sized Enterprises (SMEs), where the necessary resources and knowledge needed for performing LCA studies are generally scarce (Masoni et al., 2004).

The concept of a simplified LCA approach was introduced in the international scientific literature in the 1990s and it includes a streamlining of the scope, costs and efforts needed when an LCA study is carried out (Todd, 1995; Weitz et al., 1996). The adoption of a simplified tool is due to the complexity that industry and policy-making practitioners often encounter when conducting a full LCA (Bala et al., 2010).

Today, there is no distinction between the notion of "full LCA" and "simplified LCA" in the ISO 14040 series standards (ISO, 2006), even though a simplified LCA standard was developed in Spain in 1998 (AENOR, 1998). In addition, some authors suggested that a simplification can be directly applied in all LCA analyses (Curran and Young, 1996; Todd and Curran, 1999). Nevertheless, in the EeBGuideproject - "Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative" - Wittstock et al. (2012) proposed a distinction between "complete LCA", "simplified LCA" and "screening LCA". Despite a protracted theoretical discussion on the simplification of LCA, the interest in simplified tools and approaches for LCA has been increasing constantly in the last years (as highlighted in figure 1, where the number of articles on this issue published in the last ten years is presented; in this case, the search was carried out using the keywords "simplified LCA" or "streamlined LCA" in Scopus and Web of Science (WoS) databases). Indeed, the approach has been applied in different sectors, such as, energy resources (see e.g., Beccali et al., 2016), building design (see e.g., Hollberg and Ruth, 2016), infrastructure materials (see e.g., Feiz et al., 2015), electronic materials (see e.g., Moberg et al., 2014; Andrae, 2016), or agri-food products (see e.g., Arzoumanidis et al., 2014a). In addition, the recent update to a new version of some simplified LCA software tools available on the web free of charge after registration (namely CCaLC and eVerdEE, described in the following discussion) confirms the current interest in simplification approaches.

Furthermore, the interest in simplified approaches has recently grown when some authors developed and improved the use of simplified tools to be applied in the so-called Product Environmental Footprint (PEF) (EU, 2013), one of the most important initiatives of our time, to assess the environmental performances of all products that are commercialised in the EU. For instance, the objective of the Harmonised Environmental Sustainability in the European food & drink chain project (SENSE, 2012) was to develop a simplified tool in order to assess the sustainability of food and drink SMEs (Olafsdòttir et al., 2014), and Ramos et al. (2016) highlighted the possibility to modify this tool to be adopted in the PEF initiative. In addition, Porta et al. (2008) underlined that, in the EU project "ECOFLOWER Terlizzi" (Ecoflower, 2006), the possibility of using eVerEE for certification purposes by means of the definition of a simplified EPD (Environmental Product Declaration) programme has been investigated. Concerning the specific implementation of simplified approaches in the agri-food sector, in a literature review performed in 2013 (Arzoumanidis et al., 2013b) on simplified Life Cycle-based tools and approaches, updated to 2016 in the framework of this article, it was demonstrated that only a few scientific articles had been published on the agri-food sector, either directly related to it (six articles) or indirectly (three articles). The 2016 update showed an increase in publications on simplified LCA studies mostly in the building (e.g., Santos et al., 2016), automobile (e.g., Danilecki et al., 2017), electronics (e.g., Andrae, 2016) and renewable energy (e.g., Padey et al., 2013) sectors, whilst in the agri-food sector there were only two studies belonging to the same authors of this article (Arzoumanidis et al., 2013c; Arzoumanidis et al., 2014a). Furthermore, only two of the agri-food-related articles tackled the evaluation of more than one simplified LCA tools (Arzoumanidis et al., 2014a; Hochschorner and Finnveden, 2003) and few of them faced the robustness of these tools with respect to full LCA implementations (e.g., Hunt et al., 1998; Porta et al., 2008). Therefore, even if research comparing outcomes of different LCA software tools for the same system is not new in the international literature -- see for example the effect on the GWP100 indicator score of using different LCA tools on smartphone systems (Andrae and Vaija, 2014) -- the effect on several indicator scores of using different simplified LCA tools in the agri-food sector, also in relation with full LCAs, is poorly investigated and not well understood. Given this lack in applicative case studies within the scientific literature, this paper builds on previous research (Arzoumanidis et al., 2015) and takes into account three different simplified LCA tools, namely BilanProduit (BilanProduit, 2014), CCaLC (CCaLC, 2016) and eVerdEE (ECOSMES, 2016) and their implementation in the framework of four agri-food products (roasted coffee, lemon juice, olive oil, and red wine). The results of those applications were then analysed in parallel to the ones of full LCAs (using the ReCiPe and CML 2001 midpoint Life Cycle Impact

Assessment methods), with the following objectives: assessing the robustness of these simplified LCA tools, also in parallel to full LCA implementations; investigating their suitability for the agri-food Industry; highlighting the potential shortcomings that currently limit a wider use of the simplified approach in this industry. This article is structured as follows: firstly, the materials and methods used for carrying out the study are described. Then, the obtained results are presented for each product and each LCA implementation (full and simplified). Finally, a discussion of the results is outlined and the conclusions of the analyses along with the future developments are drawn.

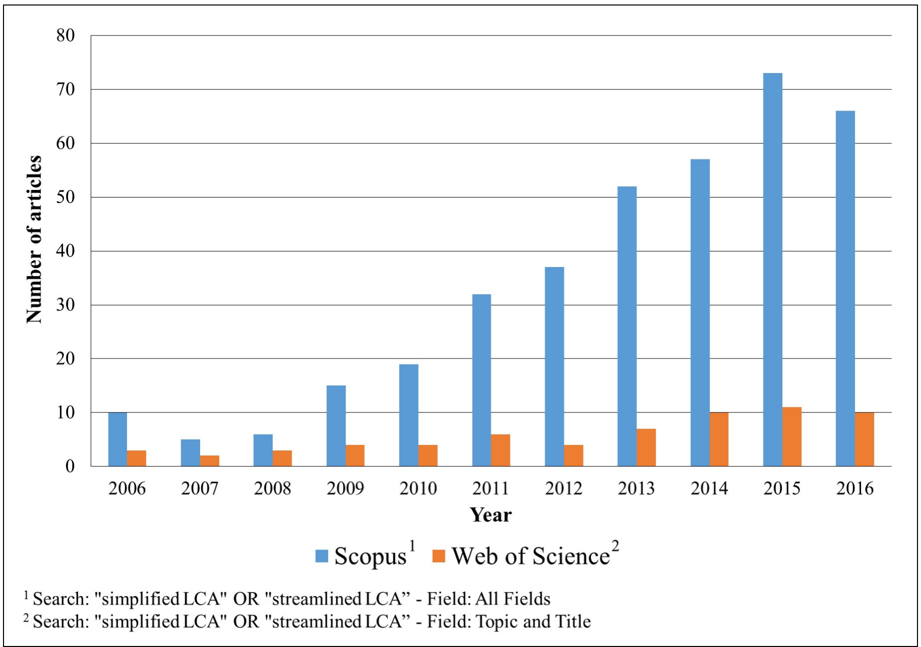

Figure 1. Articles published in the domain of “simplified LCA” or “streamlined LCA” in the last ten years (until November 25th, 2016)

2. Materials and methods

This paper builds on previous research performed by the Authors in the wine sector, where a set of simplified LCA approaches were identified through a literature review (Arzoumanidis et al., 2013b) and then tested and rated by expert and non-expert users (Arzoumanidis et al., 2014a; 2014b). The selection of the simplified approaches was performed by applying decision-making techniques (of the family of the Multi-Attribute Utility Theory) to the scores attributed to them by the users (Martìnez et al., 2009). The selected simplified approaches were then implemented in a case study in the framework of a small family-managed winery in Italy and the results were analysed in parallel to those of a full LCA (Arzoumanidis et al., 2013a; 2014a). By doing so, the strengths and weaknesses of the examined approaches were identified, not only in terms of the results obtained, but also of the modelling required for each one of them.

In the research presented here, in order to advance and broaden the previous research and to further evaluate the robustness of the results in the framework of the agri-food industry, three additional food products were considered (roasted coffee, lemon juice and olive oil) testing three simplified LCA tools (that were amongst the tools that ranked first in the aforementioned selection procedure): Bilan Produit (designed by ADEME France), CCaLC (designed by the University of Manchester) and eVerdEE (designed in the framework of the ECOSMES project by ENEA and partners). The results obtained were examined in parallel to the ones of full LCAs, which were carried out following the ISO 14044:2006 standard (ISO, 2006). In particular, it is to be noted that the full LCA implementation was carried out using the ReCiPe Midpoint (Goedkoop et al., 2009) and the CML 2001 (Guinée et al., 2002) LCIA methods[1].

2.1 Case Studies

In this section, the various case studies that were carried out will be outlined.

<u>*2.1.1. Roasted Coffee*</u>

Regarding the case study of roasted coffee, this was performed in the framework of a coffee processing company based in Sicily, Italy (Salomone et al., 2013). For this case, an analysis using a simplified LCA tool, namely eVerdEE had already been published (ibid.). The functional unit (FU) was set as *1 kg of packaged roasted coffee* and the reference period for data collection was from 2009 to 2011. The system boundary (Figure 2) was set from coffee cultivation (in Brazil), its transport (to Italy), through to its processing (in Italy), distribution (in Italy and abroad), consumption and disposal, thus cradle-to-grave (ibid.). The data regarding the agricultural phase in Brazil were retrieved from the literature (Coltro et al., 2006), whilst those in Italy were collected on site.

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[1] The original studies that were already published had used either the ReCiPe or the CML 2001 midpoint LCIA. Therefore, for this paper and in order to keep the studies homogenised, it was decided to perform both methods. Moreover, the simplified LCA tools originally taken into account by Arzoumanidis et al. (2014a) were eVerdEE, Carbonostics (Carbonostics, 2014), BilanProduit and CCaLC. The idea of the authors was to include all of them in this study, as well; nevertheless, at the time when the present study was being prepared, Carbonostics was not available anymore (Pax, personal communication) and it was thus excluded from the analysis here presented.

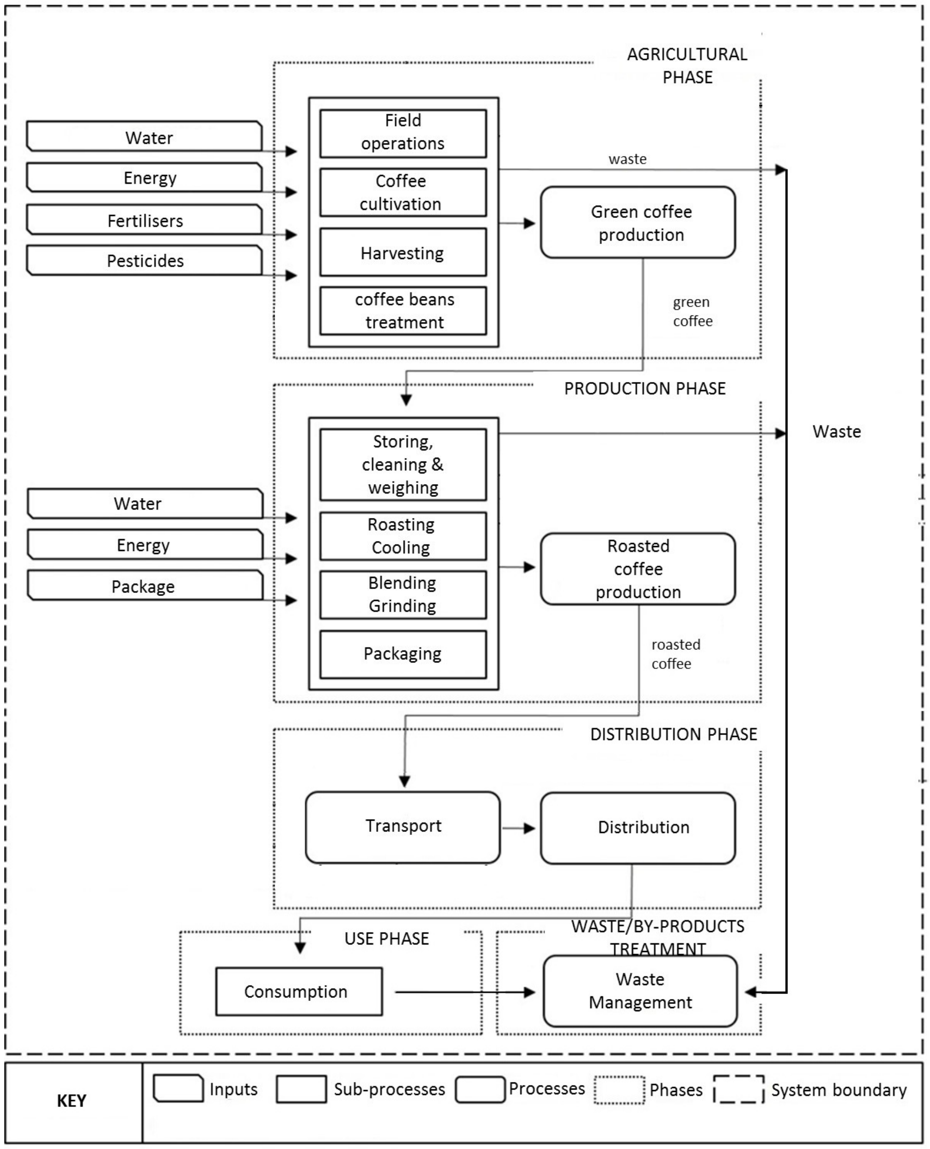

Figure 2. Flow Chart for the Roasted Coffee product system

2.1.2. Lemon Juice

As far as the lemon juice is concerned, the case study was performed in the framework of a firm based in Sicily (Italy). A full LCA implementation of this product had been already carried out (Di Bartolo, 2015). The FU was set as *1 pack containing six 1-L bottles of organic lemon juice* and the data collection was performed in the years 2014-2015. The system boundary (Figure 3) included the agricultural phase, its processing, bottling, packaging and distribution in Canada, thus cradle-to-market.

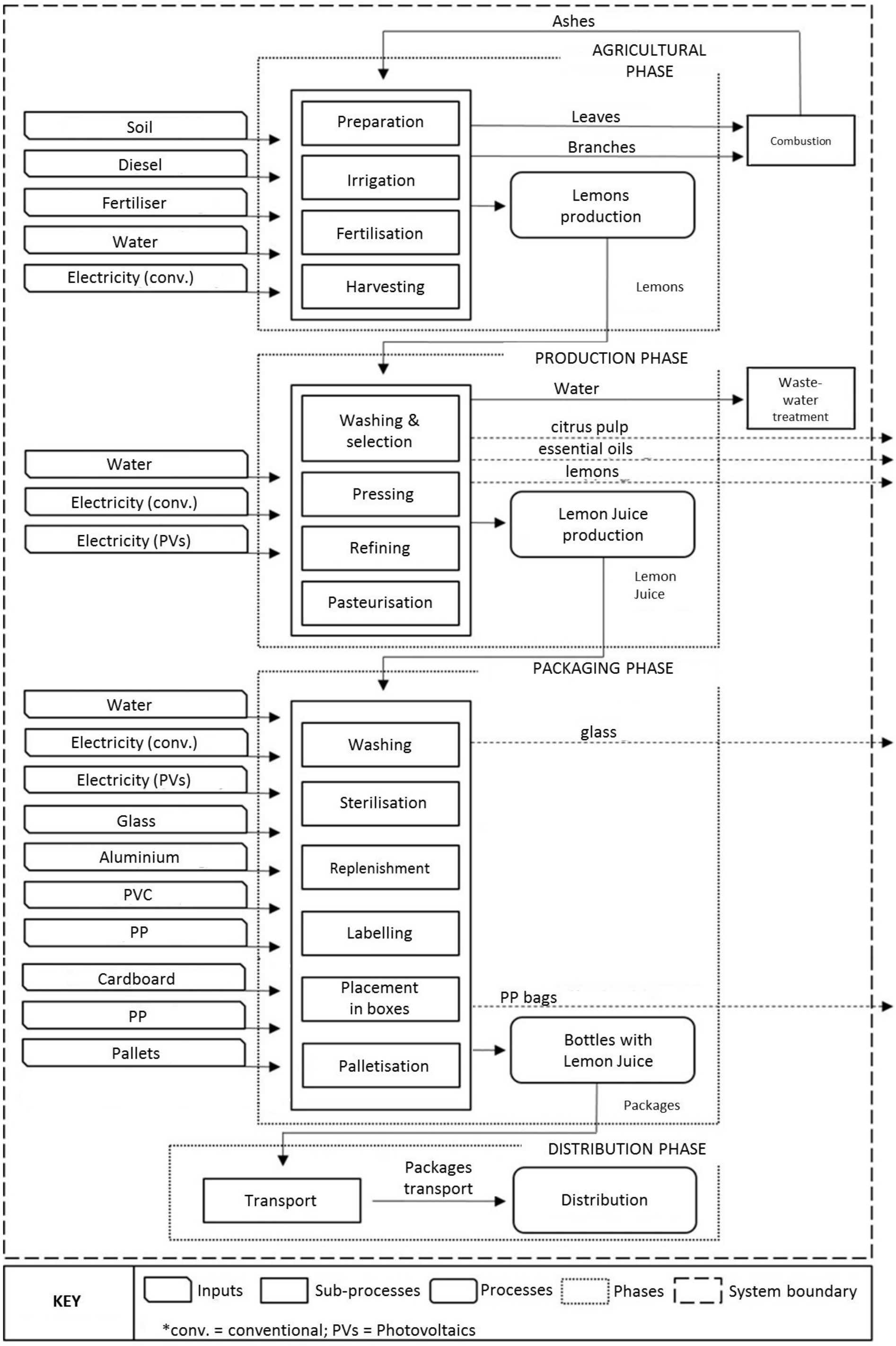

Figure 3. Flow Chart for the Lemon Juice product system

2.1.3. Olive Oil

For the case of olive oil, the analysis was performed considering the production of virgin olive oil by a *local association of oil producers* (Sicily, Italy). A full LCA implementation to 9 different scenarios had already been performed in the past (Salomone and Ioppolo, 2012); for the research presented here, only one of those scenarios was considered (identified in the cited article as "6C"), chosen as being one of the most common in Italy. As regards the agricultural phase, the chosen scenario included: organic mechanised practices, drip irrigation, grinding and scattering on fields of the pruning residues, mechanical fertilisation with compost from Olive Wet Pomace (OWP) and Olive Mill Wastewaters (OMW). As regards the olive oil extraction technology, this scenario included a continuous centrifugation with a two-and-a-half-phase system (also called modified system or water saving system). Finally, as regards the OWP and the OMW treatment, these were composted together (ibid.). The FU was defined as *1,000 kg of olives* (corresponding to 200 kg of olive oil) and the data collection was performed in the years 2009-2010. The system boundary (Figure 4) included the phases of agriculture, olive oil production and olive oil mill waste treatment (composting).

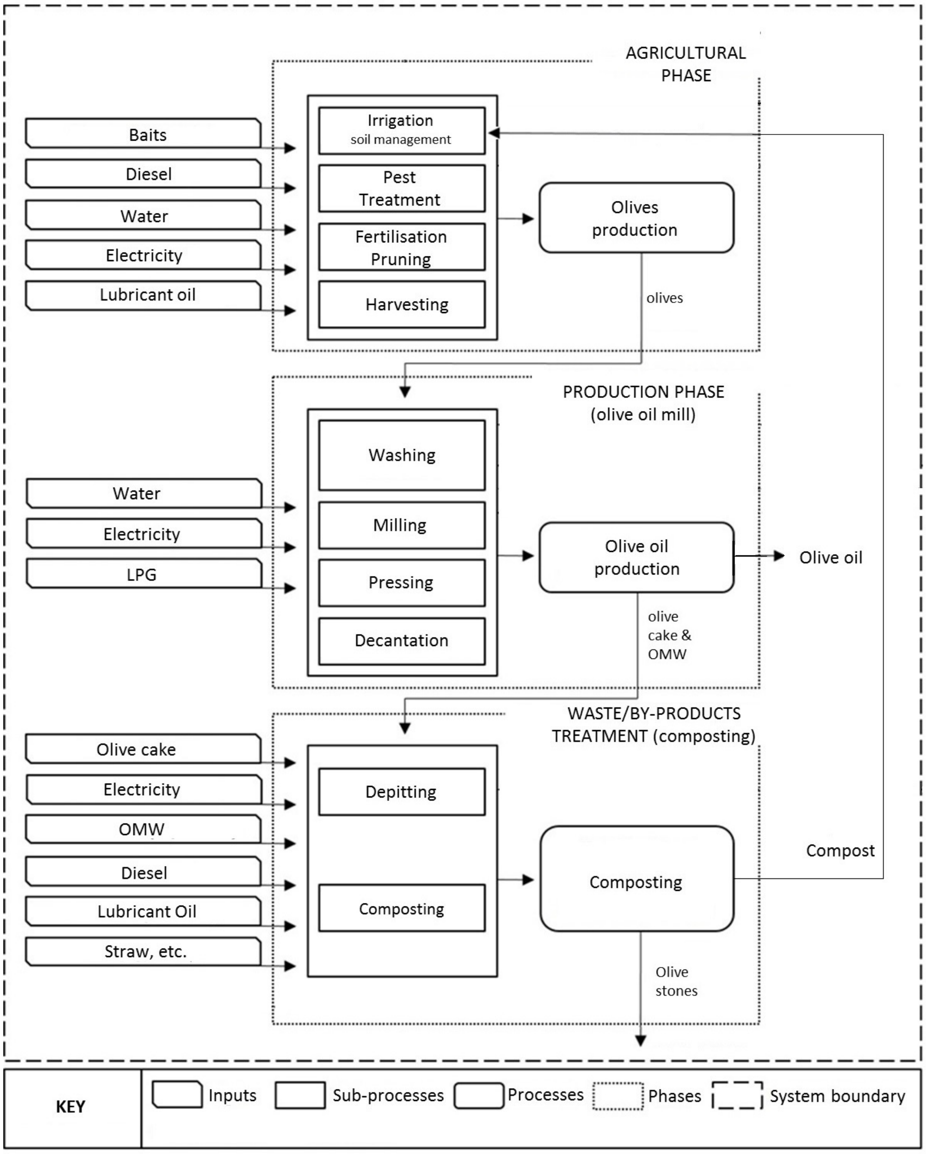

Figure 4. Flow Chart for the Olive Oil product system

2.1.4. Wine

The previous case study took into consideration the red wine *Montepulciano d'Abruzzo* produced in a small winery located in in Abruzzo, Italy (Arzoumanidis et al., 2014a). The FU was defined as a *0.75-L bottle of organic red wine "Montepulciano d'Abruzzo"*, including its primary, secondary and tertiary packaging and the data collection was performed for the crop year 2010-2011. The system boundaries (Figure 5) included the agricultural phase, the production of wine, and the distribution (ibid.). The results regarding this case study have been retrieved in order for a clearer idea to be drawn along with the other agri-food products.

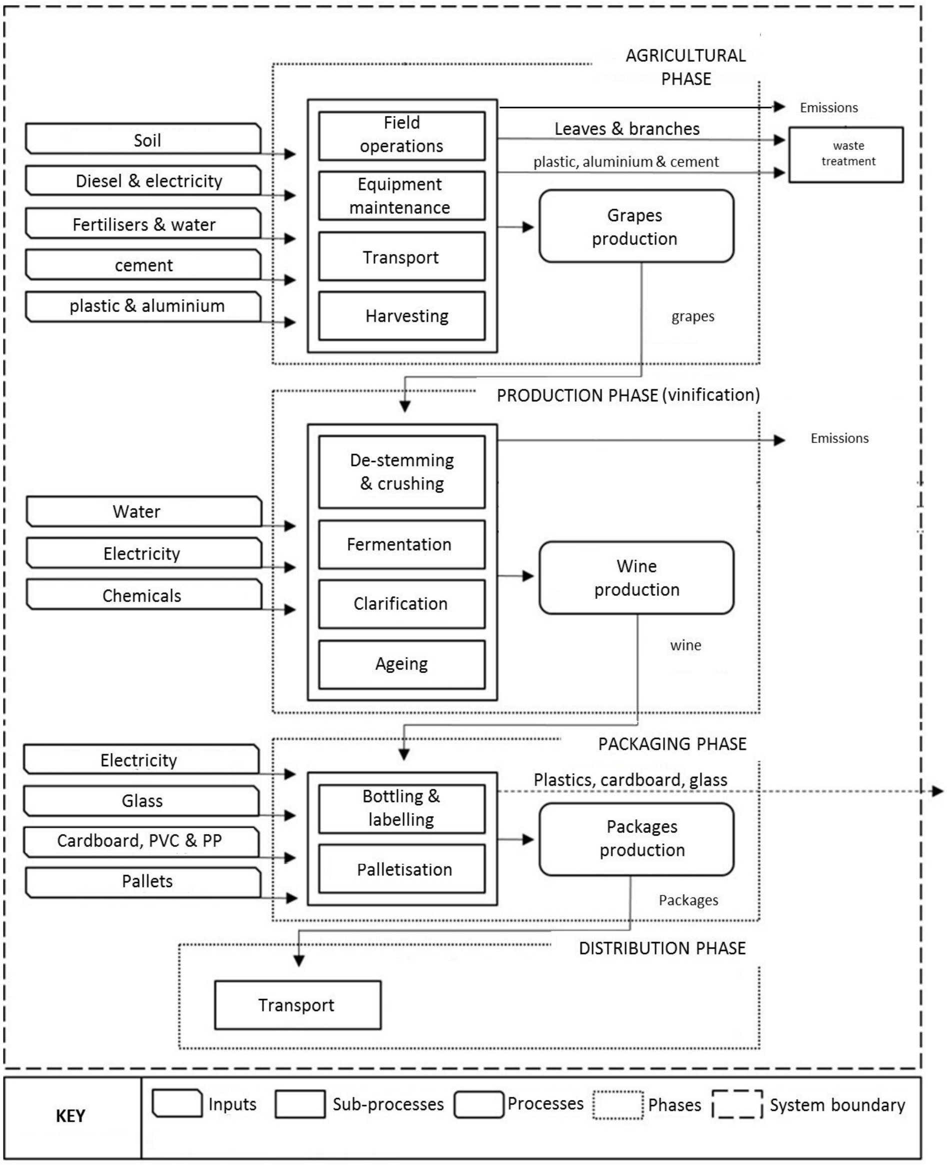

Figure 5. Flow Chart for the Red Wine product system

2.2 Simplified LCA Tools

In simplified LCA tools, the simplification may occur at the level of Life Cycle Inventory (LCI) and/or LCIA. Strategies at the former level aim at simplifying the modelling and/or reducing data collection efforts, whilst ones at the latter level at reducing the set of impact categories and facilitating the communication of the results (Arzoumanidis et al., 2013b; Nicoletti and Notarnicola, 1999). These two different simplification approaches characterise the three simplified LCA tools that were taken into consideration for this paper (BilanProduit, CCaLC and eVerdEE) as described in the following paragraphs along with some details of the main features of the tools.

In the BilanProduit tool (BilanProduit, 2014) the simplification is at the LCI level (Bewa et al., 2009). Recently, BilanProduit has developed a new version, which is directly available online (Base Impacts, 2016), but still does not include a complete database (e.g., food production processes are totally lacking). For this reason, the old version (BilanProduit, 2014), which was on a Microsoft Excel file and available only in French, was used. The same version of this tool had been used for the case study of wine (Arzoumanidis et al., 2013a), as well. The sheets of the Excel file include the phases of production, transport, use, end of life; for every entry selected in the production sheet, the user needs to specify which phase in the life cycle it is connected to (e.g., glass goes to the packaging phase, etc.). The tool also includes a specific sheet where the necessary "goal and scope"-related information can be given.

When it comes to the CCaLC tool, the simplification is at the level of LCIA (CCaLC, 2016). With respect to the previous research of the Authors (Arzoumanidis et al., 2013a), a new version of the tool was available (namely CCaLC2) and it was thus used for all the case studies presented in this paper. The tool focuses only on one environmental impact category (climate change), but it also gives some insight for other categories (Azapagic, personal communication), even though only partially, given the fact that the relevant elementary flows are not always available. However, no comparison is made between the various impact categories (normalisation). As soon as the software tool is run, a flow chart appears on the main page where the inventory data can be directly inserted by the user. This chart includes the following clickable boxes: raw materials, production (which may be divided in further stages), storage, use and waste management. All boxes are connected by transport-related entries. The goal and scope definition can be inserted via a specific section.

With regard to the eVerdEE tool[2] (ECOSMES, 2016), the simplification is both at the level of Life Cycle Inventory and Life Cycle Impact Assessment (Arzoumanidis et al., 2013b). As in the case of CCaLC, a new version of the tool became available at the time when this paper was being prepared. Therefore, the new version was used for all the case studies, even those for which an eVerdEE analysis had already been carried out. The tool is available online after registration and allows the user to insert the goal and scope data in a user-friendly way. The user can select between two different types of modelling (industry and agriculture). It has to be noted that at the moment, and due to the fact that the process of the database update is still ongoing, the two options appear to have no differences whatsoever in terms of the processes included. Moreover, the incorporated database does not provide the same processes for all phases (for example, packaging or manufacture). Therefore, if a process present in another phase's database needs to be inserted, it has to be modelled under that different phase. Finally, the report containing the final results can be printed once all the data are inserted.

The main characteristics of these three simplified tools are summarised in Table 1.

Table 1. – Main characteristics of the Simplified LCA tools

Simplified tool	**BilanProduit**	**CCaLC**	**eVerdEE**
Simplification approach	LCI level	LCIA level	LCI and LCIA levels
Version	1st	2nd	2nd
Impact categories	-Climate Change -Acidification -Eutrophication -Photochemical pollution -Energy consumption -Resources consumption -Aquatic Ecotoxicity -Human Toxicity	-Climate Change	-Climate Change -Acidification -Eutrophication -Photochemical oxidation Consumption of: *Mineral resources *Biomass *Fresh water *Non-renewable energy *Renewable energy -Ozone layer depletion
Database	EcoInvent 2 (in part)	CCaLC database & EcoInvent 2 & 3 (in	eVerdEE database & ELCD 3.2

[2] With regard to BilanProduit, the database of the new version does not include agrifood-related processes yet. This is why the new version could not be used at all. Instead, the old version of eVerdEE, containing a different database than the new one, is not available anymore. This is why the new version was chosen for this case.

		part)	
Possibility to import external databases	No	Yes	No
Online software	No	No	Yes
Final Report	No	No	Yes
Free access	Yes	Yes	Yes
Comparison of case studies	No	Yes	No

3. Results

In this section, the results of the LCA implementation for roasted coffee, lemon juice, olive oil, and red wine are presented. In particular, for each of the investigated products, the full LCA implementation is presented first, followed by the simplified implementation using BilanProduit, CCaLC and eVerdEE, respectively.

3.1 Full and simplified LCA of roasted coffee

The full LCA of roasted coffee was implemented using SimaPro 7.2.4 (Pré, 2015) as a software tool. The implementation of the full LCA method regarding the characterisation phase resulted in the agricultural phase being the most impacting one for most of the environmental impact categories taken into consideration - according to the European ReCiPe MidPoint method (H). This was followed by the use phase (in Italy) and the distribution phase. As far as the normalisation results are concerned, freshwater ecotoxicity appeared to be the most affected environmental category due to the use of fertilisers, followed by freshwater eutrophication (Figure 6).

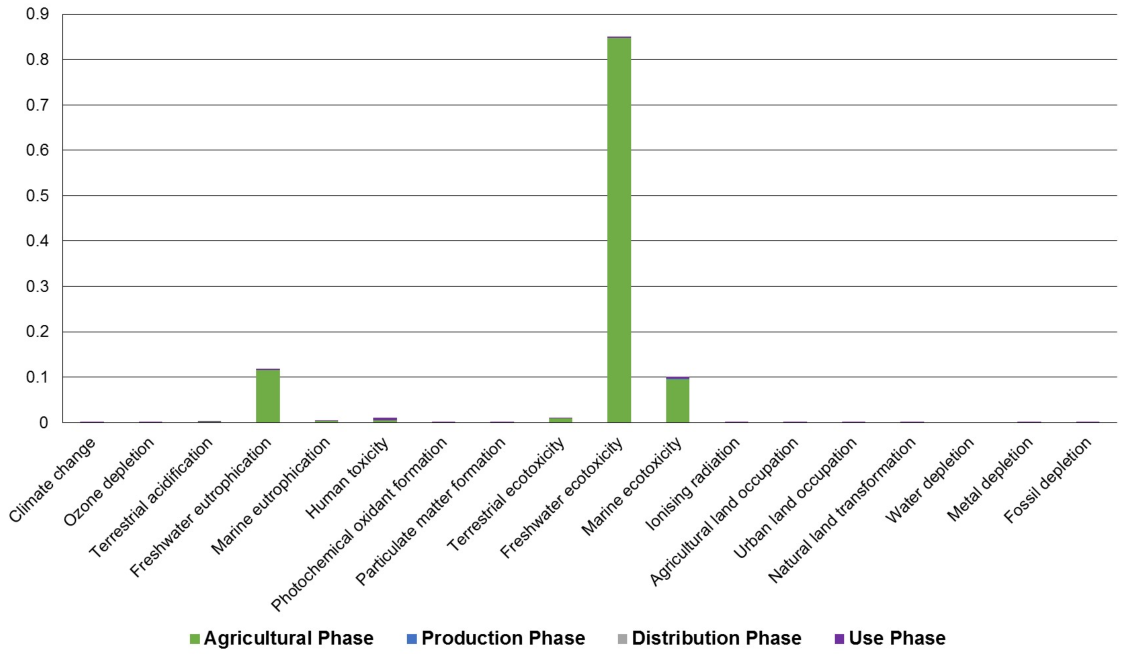

Figure 6. Full LCA implementation for roasted coffee – ReCiPe MidPoint method – Normalisation Results (SimaPro 7.2.4)

The simplified LCA of roasted coffee was first perfomed using BilanProduit. For the agricultural phase, the tool seemed to be lacking in entries related to fertilisers, limestone, pesticides, and land use. The emissions for the agriculture and packaging phases could not be inserted either. Regarding transport, the tool provided the possibility to insert separately: transport between plants, transport of packaging materials, and distribution. This kind of modelling, indeed, could provide separately the results per type of transport.

For this study, the use phase (due to electricity consumption) appeared to be the most impacting, regarding the majority of the environmental impacts taken into consideration (Figure 7). The characterisation gave, for example, the following results: climate change (2.16 kg CO_2 eq/FU), acidification (0.0099 kg SO_2 eq/FU) and eutrophication (0.0066 kg phosphate eq/FU). As far as the normalisation results are concerned, acquatic ecotoxicity followed by the consumption of resources and energy appeared to be the most affected ones.

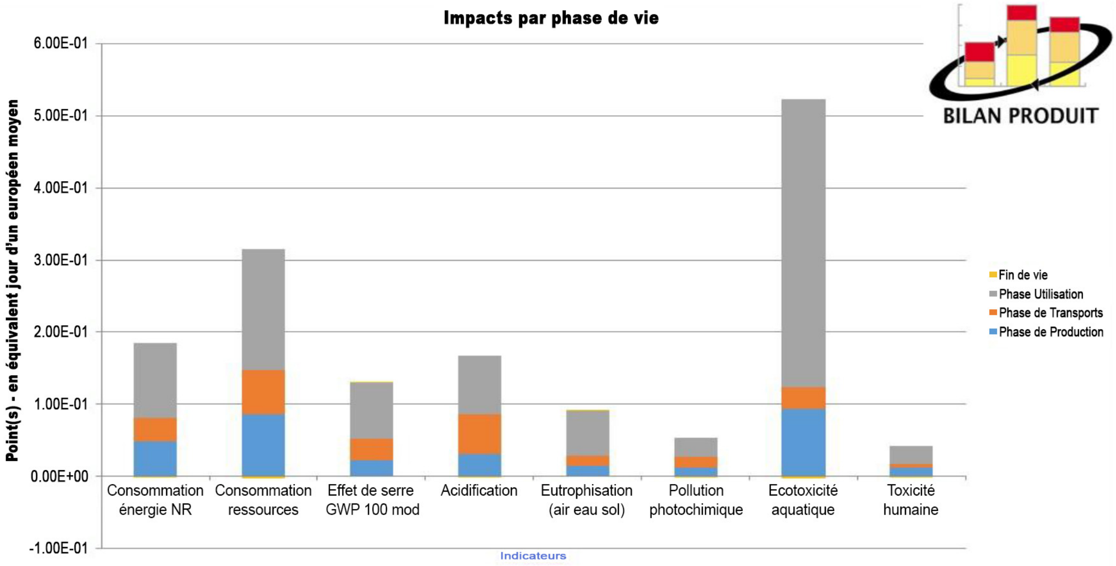

Figure 7. BilanProduit – Normalisation results for roasted coffee

When implementing the simplified LCA using CCaLC, the incorporated database of the tool, which is integrated with a part of Ecoinvent 2 and 3 databases (Ecoinvent Center, 2016), was generally found to be satisfactory for this study. Firstly, the incorporated database was searched and then, if the process was missing, this was looked for within the Ecoinvent database. Nonetheless, the database was lacking in some emissions and in land use entries (it did not include any data for the country where the agricultural phase takes place, i.e., Brazil). The CCaLC tool gives graphic results mainly for Carbon Footprint, but it also includes a set of other environmental impacts (even though only partially, as mentioned in Section 2.2). Regarding climate change, the agricultural phase (mainly due to the use of fertilisers) appeared to be the most impacting one (3.97 kg CO_2eq/FU – See Figure 8). On the other hand, the use phase seemed to be the most contributing one for acidification (0.011 kg SO2 eq/FU), eutrophication (7.37e-4 kg phosphate eq/FU), ozone layer depletion (4.7e-7 kg R11 eq/FU) and photochemical smog (7.05e-4 kg ethene eq/FU).

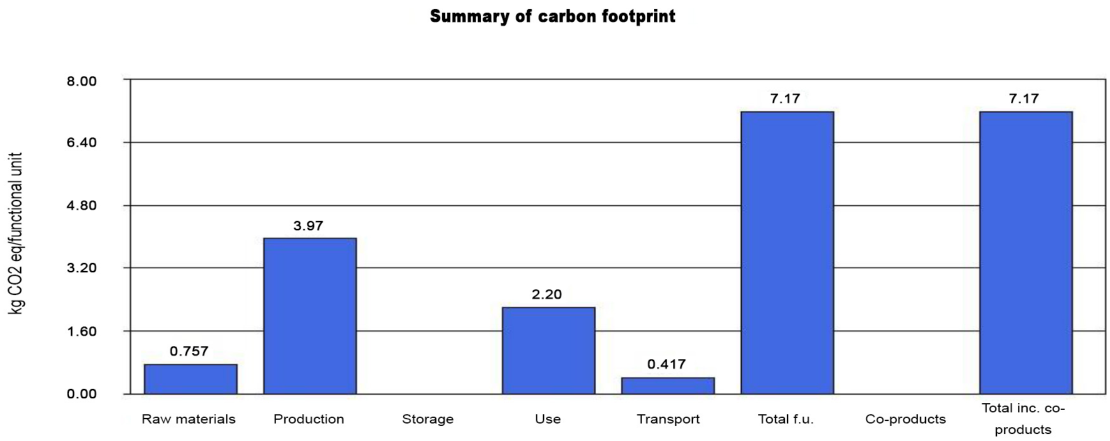

Figure 8. CCaLC – Carbon Footprint for roasted coffee

Regarding the simplified implementation using eVerdEE, due to the fact that the tool was still being updated at the time of the implementation, there was a considerable amount of processes missing within its database. Furthermore, even if the tool provided the same database for agriculture and industry (as aforementioned), the agricultural phase was created separately and then inserted in the software as a component under the tool-defined “pre-manufacture” phase, in order to facilitate the modelling. For the same reason and due to lack in specific processes under specific phases, the insertion of the packaging materials was performed mostly in the “pre-manufacture” phase and to a lesser degree in the “product packaging” phase. The characterisation results showed that the “use and end-of-life” phase was more impacting for the mineral resources consumption, energy consumption, photochemical oxidation and ozone layer depletion. On the other hand, the “pre-manufacture” phase (which, for this case study, corresponds largely to the agricultural phase with the addition of most of the packaging materials) was responsible for environmental categories such as fresh water consumption, climate change, acidification and eutrophication. When it comes to the normalisation results, eutrophication appeared to be the most affected category, followed by acidification and climate change (Figure 9).

Coffee Barbera

Indicator	Total	Pre-manufacure	Manufacure	Packaging and Distribution	Use and End of Life
Consumption of mineral resources	$3.21\ 10^{-6}$	$4.38\ 10^{-7}$	$5.94\ 10^{-7}$	$3.92\ 10^{-8}$	$2.13\ 10^{-6}$
Consumption of biomass	0	0	0	0	0
Consumption of fresh water	$7.92\ 10^{-5}$	$4.39\ 10^{-5}$	$6.46\ 10^{-7}$	$1.63\ 10^{-8}$	$3.46\ 10^{-5}$
Consumption of non-renewable energy	$7.28\ 10^{-4}$	$8.81\ 10^{-5}$	$1.15\ 10^{-4}$	$1.33\ 10^{-5}$	$5.12\ 10^{-4}$
Consumption of renewable energy	$5.13\ 10^{-4}$	$3.88\ 10^{-5}$	$2.52\ 10^{-5}$	$2.44\ 10^{-7}$	$4.49\ 10^{-4}$
Climate change	$8.58\ 10^{-4}$	$4.98\ 10^{-4}$	$2.92\ 10^{-5}$	$8.48\ 10^{-6}$	$3.22\ 10^{-4}$
Acidification	$9.19\ 10^{-4}$	$6.51\ 10^{-4}$	$3.14\ 10^{-5}$	$1.28\ 10^{-5}$	$2.24\ 10^{-4}$
Eutrophication	0.00136	0.00129	$1.30\ 10^{-5}$	$9.19\ 10^{-6}$	$5.30\ 10^{-5}$
Photochemical oxidation	$7.13\ 10^{-5}$	$8.62\ 10^{-6}$	$9.00\ 10^{-6}$	$3.30\ 10^{-6}$	$5.04\ 10^{-5}$
Ozone layer depletion	$2.08\ 10^{-6}$	$1.72\ 10^{-7}$	$9.09\ 10^{-8}$	$1.52\ 10^{-9}$	$1.81\ 10^{-6}$

Normalized Results

Figure 9. eVerdEE – Normalisation Results for roasted coffee (screenshot)

For a summary of the results using the two different LCIA methods (for the full LCA implementation) and the three simplified LCA tools, please refer to Table 2.

Table 2. Roasted Coffee: Full and Simplified LCA characterisation results

		ReCiPe MidPoint (H)	**CML 2001**	**Bilan Produit**	**CCaLC**	**eVerdEE**
Impact category	**Unit**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Climate change	kg CO_2eq	6.689		3.662	7.17	5.83
Global warming GWP 100	kg CO_2eq		6.657			
Terrestrial acidification	kg SO_2 eq	0.074				
Acidification	kg SO_2 eq		0.059	0.02		0.049
Freshwater eutrophication	kg P eq	0.034				
Marine eutrophication	kg N eq	0.022				
Eutrophication	kg PO_4^-eq		0.128	0.01		0.013
Photochemical oxidant formation	kg NMVOC	0.02				
Photochemical oxidation	kg C_2H_4		0.001			0.001
Photochemical pollution	kg C_2H_4			7.9E-4		
Human toxicity	kg 1,4-DBeq	1.173	1.694	0.755		
Marine ecotoxicity	kg 1,4-DBeq	0.243				
Marine aquatic ecotoxicity	kg 1,4-DBeq		1,508.919			
Aquatic ecotoxicity	kg 1,4-DBeq			2.33		
Freshwater ecotoxicity	kg 1,4-DBeq	3.68				
Freshwater aquatic ecotoxicity	kg 1,4-DBeq		0.624			
Terrestrial ecotoxicity	kg 1,4-DBeq	0.062	0.041			
Water depletion	m^3	0.04				
Metal depletion	kg Fe eq	0.161				
Abiotic depletion	kg Sb eq		0.027			
Resources consumption	kg Sb eq			0.03		
Mineral Resources Consumption	kg Sb eq					1.84E-7
Fossil depletion	kg oil eq	1.193				
Energy consumption	MJ eq			77.089		
Non renewable energy consumption	MJ					43.2
Renewable energy consumption	MJ					4.72
Biomass consumption	kg					0
Ozone depletion	kg CFC-11eq	1.16E-6				
Ozone layer depletion	kg CFC-11eq		1.27E-6			1.53E-7
Particulate matter formation	kg PM10 eq	0.014				
Ionising radiation	kg U235eq	0.281				
Agricultural land occupation	m^2a	0.578				
Urban land occupation	m^2a	0.025				
Natural land transformation	m^2	7.2E-4				

3.2 Full and simplified LCA of lemon juice

As far as the full LCA implementation of lemon juice is concerned, the results demonstrated that it is the distribution phase to be blamed for most of the impacts on the environment, followed by the bottling and the processing phases (Di Bartolo, 2015). When it comes to the normalisation results (Figure 10), natural land transformation was identified to be the most affected environmental category. What followed were the categories of marine toxicity, and freshwater eutrophication.

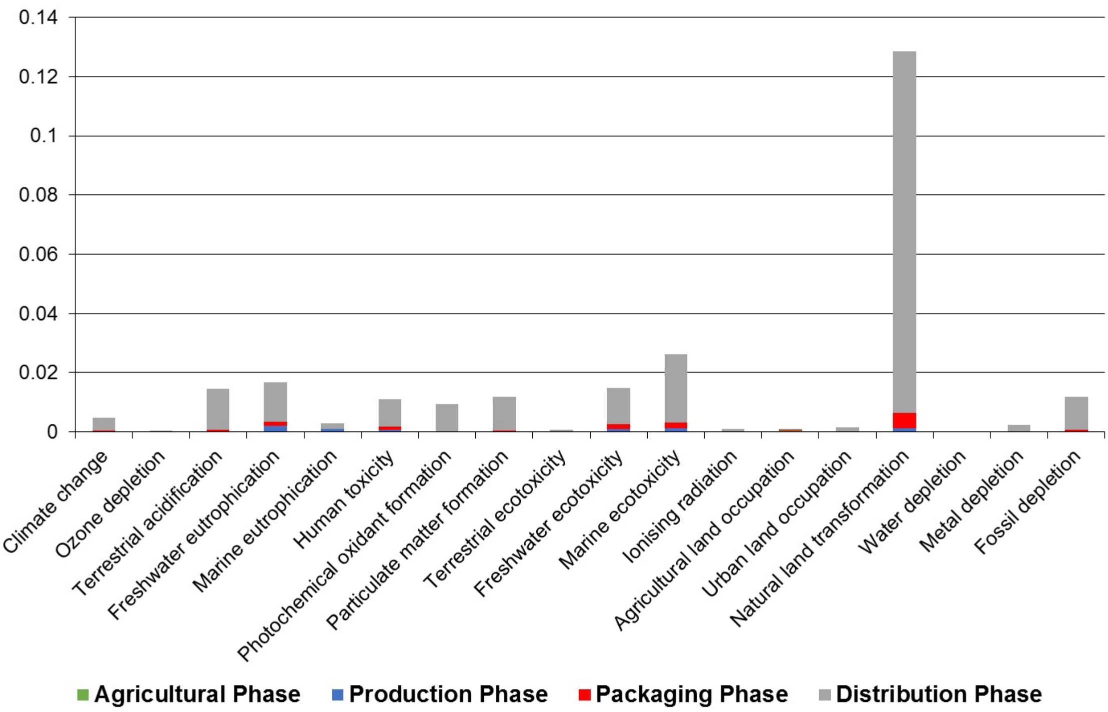

Figure 10. Full LCA implementation for lemon juice –ReCiPe MidPoint method – Normalisation Results (Di Bartolo, 2015)

Using BilanProduit for the simplified LCA implementation, since the use and the waste management phases were out of the system boundary, only the sheets of "production" and "transport" were compiled. The database of the tool was found to be lacking in processes related to the use of organic fertilisers (farmyard manure).

For this study, the production phase (as defined by the tool) was found to be the most impacting one for all environmental impact categories. Within this, the use of glass for the primary packaging (bottling phase) appeared to be the most affecting process, followed by the electricity consumption during the processing phase. As far as the normalisation results are concerned,

Figure 11 demonstrates that resources consumption seemed to be the most affected environmental impact. This was followed by aquatic ecotoxicity.

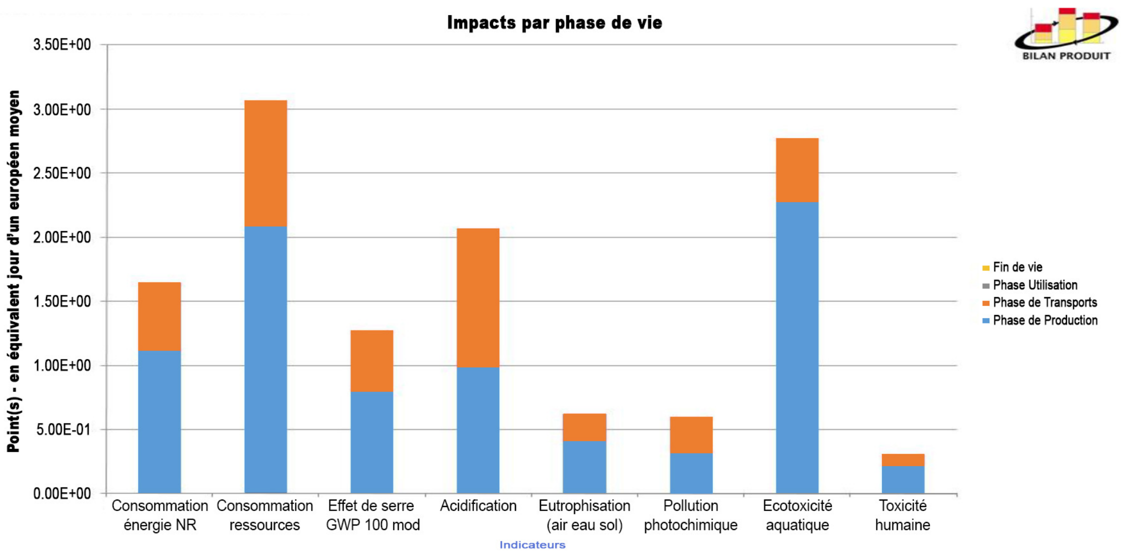

Figure 11. BilanProduit – Normalisation results for lemon juice

When it comes to CCaLC, the tool was found to be sufficient when it comes to processes in its incorporated database. In most of the cases where the same process was available in both the CCaLC and Ecoinvent databases (both included in the incorporated one), the former was preferred in order for its robustness to be controlled.

The results regarding climate change showed that the use of raw materials was the most impacting one (3 kg CO_2 eq/FU - See Figure 12). Within this, it was the use of glass (i.e., for the bottling phase) that appeared to have the most significant impact (2.27 kg CO_2 eq/FU). The transport phase was only second to the use of raw materials (2.17 kg CO_2 eq/FU).

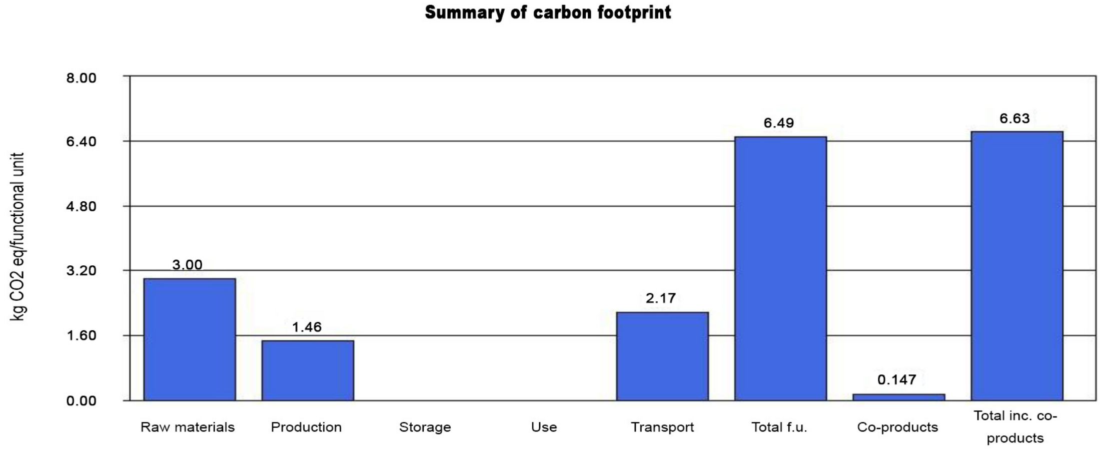

Figure 12. CCaLC – Carbon Footprint for lemon juice

The modelling with eVerdEE was performed in the same way as in the case of the roasted coffee (separately for the agricultural phase and then incorporated as a component). Moreover, the tool was found to be lacking in several agriculture-related inputs. The characterisation results showed that the “use and end-of-life” phase (which for modelling reasons contained data from other phases) was the most impacting for all environmental categories such as mineral resources consumption, energy consumption, eutrophication, acidification, climate change, etc. With regard to the normalisation results, it appeared that fresh water consumption and non-renewable energy consumption were the most affected categories, followed by climate change and acidification (see Figure 13).

Lemon Juice Eurofood

Indicator	Total	Pre-manufacure	Manufacture	Packaging and Distribution	Use and End of Life
Consumption of mineral resources	$5.38\ 10^{-5}$	$2.07\ 10^{-11}$	$7.66\ 10^{-6}$	$4.38\ 10^{-7}$	$4.57\ 10^{-5}$
Consumption of biomass	0	0	0	0	0
Consumption of fresh water	0.00159	$3.77\ 10^{-9}$	0.00157	$1.15\ 10^{-6}$	$1.40\ 10^{-5}$
Consumption of non-renewable energy	0.00102	$1.71\ 10^{-9}$	$2.90\ 10^{-4}$	$1.04\ 10^{-4}$	$6.29\ 10^{-4}$
Consumption of renewable energy	$3.75\ 10^{-4}$	$8.82\ 10^{-11}$	$2.34\ 10^{-4}$	$4.09\ 10^{-5}$	$9.98\ 10^{-5}$
Climate change	$6.36\ 10^{-4}$	$2.82\ 10^{-10}$	$2.18\ 10^{-4}$	$6.76\ 10^{-5}$	$3.51\ 10^{-4}$
Acidification	$4.80\ 10^{-4}$	$1.61\ 10^{-10}$	$1.30\ 10^{-4}$	$1.04\ 10^{-4}$	$2.46\ 10^{-4}$
Eutrophication	$2.38\ 10^{-4}$	$9.85\ 10^{-11}$	$5.46\ 10^{-5}$	$7.25\ 10^{-5}$	$1..11\ 10^{-4}$
Photochemical oxidation	$1.16\ 10^{-4}$	$7.75\ 10^{-11}$	$2.94\ 10^{-5}$	$2.64\ 10^{-5}$	$6.06\ 10^{-5}$
Ozone layer depletion	$2.12\ 10^{-6}$	$6.57\ 10^{-13}$	$9.29\ 10^{-7}$	$5.89\ 10^{-8}$	$1.13\ 10^{-6}$

Normalized Results

Figure 13. eVerdEE – Normalisation results for lemon juice (screenshot)

A summary of the results of the full LCA implementation for lemon juice and the related three simplified LCA results is presented in Table 3.

Table 3. Lemon Juice: Full and Simplified LCA characterisation results

		ReCiPe MidPoint (H)	**CML 2001**	**Bilan Produit**	**CCaLC**	**eVerdEE**
Impact category	**Unit**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Climate change	kg CO_2eq	54.504			6.63	4.33
Global warming GWP 100	kg CO_2eq		54.528	35.837		
Terrestrial acidification	kg SO_2 eq	0.5				
Acidification	kg SO_2 eq		0.52	0.254		0.026
Freshwater eutrophication	kg P eq	0.007				
Marine eutrophication	kg N eq	0.029				
Eutrophication	kg PO_4^-eq		0.089	0.065		0.002
Photochemical oxidant formation	kg NMVOC	0.528				
Photochemical oxidation	kg C_2H_4		0.017			0.002
Photochemical pollution	kg C_2H_4			0.009		

Human toxicity	kg 1,4-DBeq	6.907	14.945	17.205	
Marine ecotoxicity	kg 1,4-DBeq	0.229			
Marine aquatic ecotoxicity	kg 1,4-DBeq		31.48		
Aquatic ecotoxicity	kg 1,4-DBeq			7.758	
Freshwater ecotoxicity	kg 1,4-DBeq	0.164			
Freshwater aquatic ecotoxicity	kg 1,4-DBeq		5.019		
Terrestrial ecotoxicity	kg 1,4-DBeq	0.005	0.01		
Water depletion	m^3	77.956			
Metal depletion	kg Fe eq	1.723			
Abiotic depletion	kg Sb eq		0.373		
Resources consumption	kg Sb eq			0.292	
Mineral Resources Consumption	kg Sb eq				3.09E-6
Fossil depletion	kg oil eq	18.239			
Energy consumption	MJ eq			690.025	
Non renewable energy consumption	MJ				60.7
Renewable energy consumption	MJ				3.45
Biomass consumption	kg				0
Ozone depletion	kg CFC-11eq	7.57E-6			
Ozone layer depletion	kg CFC-11eq		7.52E-6		1.56E-7
Particulate matter formation	kg PM10 eq	0.176			
Ionising radiation	kg U235eq	6.374			
Agricultural land occupation	m^2a	3.509			
Urban land occupation	m^2a	0.619			
Natural land transformation	m^2	0.021			

3.3 Full and simplified LCA of olive oil

As far as the full LCA for olive oil production in Salomone and Ioppolo (2012) is concerned, several LCIA methods were used, for example: CML 2 baseline 2000, Eco-Indicator 99, ReCiPe Endpoint, Impact 2002 and EDIP 2003, thus taking into consideration both the problem-oriented methods and the damage-oriented ones. The full LCA characterisation results showed that the agricultural phase is to be blamed for most of the impacts on the environment. This was mainly connected to fertilisation, the use of lube oil and diesel (in the mechanised activities) and of land. Furthermore, the marine eutrophication, followed by freshwater eutrophication were the most affected environmental categories (Figure 14), using the ReCiPe MidPoint method. It is to be noted here that the global warming potential had a negative value (-614 kg CO_2 eq/FU) due to the avoided production of fertilisers replaced by compost as a by-product (Salomone and Ioppolo, 2012).

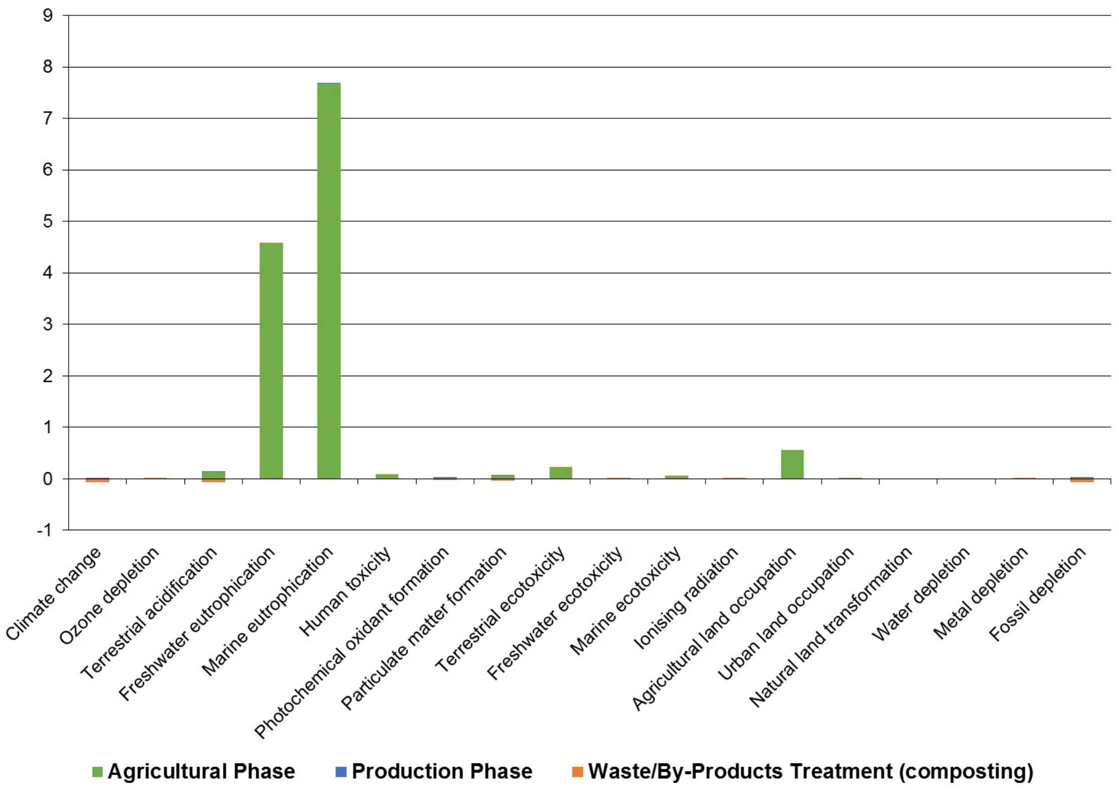

Figure 14. Full LCA implementation for olive oil – ReCiPe MidPoint method – Normalisation Results (Salomone and Ioppolo, 2012)

The implementation of simplified LCA using BilanProduit, showed that the database of the tool was lacking in entries, such as compost and straw. Moreover, as in the case of roasted coffee, emissions could not be inserted here. Since the system boundary did not include phases such as transport and end-of-life, only the "production" sheet was filled in. When it comes to the normalisation results, it appeared that the consumption of resources was the most affected environmental category, followed by acquatic ecotoxicity and energy consumption. As it can be deduced by Figure 15, the electricity comsumption in all phases (especially during the agricultural and the composting ones), as well as the diesel consumption during the composting phase, seemed to be the most impacting ones. For instance, regarding climate change the electricity consumption during the agricultural phase reached 24,490 kg CO_2 eq/FU, followed by the diesel consumption in the composting facility (4,237 kg CO_2 eq/FU).

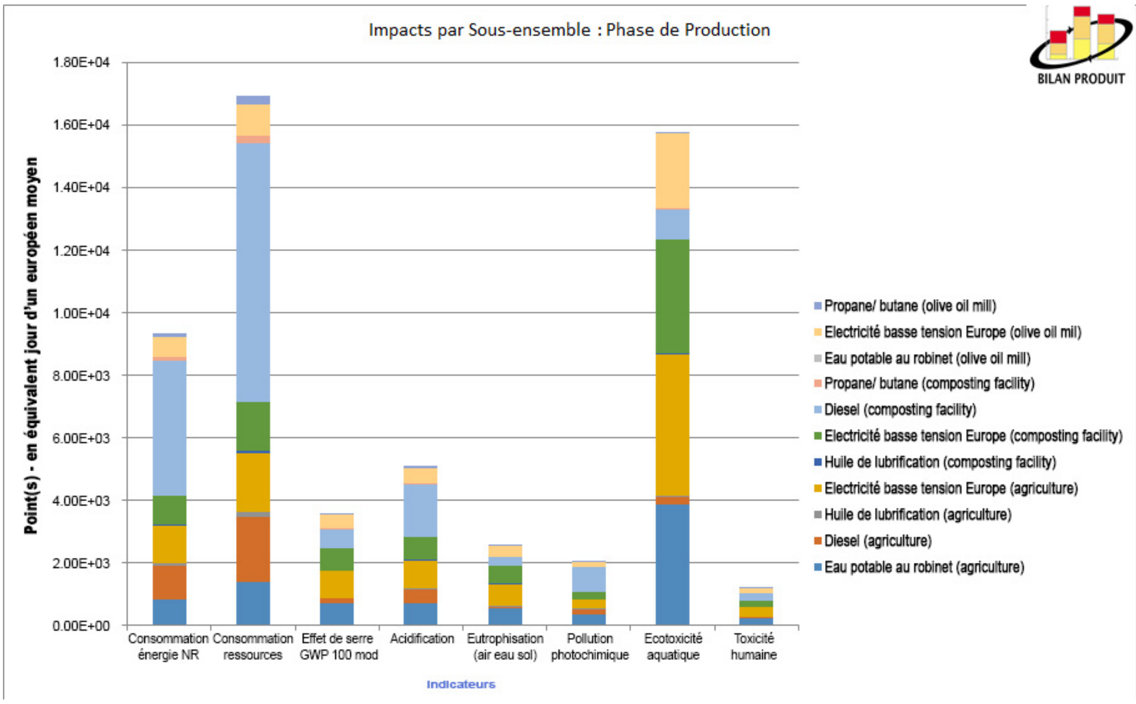

Figure 15. BilanProduit – Normalisation results for olive oil (production phase)

Concerning the CCaLC tool, the first issue to be highlighted is that the tool is provided with a built-in option to deal with the multifunctionality issue for the by-products (olive stones and compost), by using system expansion - in the same way as it was dealt with in the full LCA implementation (Salomone and Ioppolo, 2012). The results regarding climate change (Figure 16) showed that the composting phase was the most impacting one, due to diesel consumption by the machinery (3,288 kg CO_2 eq/FU). The overall carbon footprint had a negative value (-1,942 kg CO_2 eq/FU) due to environmental credit related to the use of by-products as fertilisers (as in the full LCA results). As far as the other environmental impacts are concerned, the sum of the raw materials used for all phases was the one that contributed the most.

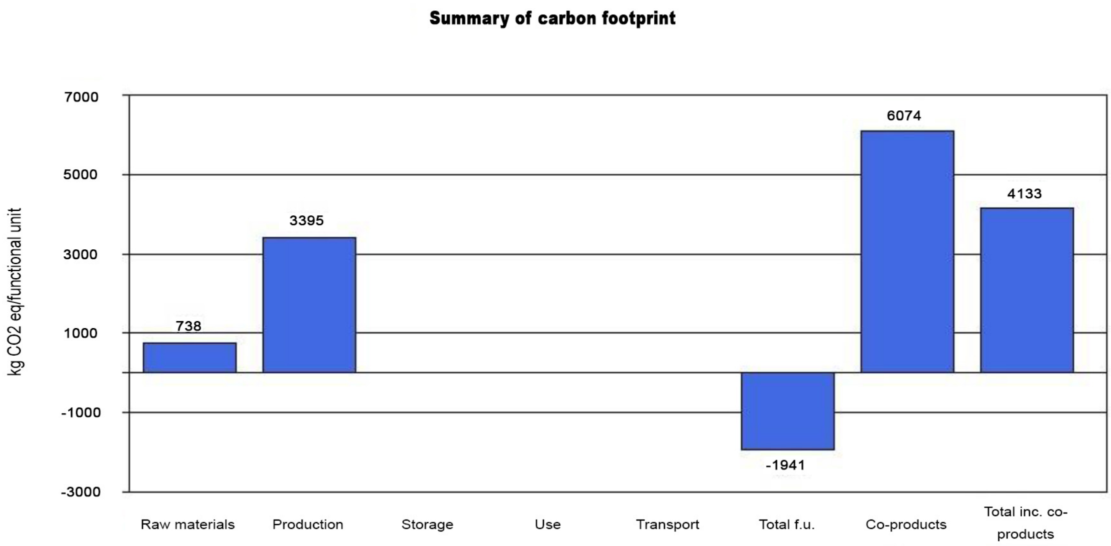

Figure 16. CCaLC – Carbon Footprint for olive oil

The modelling with eVerdEE was performed in the same way as for the other products and the lack in agriculture-related processes was hilghlighted here, as well. As far as the characterisation results are concerned, the "use and end-of-life" phase, which included the composting phase, was found to be more impacting for most of the environmental impact categories (for instance, mineral resources consumption, energy consumption, climate change, acidification, and photochemical oxidation). The "pre-manufacture" phase was responsible for categories such as fresh water consumption, eutrophication and ozone layer depletion. The normalisation results (Figure 17) highlighted that the most affected category was eutrophication, followed by energy consumption and climate change.

Olive oil ME

Indicator	Total	Pre-manufacure	Manufacure	Packaging and Distribution	Use and End of Life
Consumption of mineral resources	0.0352	$7.39\ 10^{-4}$	$2.75\ 10^{-5}$	0	0.0345
Consumption of biomass	$9.18\ 10^{-6}$	0	0	0	$9.18\ 10^{-6}$
Consumption of fresh water	0.165	0.164	0.00116	0	$1.81\ 10^{-4}$
Consumption of non-renewable energy	0.295	0.0181	0.00556	0	0.274
Consumption of renewable energy	0.0302	0.00700	0.00340	0	0.0198
Climate change	0.189	0.0108	0.00257	0	0.175
Acidification	0.0711	0.00541	0.00174	0	0.0639
Eutrophication	2.71	2.60	$4.35\ 10^{-4}$	0	0.0999
Photochemical oxidation	0.0458	0.00141	$4.44\ 10^{-4}$	0	0.0439
Ozone layer depletion	$6.71\ 10^{-5}$	$3.48\ 10^{-5}$	$1.24\ 10^{-5}$	0	$1.99\ 10^{-5}$

Normalized Results

Figure 17. eVerdEE – Normalisation results for olive oil (screenshot)

For a summary of the results for olive oil production using two different LCIA methods (for the full LCA implementation) and the three simplified LCA tools, please refer to Table 4.

Table 4. Olive oil: Full and Simplified LCA characterisation results

		ReCiPe MidPoint (H)	**CML 2001**	**BilanProduit**	**CCaLC**	**eVerdEE**
Impact category	**Unit**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Climate change	kg CO_2eq	-619.53			-1,941	1,280
Global warming GWP 100	kg CO_2eq		-613.54	99,571.1		
Terrestrial acidification	kg SO_2 eq	2.327				
Acidification	kg SO_2 eq		1.409	616.92		3.82
Freshwater eutrophication	kg P eq	1.898				
Marine eutrophication	kg N eq	77.572				
Eutrophication	kg PO_4^-eq		39.061	268.3		26.5
Photochemical oxidant formation	kg NMVOC	0.051				
Photochemical oxidation	kg C_2H_4		-0.014			0.755

Photochemical pollution	kg C_2H_4			30.386	
Human toxicity	kg 1,4-DBeq	51.485	18.75	66,248.4	
Marine ecotoxicity	kg 1,4-DBeq	0.414			
Marine aquatic ecotoxicity	kg 1,4-DBeq		44.523		
Aquatic ecotoxicity	kg 1,4-DBeq			44,045.9	
Freshwater ecotoxicity	kg 1,4-DBeq	0.112			
Freshwater aquatic ecotoxicity	kg 1,4-DBeq		8.306		
Terrestrial ecotoxicity	kg 1,4-DBeq	1.737	0.187		
Water depletion	m^3	304.8			
Metal depletion	kg Fe eq	0.643			
Abiotic depletion	kg Sb eq		-1.41		
Resources consumption	kg Sb eq			1,597.7	
Mineral Resources Consumption	kg Sb eq				0.002
Fossil depletion	kg oil eq	-58.935			
Energy consumption	MJ eq			3,877,185.2	
Non renewable energy consumption	MJ				17,700
Renewable energy consumption	MJ				278
Biomass consumption	kg				1,470
Ozone depletion	kg CFC-11eq	1.2E-4			
Ozone layer depletion	kg CFC-11eq		1.2E-4		4.93E-6
Particulate matter formation	kg PM10 eq	0.289			
Ionising radiation	kg U235eq	3.456			
Agricultural land occupation	m^2a	2,500			
Urban land occupation	m^2a	0.199			
Natural land transformation	m^2	0			

3.4 Full and simplified LCA of red wine

The full LCA characterisation results for the red wine (using the ReCiPe [H] MidPoint method) showed that the agricultural phase has the highest impact for some impact categories, e.g., terrestrial ecotoxicity, metal depletion, agricultural land occupation, freshwater eutrophication, freshwater ecotoxicity and marine ecotoxicity. On the other hand, the packaging phase was to blame for most of the categories such as fossil depletion, natural land transformation, ozone depletion, ionizing radiation and, to a lesser degree, for climate change.

As far as the normalisation results are concerned (Figure 18), marine ecotoxicity had the highest score, followed by human toxicity and freshwater ecotoxicity. The use of green glass for the wine bottles (in the packaging phase) was by far the most impacting one for almost all the impact categories.

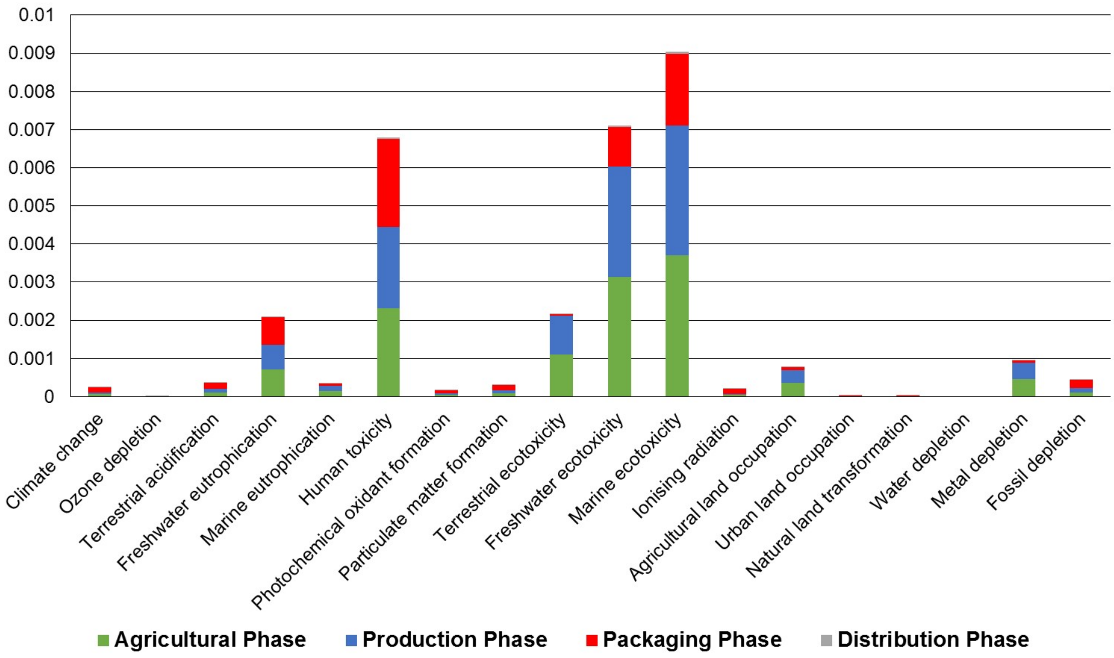

Figure 18. Full LCA implementation for wine – Normalisation Results (Arzoumanidis et al. 2013a)

When the simplified LCA was implemented, the tool BilanProduit appeared to be lacking in specific fertilisers' entries within its database, whilst the database provided sufficient entries for the pesticides. The results showed that the production phase (that included both agriculture and vinification) is the most influencing one for all the environmental impact categories. The category that is most affected appears to be by far the aquatic ecotoxicity, followed by the consumption of resources (Figure 19). For both cases, it is the transport of raw materials that is the most influencing.

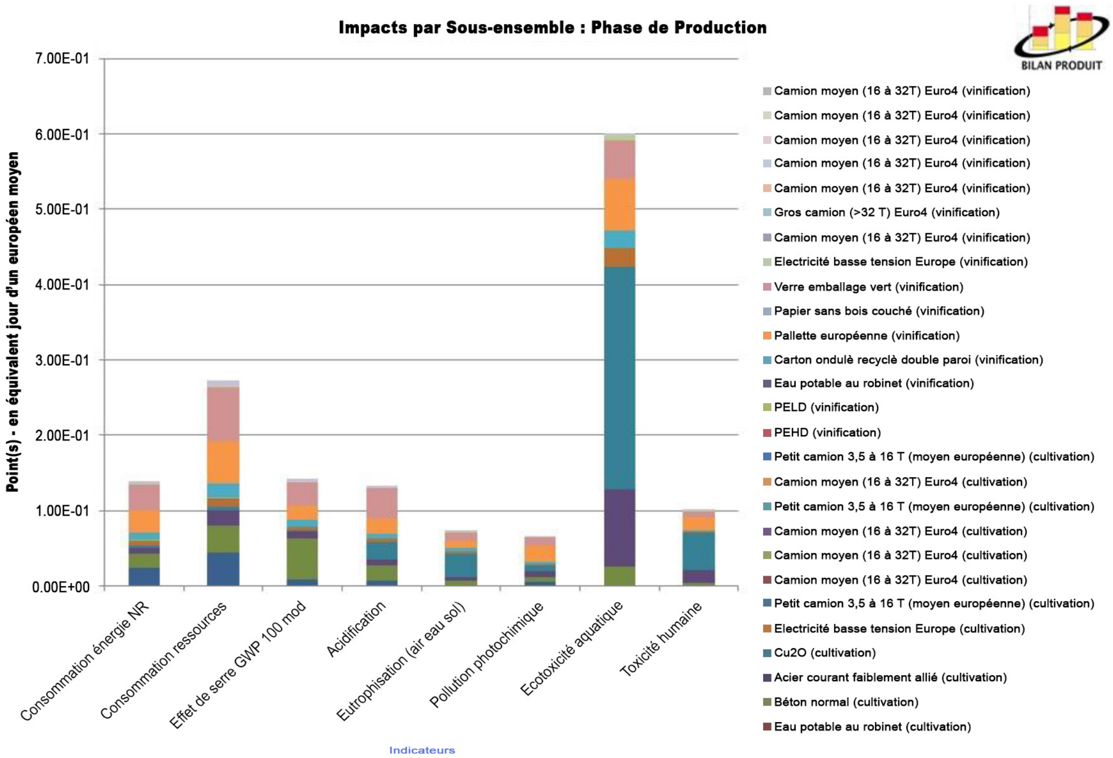

Figure 19. BilanProduit – Normalisation results for wine (Arzoumanidis et al. 2014a)

In the case of CCaLC implementation, no missing processes could be identified in the incorporated database of the tool. The results showed that the use of raw materials had the highest impact for the climate change category (Figure 20), followed by production and transport. Regarding other environmental impacts, such as acidification, eutrophication, human toxicity, ozone layer depletion and photochemical smog, the raw materials stage resulted as having the highest impact followed by transport in most of the cases.

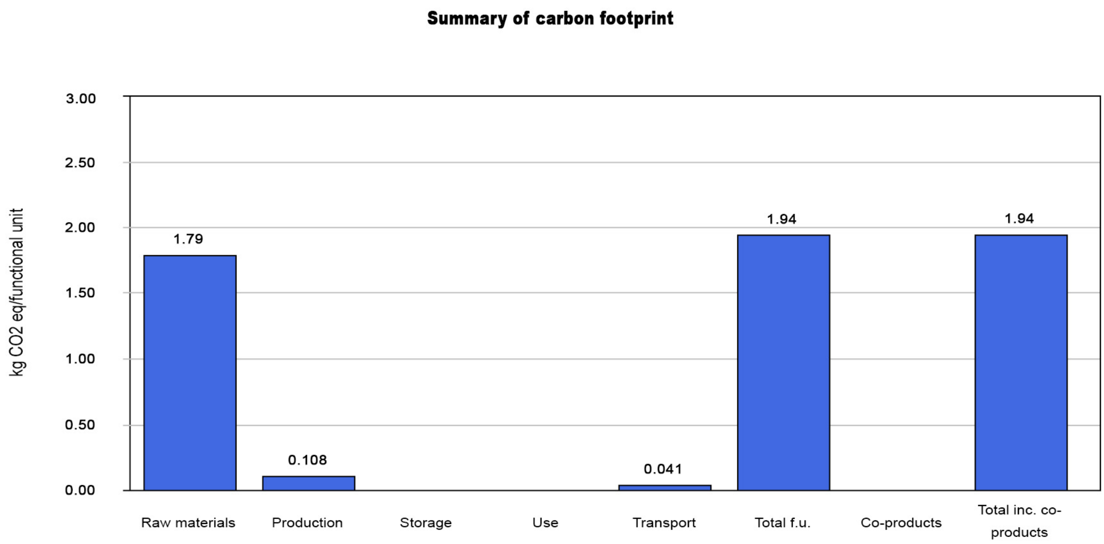

Figure 20. CCaLC – Carbon Footprint for wine

Using eVerdEE, as with the other agri-food products under study, the agricultural phase was created separately and included as a component in the model. Since not all of the packaging materials were found under the “product packaging” phase, half of them (all plastic materials) were inserted in the “auxiliary materials” under the “manufacture” phase. The results of the characterisation demonstrated that the “packaging and distribution” phase was the most impacting for most of the environmental impact categories (i.e., mineral resources consumption, fresh water consumption, energy consumption, climate change, acidification, photochemical oxidation, ozone layer depletion). On the other hand, the “pre-manufacture” phase was to blame for eutrophication. Regarding the normalised results, it appeared that the consumption of energy was the most affected environmental impact category, followed by climate change (Figure 21).

Montepulciano d’Abruzzo

Indicator	Total	Pre-manufacure	Manufacure	Packaging and Distribution	Use and End of Life
Consumption of mineral resources	$1.54\ 10^{-5}$	$6.92\ 10^{-8}$	$2.90\ 10^{-6}$	$1.25\ 10^{-5}$	0
Consumption of biomass	$7.65\ 10^{-10}$	0	$7.65\ 10^{-10}$	0	0
Consumption of fresh water	$9.65\ 10^{-6}$	$3.45\ 10^{-6}$	$3.81\ 10^{-7}$	$5.82\ 10^{-6}$	0
Consumption of non-renewable energy	$2.38\ 10^{-4}$	$1.84\ 10^{-5}$	$3.34\ 10^{-5}$	$1.86\ 10^{-4}$	0
Consumption of renewable energy	$1.74\ 10^{-4}$	$2.52\ 10^{-7}$	$6.44\ 10^{-6}$	$1.67\ 10^{-4}$	0
Climate change	$1.49\ 10^{-4}$	$1.25\ 10^{-5}$	$1.94\ 10^{-5}$	$1.17\ 10^{-4}$	0
Acidification	$1.00\ 10^{-4}$	$1.90\ 10^{-5}$	$8.19\ 10^{-6}$	$7.32\ 10^{-5}$	0
Eutrophication	$1.11\ 10^{-4}$	$6.77\ 10^{-5}$	$3.30\ 10^{-6}$	$4.04\ 10^{-5}$	0
Photochemical oxidation	$2.46\ 10^{-5}$	$7.56\ 10^{-7}$	$4.76\ 10^{-6}$	$1.91\ 10^{-5}$	0
Ozone layer depletion	$4.95\ 10^{-7}$	$2.54\ 10^{-9}$	$2.21\ 10^{-8}$	$4.70\ 10^{-7}$	0

Normalized Results

Figure 21. eVerdEE – Normalisation Results for wine (screenshot)

A summary of the results of the full LCA implementation for red wine and the related three simplified LCA results is presented in Table 5.

Table 5. Red Wine: Full and Simplified LCA characterisation results

		ReCiPe MidPoint (H)	**CML 2001**	**BilanProduit**	**CCaLC**	**eVerdEE**
Impact category	**Unit**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Climate change	kg CO_2eq	1.708			1.94	1.01
Global warming GWP 100	kg CO_2eq		1.704	4.042		
Terrestrial acidification	kg SO_2 eq	0.014				
Acidification	kg SO_2 eq		0.013	0.017		0.005
Freshwater eutrophication	kg P eq	6E-4				
Marine eutrophication	kg N eq	0.002				
Eutrophication	kg PO_4^-eq		0.006	0.008		0.001
Photochemical oxidant formation	kg NMVOC	0.008				
Photochemical oxidation	kg C_2H_4		5.3E-4			4.06E-4
Photochemical pollution	kg C_2H_4			9.9E-4		

Human toxicity	kg 1,4-DBeq	0.797	2.227	5.641	
Marine ecotoxicity	kg 1,4-DBeq	0.022			
Marine aquatic ecotoxicity	kg 1,4-DBeq		1,908.64		
Aquatic ecotoxicity	kg 1,4-DBeq			1.687	
Freshwater ecotoxicity	kg 1,4-DBeq	0.031			
Freshwater aquatic ecotoxicity	kg 1,4-DBeq		2.398		
Terrestrial ecotoxicity	kg 1,4-DBeq	0.014	0.04		
Water depletion	m^3	0.017			
Metal depletion	kg Fe eq	0.421			
Abiotic depletion	kg Sb eq		0.013		
Resources consumption	kg Sb eq			0.0265	
Mineral Resources Consumption	kg Sb eq				8.88E-7
Fossil depletion	kg oil eq	0.585			
Energy consumption	MJ eq			59.704	
Non renewable energy consumption	MJ				14.1
Renewable energy consumption	MJ				1.6
Biomass consumption	kg				0.122
Ozone depletion	kg CFC-11eq	1.51E-7			
Ozone layer depletion	kg CFC-11eq		1.43E-7		3.64E-8
Particulate matter formation	kg PM10 eq	0.004			
Ionising radiation	kg U235eq	0.258			
Agricultural land occupation	m^2a	4.219			
Urban land occupation	m^2a	0.02			
Natural land transformation	m^2	3.9E-4			

4. Discussion

The comparison of the three different simplified LCA tools, BilanProduit, CCaLC and eVerdEE through their implementation in the framework of four agri-food products (roasted coffee, lemon juice, olive oil, and red wine) and the parallel analysis with the related full LCAs, allowed the Authors to highlight several aspects of the case studies that should be intended as determining factors of the robustness and suitability of each tool and of the general Simplified LCA approach within the agri-food industry. Such aspects can be summarised in: a) modelling, b) databases, c) environmental impact categories affected, d) most impacting phases in the life cycle of the product. These issues were selected as being (generally) the most relevant in terms of methodology in LCA. Relating to the modelling issue, the various choices that had to be made in order to include all flows and processes are tackled. In some cases, these were choices that were made by the user or by the tool itself (in other words, the tool did not allow for a different way to insert a flow). In general, these modelling differences resulted in different models containing not always comparable phases. With regard to the second aspect analysed, the databases, all the choices made in order to insert a flow or a process that best described the actual measured one are included. The completeness of the databases for these case studies is measured. As far as the most affected environmental impact categories and the most impacting phases in the lyfe cycle of the product are concerned, these are important during the interpretation phase of an LCA analysis. These are examined and presented for all products and for the different simplified tools (in parallel to full LCA implementations).

A summary of the findings, regarding the three simplified LCA tools analysed and the full LCA implementations, is presented in Table 6.

Table 6. Summary of the findings

		BilanProduit	CCaLC	eVerdEE	Full LCA
Modelling	Roasted Coffee	- The built-in “Production phase” included: agriculture, packaging, roasted coffee production - Transport between plants, packaging transport and distribution activities were inserted separately	- Agriculture, roasted coffee production and packaging were modelled separately under “Production” - Raw materials were modelled as a separate category	- Agriculture: created separately and included in the model as a component - Production: under the “manufacture” phase - Packaging: under the “pre-manufacture” phase - Transport: under the “product distribution” phase - Use: under the “product use” phase - Some inputs had to be included under different tool-defined phases	Fully-detailed modelling performed per phase and process
	Organic Lemon Juice	- The built-in “Production phase” included: agriculture, processing, bottling and packaging	- Agriculture, processing, bottling and packaging were modelled separately under “Production” - Raw materials were modelled as a separate category	- Agriculture: created separately and included in the model as a component - Production: under the “manufacture phase” - Packaging: under the “product packaging” and “product use” phases - Distribution: under the “product distribution” phase - Some inputs had to be included under different tool-defined phases	
	Olive Oil	- The built-in “Production phase” included: agriculture, olive oil mill, composting facility	- Agriculture, olive oil mill and composting facility were modelled separately under “Production” - Raw materials were modelled as a separate category	- Agriculture: created separately and included in the model as a component - Production: under the “manufacture phase” -Waste and by-prducts treatment: under the “product use” phase - Some inputs had to be included under different tool-defined phases	
	Organic Red Wine	- The built-in “Production phase” included: agriculture and vinification	- Agriculture and vinification were modelled separately under “Production” - Raw materials were modelled as a separate category	- Agriculture: created separately and included in the model as a component -Vinification: under “pre-manufacture” and “manufacture” phases -Packaging: under the “product packaging” and “product packaging” phases - Some inputs had to be included under different tool-defined phases	
Built-in Databases	Roasted Coffee	- Lack in fertilisers, limestone, pesticides, land use (agricultural phase) - Lack in emissions	- Lack in emissions - Land use (there was no entry for the production country - Brazil) - Some processes were not found in the CCaLC database, but were retrieved from the incorporated EcoInvent database	- Lack in some emissions - Lack in fertilisers and pesticides	Lack in some agriculture-related emissions (estimated)
	Organic Lemon Juice	- Lack in fertilisers	- Some processes were not found in the CCaLC database, but were retrieved from the incorporated EcoInvent database	- Lack in fertilisers	Lack in some agriculture-related emissions (estimated)
	Olive Oil	- Lack in compost and straw	- Some processes were not found in the CCaLC database, but were retrieved from the incorporated EcoInvent database	- Lack in: compost and straw - Lack in fertilisers and pesticides	Lack in some agriculture-related emissions (estimated)
	Organic Red Wine	- Lack in fertilisers - Lack in specific pesticides - Lack in yeasts and activators (vinification)	- Some processes were not found in the CCaLC database, but were retrieved from the incorporated EcoInvent database - Lack in specific pesticides - Lack in yeasts and activators (in the vinification phase)	- Lack in some emissions - Lack in pesticides	- Lack in some agriculture-related emissions (estimated) - Lack in specific pesticides - Lack in yeasts and

<table>
<tr><td></td><td></td><td></td><td colspan="2"></td><td></td><td>activators (vinification)</td></tr>
<tr><td rowspan="4">Environmental Impact Categories affected</td><td>Roasted Coffee</td><td>- Aquatic ecotoxicity
- Resources consumption
- Energy Consumption</td><td colspan="2">Non-applicable (the tool focuses on one impact category)</td><td>- Eutrophication
- Acidification
- Climate change</td><td>- Freshwater ecotocity
- Freshwater eutrophication</td></tr>
<tr><td>Organic Lemon Juice</td><td>- Resources consumption
- Aquatic ecotoxicity</td><td colspan="2">Non-applicable (the tool focuses on one impact category)</td><td>- Water consumption
- Energy consumption</td><td>- Natural land transformation
- Marine Ecotoxicity</td></tr>
<tr><td>Olive Oil</td><td>- Resources consumption
- Aquatic ecotoxicity
- Energy consumption</td><td colspan="2">Non-applicable (the tool focuses on one impact category)</td><td>- Eutrophication
- Energy consumption
- Climate change</td><td>- Marine eutrophication
- Freshwater eutrophication</td></tr>
<tr><td>Organic Red Wine</td><td>- Aquatic ecotoxicity
- Resources consumption</td><td colspan="2">Non-applicable (the tool focuses on one impact category)</td><td>- Energy consumption
- Climate change</td><td>- Marine ecotoxicity
- Human toxicity</td></tr>
<tr><td rowspan="4">Most impacting phases</td><td>Roasted Coffee</td><td>- Use phase</td><td rowspan="4">Impact category: global warming</td><td>- Production phase</td><td>- Use and end-of-life (tool-defined phase)
- Pre-manufacture (tool-defined phase)</td><td>- Agricultural phase
- Use phase (Italy)</td></tr>
<tr><td>Organic Lemon Juice</td><td>- Production phase (within bottling and processing)</td><td>- Raw materials (within this: the use of glass for bottling)</td><td>- Use and end-of-life (tool-defined phase)</td><td>- Distribution phase</td></tr>
<tr><td>Olive Oil</td><td>- Agricultural phase
- Composting phase</td><td>- Composting phase
- Raw materias</td><td>- Use and end-of-life (tool-defined phase)</td><td>- Agricultural phase</td></tr>
<tr><td>Organic Red Wine</td><td>- Production phase (including both agriculture and vinification/ packaging phases)</td><td>- Raw materials</td><td>- Packaging and distribution (tool-defined phase)</td><td>- Agricultural phase
- Packaging phase</td></tr>
</table>

As regards modelling, it can be deduced by Table 6 that it was not possible to model all four products in the same way for the three different simplified LCA tools (in some cases they included the same life cycle stages, in others they did not). Nevertheless, the modelling was found to be quite similar for two of the simplified tools (CCaLC and BilanProduit), whilst this was not the case in the parallelism with other simplified tools (see for example, Arzoumanidis et al., 2014a). On the other hand, eVerdEE was the tool that used different modelling, both in terms of the fact that the agricultural phase was incorporated as a component (that was modelled separately) and of the fact that many of the processes or sub-phases had to be included under other phases, due to database restrictions[3] (see Sections 3.1, 3.2, 3.3, 3.4).

Regarding the databases used by the tools, it was found that the lack in agriculture-related processes (such as fertilisers and emissions) is of great importance for the analysis of agri-food products. Even though the full LCA software does not always guarantee a full availability of agri-food processes, the simplified tools appeared to be greatly lacking as regards those processes. When it comes to the use of different databases for each tool, the choice of the flows and processes to be considered was found to be also crucial for the final results (see for example, the case of lemon juice, where the most affected life cycle phase was different for the various analyses due to the use of different databases). As far as the data quality is concerned, an attempt was made to illustrate it in terms of the degree of matching between the processes selected from the database and the actual ones. Table 7 shows the results of such an analysis, where for each simplified tool the percentage of processes that corresponded to an *actual*, a *similar*, or a *less similar* one is given. CCaLC appears to receive, on average, the highest actual-process percentages. This is probably due to the fact that, as aforementioned (please refer to Sections 3.1, 3.2, 3.3, 3.4), the EcoInvent database was used in cases when a process could not be found within the CCaLC database, thus increasing the number of flows that were more similar or even identical to the real ones.

[3] To the best of the authors' knowledge this issue will be resolved once the new database will be implemented.

Table. 7. Tools' database data quality analysis - percentage of processes selected from the tools' databases that exactly matched the actual process, or were somehow similar (or less similar) to the real ones

Product	Tool	Actual process	Similar Process	Less similar Process
Roasted Coffee	BilanProduit	12.5%	79.17%	8.33%
	CCaLC	35%	65%	0%
	eVerdEE	50%	45%	5%
Lemon Juice	BilanProduit	21.43%	71.43%	7.14%
	CCaLC	70.59%	23.53%	5.94%
	eVerdEE	50%	37.5%	12.5%
Olive Oil	BilanProduit	75%	25%	0%
	CCaLC	92.85%	7.15%	0%
	eVerdEE	81.82%	9.09%	9.09%
Red Wine	BilanProduit	38.46%	61.54%	0%
	CCaLC	68.18%	31.82%	0%
	eVerdEE	58.82%	41.18%	0%

As far as the most affected environmental impact categories are concerned, the various simplified tools provided different results, both amongst them and between them and the full LCA. For example, for the case of olive oil, the agricultural phase seemed to be the most impacting, while for BilanProduit this was not the case. This was because agriculture-related processes and emissions were missing in the database of the simplified tool. There were only a few exceptions to this general outcome: for instance, in the case of the lemon juice, water consumption emerged as a hot-spot in both full LCA and eVerdEE, and, to a certain extent, in BilanProduit (as resources consumption, in general).

A similar heterogeneity was found also regarding the most impacting phases in the life cycle of the product both amongst the various simplified tools and between them and the full LCA implementation. In this case, some of the tools delivered similar results in couples, but there was never a unanimous outcome on the most impacting phase(s) (see Table 6). For instance, regarding lemon juice, the differences in the results depend on the use of similar (but not the same) processes from the incorporated databases, since these were different for each case, e.g., the transoceanic freight ship from the ecoinvent database was used for the full LCA, while "container ship" was used for CCaLC. Given the fact that the trip by sea that was taken into account was quite long, the choice of different processes that were present in the different tools has played a significant role in the outcome.

5. Conclusions and future developments

Three different simplified LCA tools were implemented in parallel to full LCAs for four different agri-food products in order to assess the robustness, suitability and shortcomings of the simplified approach in this industry. As far as the results are concerned, the simplified LCAs did not always agree with the full LCA implementation both when it comes to which phases were more impacting than the others and to which environmental impact category was more affected than the others (See Table 6). This was because of some shortcomings such as (a) the phases were not always modelled in the same way (in some cases they included the same life cycle stages, in others they did not); (b) the tools (both simplified and not) did not take into consideration the same environmental impact categories; (c) some flows and processes were lacking in the incorporated databases; (d) some of the connections between the flows and the corresponding environmental impacts were lacking.

As a general consideration, the tools examined demonstrated to be quite suitable for the agri-food industry, but several limitations still persist and the tools should be improved in order to make them more robust when implemented in such a specific sector. Indeed, the analysis carried out allows us to highlight some general improvements that could be advantageous in realising a specific simplified tool for agro-food products. First of all, the tool should allow a more flexible modelling: a subdivision in upstream, core and downstream phases (e.g., instead of the "pre-manufacture" used in the eVerdEE, more aligned on manufacturing processes) should be ensured, allowing the potential subdivision of each phase into further sub-stages -similarly to what happens in many EPDs in the food and drink industry- (EPD International, 2015). Furthermore, sector-specific inventory and modelling including the missing accounting of specific aspects associated to the agri-food supply chain, such as agricultural operations, fertilisers and plant protection products application, irrigation assumptions, etc. are of urgent importance (see for example, Crenna et al., 2017). Also, the assumptions underpinning the currently adopted inventories should be better understood (see for example, Corrado et al., 2016). Secondly, a set of specific impact categories should be included, with reference to the most impacting categories generally linked to agri-food products (e.g., climate change, eutrophication, etc.) or more immediate and easier to communicate (e.g., carbon footprint, water footprint, and ecological footprint). Thirdly, flows and processes common in the agri-food chains should be included, such as fertilisers. Indeed, a wider use of the simplified approach in the agri-food industry is strongly related to the existence of food-specific flows and processes in the incorporated databases; poor data quality and availability is a critical issue also in full LCAs; however, that issue becomes particularly relevant when a simplified LCA has to be adopted by SMEs in order to obtain an environmental product certification or declaration.

Therefore, efforts to develop more comprehensive databases would be essential for the sector, both for full and simplified LCAs.

Finally, coming back precisely to the concept of full and simplified LCA, the analysis has not been able to settle the disagreement due to the different ideas, observed in the international scientific literature, regarding the real existence of a distinction between the concept of “full LCA” and “simplified LCA”. On the one hand, simplification can be an intrinsic procedure of a full LCA in order to make it easier to perform, on the other hand, streamlining can be considered as a distinct approach and this is supported by the possibility to carry out an analysis using dedicated simplified LCA software tools. The Authors encompass the view of Wittstock et al. (2012) who claim that the simplified LCA “lies somewhere between the screening LCA and the complete LCA” and, in this sense, it is obvious that it simplifies the use of the LCA methodology “but to a more advanced LCA stage than for a screening LCA”. In this context, a simplified tool specifically designed for agro-food products should be a tool able to be modelled and adapted by the practitioner, allowing an ease and relatively fast implementation of LCA with a precise set of data. Future analyses may include the latest versions of eVerdEE and BilanProduit along with the implementation of the simplified tools in the framework of other agri-food products in order for more robust results to be obtained.

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