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LCA FOR AGRICULTURE

Multifunctional modelling in the life cycle assessment of honey considering pollination

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Abstract

Purpose An apicultural system is characterised by multifunctionality, with one of the functions being the pollination service performed by honeybees, which is of fundamental importance for the nutrition of mankind. The discussion on including ecosystem services in the life cycle assessment (LCA) methodology has opened; this article proposes an alternative way of considering ecosystem services in the specific case of a multifunctional system. Indeed, in an LCA implementation, this study applies an economic allocation between the main product (honey) and the pollination service performed by domesticated honeybees for the ecosystems. Here, the consideration of the pollination service in two honey (orange-blossom and cherry-blossom) LCA case studies is examined.

Methods The multifunctionality was managed by performing an economic allocation between the main product (honey) and the pollination service. The economic value of the main product was calculated by using specific costing approaches for honey, whilst the one of the pollination service by using its market value, where applicable, or on the basis of the dependence of the two species of fruit trees (related to the two types of honey analysed) upon pollination. The calculated values were then used in the main scenario of the study.

Results and discussion The results of the case studies showed that the potential environmental impact of honey decreases for all impact categories when the economic allocation is performed. Electricity consumption for the storage of supers in the hives placement phase and the use of packaging materials were found to be the most impacting processes for both honey types, as well as the transport by aircraft for the distribution of the product overseas. Water consumption was the first most affected impact category, followed by human carcinogenic toxicity and terrestrial ecotoxicity. A sensitivity analysis confirmed the results.

Conclusions Given the identified hotspots, an attempt should be made to reduce the impact of glass (for the jar) and steel (for the lid) by reducing their mass per unit as well as the electricity consumption for the refrigeration of supers. Furthermore, different options for distributing the product abroad should be examined.

Keywords Ecosystem service · Beekeeping · Apiculture · Pollination · Economic allocation · Multifunctionality · Case studies · Domesticated honeybees

1 Introduction

The United Nations 2030 Agenda (UN, 2016) has clearly defined the need for a transition towards sustainable development. Amongst the various Goals set by the Agenda, Goal 15 undoubtedly stressed the protection, restoration and sustainable use of terrestrial ecosystems. Understanding the diversity of how the physical and biological processes of the Earth work can act as a framework for the flow of energy and materials through organisms (Chapin III 2011). One of the services connected to biodiversity is pollination (Schulze et al. 2019), which, for the case of domesticated insects, is a service provided to the ecosystem rather than provided by it (Arzoumanidis et al. 2019). Pollination can be regarded as

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a regulating service,[1] as it can be considered as an effect of ecosystems on processes that go beyond their boundaries and it is not directly used by humans but eventually provide them with an important benefit, i.e. nutrition (Chapin III 2011; Science for Environment Policy 2015). Furthermore, the relation between ecosystems and pollinators can be quite strong. Indeed, changes in the ecosystems may influence the spreading, abundance and efficiency of pollinators (Alcamo et al. 2003). Wind and animals are the most important means of pollen transfer, with pollination by wind being able to travel over greater distances (even though the success may decline greatly with distance) and with pollen carried by animals being of higher probability of ending up on the stigma of a conspecific (Schulze et al. 2019). Such a service can influence both natural and agricultural ecosystems (FAO 2018). Even though most crops can produce yield even without insect pollination (Hanley et al. 2015), a great number of them depend to some degree on it (Klein et al. 2007). In many cases, such a service may be considered to be irreplaceable (or the technology necessary to replace them could be expensive) (Southwick and Southwick 1992; Palmer et al. 2004). Nonetheless, the success of the pollination service, which is related to the number of pollinator insects, may be subject to the use of pesticides, climate change and parasites (Greenleaf and Kremen 2006; Klein et al. 2007). Indeed, in Italy, the appearance of a parasite, a small hive beetle (*Aethina tumida*), has caused a great number of issues to beekeepers, as these parasites tend to infest honeybee colonies and thus affect the trade of apicultural products (Granato et al. 2016).

Life cycle assessment (LCA) has become an increasingly widespread methodology for the assessment of the environmental performance of goods and services in the agri-food sector (Arzoumanidis et al. 2013), whilst the product honey was found to be rarely analysed (Arzoumanidis et al. 2019). Even though some attempts have been made recently in order to include services provided by the ecosystem in the LCA methodology, especially when it comes to impact assessment (e.g. Crenna et al. 2020; Othoniel et al. 2019; Rugani et al. 2019; Zhang et al. 2010), the pollination service by man-managed honeybees has been rarely considered in LCA case studies as a service provided to the ecosystem (Arzoumanidis et al. 2019).

The environmental assessment of such a service may be influenced by the way it is perceived methodologically. One of the characteristics of pollination is that this is a service provided directly to the ecosystem and only indirectly to humans. It can thus be considered as an environmental impact, obviously a positive one. Therefore, in this case, the pollination service is not considered to be a joint product of the system, as it is not intended for the market, but as an elementary flow towards the environment (ISO 2006a). Its (positive) environmental impact can thus be attributed to the overall product system under study and it should be meticulously calculated by using the existing life cycle impact assessment (LCIA) methods. To the best of the authors' knowledge, current LCIA methods do not take into consideration the pollination for a lack of a clear link between the various anthropogenic activities and the pollinators with regard to the way species diversity can be connected to the functioning of the ecosystem and human well-being (Crenna et al. 2017). Recent studies (e.g. Crenna et al. 2017, 2020) have proposed the inclusion of such a service as an objective to be protected, mainly from intensive agricultural practices (use of chemicals/pesticides and loss of habitat that is essential for pollinators). Indeed, recently, some LCIA methods, such as ReCiPe, Eco-Indicator (Goedkoop and Spriensma 2001) and Impact 2002+ (Jolliet et al. 2003), which include also endpoint modelling, have introduced a focus on biodiversity, via, e.g. fraction of species that has potentially been lost compared with a natural or undisturbed area or the introduction of another not desired species (Goedkoop 2016). The existence or absence of the pollination service may therefore be able to favour or hinder the enrichment of biodiversity.

Another way to look at how to calculate the environmental impact of the pollination service for the case of domesticated honeybees is to perceive it as one of the functions of a multifunctional system (others being the provision of honey, beeswax, royal jelly, etc.) and thus consider it having a market value. In the LCA methodology, in general, a service that is provided by the product system under study can be considered as one of the products (co-product) deriving from the same system, and it thus belongs to a system that generates more functions. In the case of a multifunctional system, the ISO 14040:2006 and 14044:2006 standards (ISO, 2006a; ISO, 2006b) provide a series of options for the management of such a multifunctionality. When defining the multifunctionality of a system, it is important to distinguish the flows under study between co-products and wastes. Indeed, a waste can be considered as a non-desired flow and therefore without a market value. On the other hand, a co-product is a flow with a market value, but it is not the object of the analysis. The management of multifunctionality can thus regard allocating the environmental impact not only between the main product and the various co-products, but also in cases of open-loop recycling or for functions that are provided by the combination of waste treatment and energy production (Raggi 2017). In the case of an apiculture product system and given that no common physical properties can be identified among the various co-products, the allocation of the environmental impact could be based on the economic value of the co-products, which the pollination service and the other joint products of the system have in common. In this way, part of the environmental impact that is generated by the production of honey could be compensated for by pollination, which is offered to the ecosystem, thus reducing

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[1] Pollination is considered as a service by the authors. Nonetheless, some terminological subtleties have been expressed, e.g. according to Boyd and Banzhaf (2007), pollination is not a service itself, but an ecosystem function and that the final ecosystem service provided by such a function is the delivery of sexually viable pollen to the crop.

the overall environmental impact of honey (Arzoumanidis et al. 2019).

This article builds upon previous research (Arzoumanidis et al. 2019), by providing the LCA application to two different types of honey with the consideration of the pollination service. Apart from the previous work of the authors, the issue of considering the pollination service as a function of a multifunctional system was found to be poorly tackled (e.g. Kendall et al. 2013; Mujica et al. 2016, who focus only on carbon footprint (CF) and not on a full LCA). This article is structured as follows: the different hypotheses that were taken into account with respect to the previous research along with the LCA phases of goal and scope definition (GSD) and life cycle inventory (LCI) are outlined in Sect. 2. In Sect. 3, the results are presented and discussed. Finally, conclusions and future developments are drawn in Sect. 4.

2 Materials and methods

Both case studies were performed by using the SimaPro v9.0 LCA software (Pré 2020) and its incorporated Ecoinvent 3.5 database (Ecoinvent Center 2020), following the ISO 14040:2006 and 14044:2006 international standards (ISO 2006a; ISO 2006b). With respect to the previously published case study (Arzoumanidis et al. 2019), a second type of honey, namely cherry-blossom honey, was examined in order to increase the robustness of the results. The original case study on orange-blossom honey was performed ex novo, given that a new hypothesis was taken into consideration. Indeed, the value of honey was not the same as in the previous case study. Such a value was used as a basis for performing the economic allocation (please refer to Sects. 2.1 and 2.2). In the previous study, the selling price of the orange-blossom honey was used; whilst in this one, the value of the production of honey was calculated (please refer to Sect. 2.2.1) and then used for both types of the product. This hypothesis was made from a methodological point of view due to the fact that the multifunctionality actually occurs before the product is sold, as well as for testing the robustness of the results obtained before. The two specific types of honey were selected due to the difference in the relevant crops' dependence upon the pollination service (as described in Sect. 2.2.1). The rest of the assumptions were made based on Arzoumanidis et al. (2019) for consistency reasons, as described briefly in Sects. 2.1 and 2.2. The general flow chart regarding both products under study is represented in Fig. 1.

2.1 Goal and scope definition

The goal of the two studies was to identify the environmental hotspots of the life cycle of two types of honey (orange-blossom and cherry-blossom honey, case study "A" and case study "B" hereafter) produced by the same small-sized Italian apicultural company as well as the environmental impacts that were mainly affected by the product system under study. The audience, for which such a study is intended, may include scientists, beekeeping companies and consumers. As far as the functional unit (FU) is concerned, this was defined as a 250-g jar of honey of each type, including its primary, secondary and tertiary packaging. The life cycle stages included in the system boundary consist of honey production and collection, processing, packaging, distribution and waste treatment (thus a "cradle-to-grave" analysis).

As far as the multifunctionality issue is concerned, the various functions of the system included the production of honey and beeswax (which returned as an input to the system, in the phase of "hives placement"—please refer to Fig. 1) and the provision of the pollination service. In the first case (beeswax), this issue was dealt with via physical allocation (by mass) whereas in the second case (pollination), it was dealt via economic allocation (please refer to Sect. 2.2.1).

Finally, with regard to the selection of the environmental impact categories, the ReCiPe 2016 Midpoint (H) method (Huijbregts et al. 2016) was used.

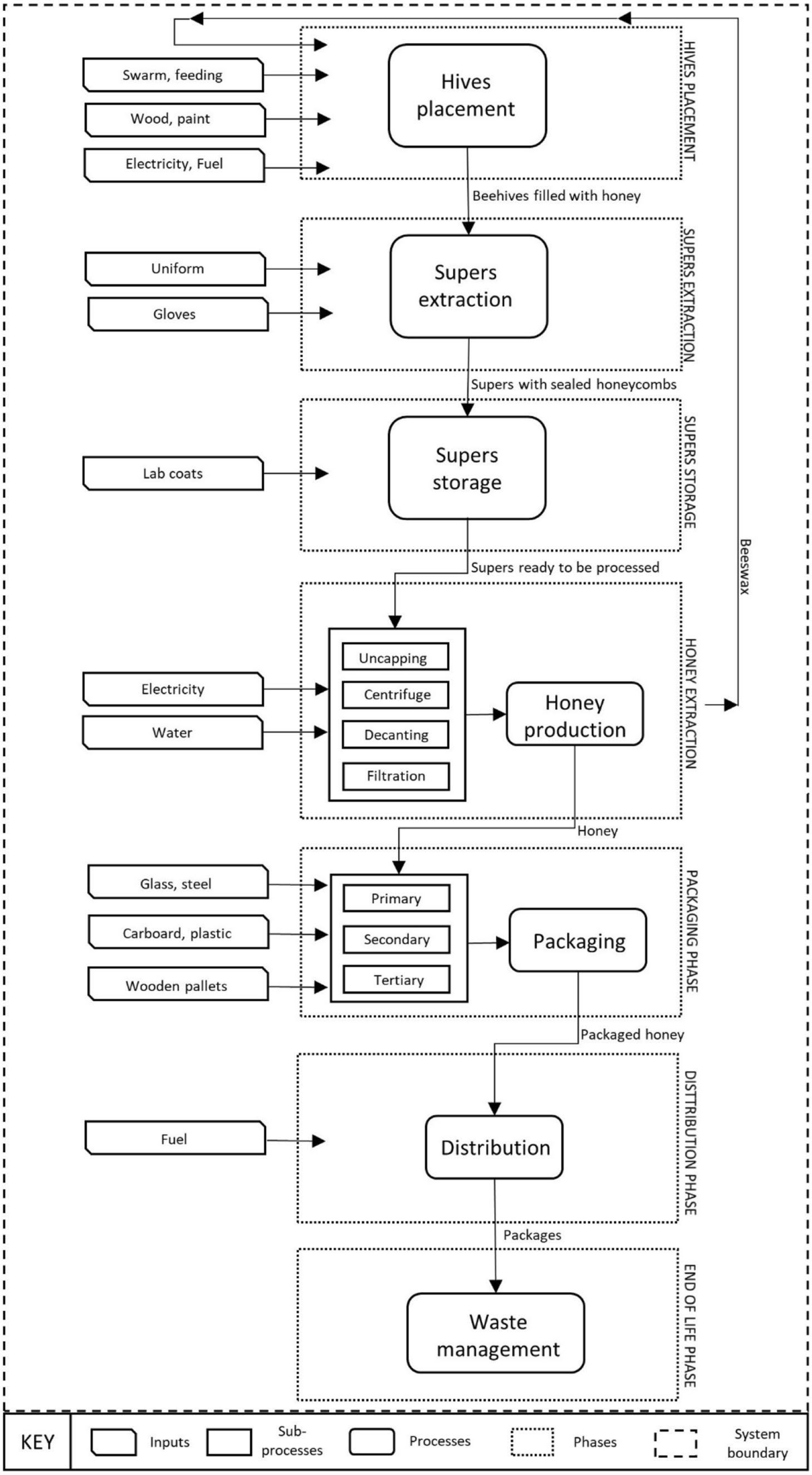
2.2 Life cycle inventory

The data for the LCI phase were collected on-site for the year 2013 at the premises of a firm located in the Abruzzo region in Italy. During the first stage of the life cycle, the hives containing honeybees (*Apis mellifera*) were transported by truck near an orange grove at a distance of 180 km from the firm for case study "A" and near a cherry grove at a distance of 315 km from the firm for case study "B". Such trips were, then, repeated by van in order for the staff to perform systematic controls. The supers inserted in the hives had been previously stored in refrigerator rooms for 2 months. All data for inputs as well as relevant processes, such as transport-related fuel consumption, wood and paint for the hives, specific medicines for the honeybees, etc., and their packaging and transport (where applicable) were collected on-site and/or they were carefully selected from the incorporated Ecoinvent 3.5 database. The full inventory cannot be disclosed due to confidentiality reasons.

The following stage of the life cycle includes the supers extraction and storage by the beekeepers. Inputs in this case included gloves, lab coats, uniforms and internal handling (electricity consumption for the electric forklifts).

Honeycomb uncapping is the next stage. Here, several electric machines are used (such as uncapping machine, a press, a centrifuge and a conveyor belt) as well as inputs for the filtration sub-phase. After uncapping is performed, the obtained

Fig. 1 Life cycle flow chart of the products under study



beeswax is transported to a firm in another region (Piedmont) only to arrive back to the beekeeping company and be used as an input for the "hives placement" stage. All transport by lorry to and from the apicultural firm were included in the analysis, whilst the processing that occurs in this firm was excluded due to the fact that no reliable data were provided directly by the firm or found in the literature.

The following stage comprises the packaging of the obtained honey, which for both cases is made of a glass jar, a steel lid and a paper label (as primary packaging), a cardboard box and adhesive tape (as secondary packaging) and a plastic film and pallets (as tertiary packaging). All these inputs and their respective packaging materials and transport were taken into consideration, as well.

In case "A", the product is then distributed in Italy and abroad. In Italy, 70% in the region of Abruzzo, 5% in Lazio and 5% in Sicily, whilst abroad it concerned 15% in the USA and 5% in France. When it comes to case "B", the product was distributed as follows: 67% in Abruzzo, 13% in Apulia and 5% in Lazio (in Italy) and 15% in the USA. The distribution within Italy as well as to France is performed by lorries, with the exception of Sicily, for which a short trip by ship is required in addition to the one by lorry. The distribution to the USA is carried out by aircraft.

All in all, the "A" case yielded 7120 jars, whilst product "B" resulted in 2660 jars. The productivity was 80.91 jars/hive for "A" and 30.23 jars/hive for "B".

Finally, the quality of the data used in these studies was assigned by following the ILCD Handbook data quality indicators (European Commission, 2010). The resulting score was "basic quality" (overall scoring 2.0) for both case studies (technological representativeness 1, geographical representativeness 1, time-related representativeness 1, completeness 1, precision/uncertainty 3, methodological appropriateness and consistency 1).

2.3 Multifunctionality management for honey and the pollination service

As aforementioned, an economic allocation was implemented in order to deal with the multifunctionality issue between honey and the pollination service. In order to do so, the values of both honey and pollination were calculated.

With regard to the economic value of honey, this was calculated on the basis of the value of the production of honey, starting from the firm costs (Finocchio 2011; Brun et al. 2015). This adopted costing approach features the simplifications and approximation limits, which are typically highlighted by management accounting studies on micro-firms and small- and medium-sized enterprises (Mitchell and Reid 2000; Alattar et al. 2009; Biondi et al. 2017; Ndemewah et al. 2019). The costs of the firm must be divided into costs that exhaust their function once (for example, the candied fruit that is fed to the honeybees, the fuel used to transport the hives, etc.) and costs the utility of which is repeated and protracted over time (e.g. hives, honey extractors, ripeners, etc.). Indeed, in the calculation of total costs on an annual basis, several aspects were taken into consideration, as follows:

(a) Various expenditures = 22.34 EUR per hive: feed for the bees (e.g. candied fruit, syrup, sugar), pesticides (oxalic acid), fuel (diesel), car inspections;
(b) Restoration costs = 98.41 EUR per hive: machinery and equipment, calculated for different years of depreciation for each piece (e.g. 20 years for hives, frames for supers and supers, 5 years for honeycombs, 25 years for hive supports, 15 years for feeders, 2 for bee smoker and 10 years for the shoulder blower);
(c) Maintenance costs = 8.80 EUR per hive;
(d) Salaries = 10.89 EUR per hive.

Therefore, the total economic value for a hive is 140.44 EUR (related to the annual costs), which corresponds to a honey economic value (HV): $HV_A = 1.67$ EUR per jar (i.e. per FU) for case "A" and $HV_B = 4.42$ EUR for case "B".

When it comes to the economic value of the pollination service, the apicultural firm did not receive any remuneration for the pollination service for case "A", whilst it did for case "B". For this reason, a market value was assumed to exist for "B", which corresponds to the price agreed upon between the farmers and the apiculture firm. For this reason, the value of pollination for "B" was considered both by using the calculation method for "A", as described below (hereafter scenario "B_c"—for "calculated"—and scenario "B_m"—for "market").

Regarding "B_m", this was provided directly from the firm as 25 EUR per hive, as the amount of money paid by farmers for the pollination service. This is translated as the pollination economic value (PV): $PV_{Bm} = 0.83$ EUR per jar (i.e. per FU), for the reference year of data collection. On the other hand, for cases "A" and "B_c", the economic value of the pollination service, EVIP, was calculated as in Arzoumanidis et al. (2019), based on the values of the total value of crop (TVC) and the dependence ratio (DR). TVC is calculated as the product of the unit producer price (economic value/mass) times the production (mass) and DR reflects the dependence of that crop upon pollination. In this way, the following equation proposed by Gallai and Vaissière (2009) was thus used:

$EVIP = TVC \times DR$ (1)

Given that the SimaPro software uses USD 2015 as reference unit of measure for currency, all EUR values have been deflated to EUR 2015, and then, the exchange rate of 2015 of 1.11 EUR/USD was taken into consideration (Statista 2020). Therefore, Eq. 1 gave $EVIP_A = 19{,}626{,}817.30$ EUR for case "A" and $EVIP_{Bc} = 156{,}439{,}777.50$ EUR for case "B_c". Such a significant difference between $EVIP_A$ and $EVIP_{Bc}$

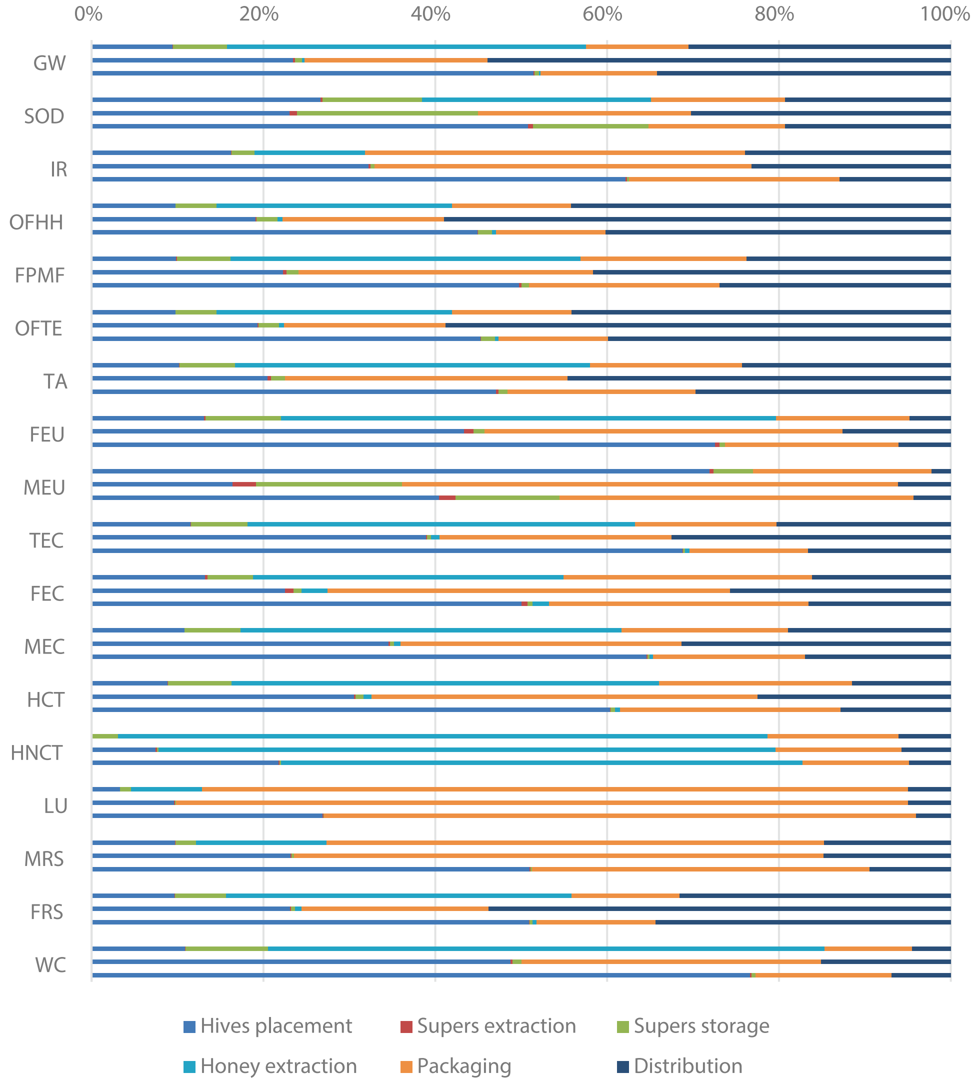


Fig. 2 Characterisation results for the base scenarios; order of scenarios from top to bottom is A, B_c and B_m for each environmental category—extracted from SimaPro (Pré 2020)

depends greatly on the DR upon pollination for these two fruit trees. Indeed, $DR_A = 0.05$ and $DR_{Bc} = 0.65$ (FAO 2020a), and this is the reason why these two types of honey were selected. As far as the TVC_A and TVC_{Bc} values are concerned, these were calculated based on the unit producer price and on the production of oranges/cherries from the FAO statistics website (FAO 2020b). The quantity of honey produced in Italy for 2013 was 9.5 million kg (OSN 2017). Furthermore, it was assumed that 30% of the production was for orange-blossom honey and 30% was for cherry-blossom honey (base scenario) (Arzoumanidis et al. 2019); a sensitivity analysis for different scenarios is provided in Sect. 3.2. Therefore, the economic values of pollination per jar (i.e. per FU) resulted in $PV_A = 2.76$ EUR for case "A" and in $PV_{Bc} = 13.72$ EUR for case "B_c".

The economic allocation was thus applied for the various economic values that were calculated for honey (HV_A, HV_B) and for the pollination service (PV_A, PV_{Bm}, PV_{Bc}).

3 Results and discussion

3.1 Life cycle impact assessment and interpretation

The environmental impact categories that were taken into account were the ones covered by the selected LCIA method, i.e. ReCiPe 2016 Midpoint (H). For these case studies, the mandatory steps (classification and characterisation), as well as the optional step of normalisation, were performed. For the base scenarios "A," "B_m", and "B_c", the economic allocation coefficients were calculated (i) for "A": 37.66% for the main product (honey) and 62.34% for the pollination service; (ii) for "B_m": 84.19% for honey and 15.81% for pollination; and (iii) for "B_c": 24.36% for honey and 75.64% for pollination. The characterisation results are shown in Fig. 2.

When it comes to the characterisation results (Fig. 2), it is not quite clear which is the most impacting phase, as for different impact categories and scenarios, different phases prevail. The packaging phase is the most important for impact

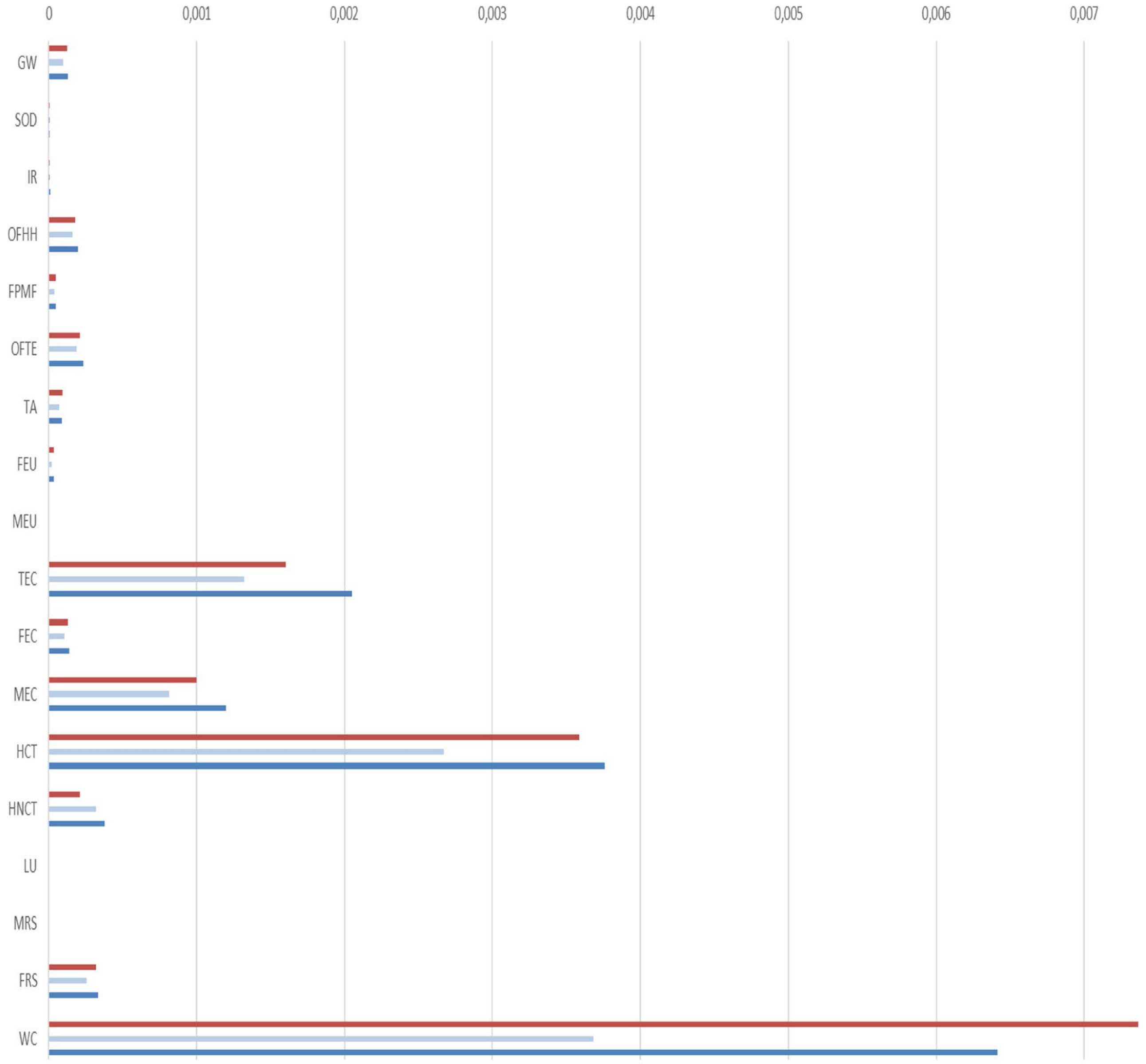


Fig. 3 Normalisation results for the base scenarios; scenario A in red, scenario B_c in light blue and scenario B_m in dark blue—extracted from SimaPro (Pré, 2020)

categories such as land use (LU) and mineral resource scarcity (MRS) as well as quite important for ionizing radiation (IR). For water consumption (WC), freshwater ecotoxicity (FEC), marine eutrophication (MEU), fine particulate matter formation (FPMF), human carcinogenic toxicity (HCT), terrestrial acidification (TA) and terrestrial ecotoxicity (TEC), this phase is more important for the B_c scenario rather than for A and B_m. The hives placement phase is the most influencing for the B_m scenario for a great number of impact categories, such as global warming (GW), stratospheric ozone depletion (SOD), IR, FPMF, ozone formation human health (OFHH), freshwater eutrophication (FEU), TEC, freshwater ecotoxicity (FEC), marine ecotoxicity (MEC), HCT, MRS, fossil resource scarcity (FRS) and WC. For scenarios A and B_c, this is not the case. The phase of honey extraction reached for all scenarios the highest influence for human non-carcinogenic toxicity (HNCT) and, more specifically, for scenario A (for GW, FEU, TEC, MEC, HCT, FRS and WC). The distribution phase was the most influencing mainly for scenario B_c (for GW, OFHH, ozone formation terrestrial ecosystems (OFTE) and FRS), but also GW and OFTE in general. Finally, the phases of supers extraction and supers storage impact the least for all impact categories and scenarios.

The normalisation results (Fig. 3) highlighted WC as the most influenced impact category, followed by HCT

Table 1 Contribution analysis: the five most impacting processes for the three most influenced impact categories per scenario—extracted from SimaPro (Pré 2020)

Order of significance of the processes	Scenario A	Scenario B_c	Scenario B_m
		WC	
1	Electricity consumption (hives placement)	Glass (packaging)	Electricity consumption (hives placement)
2	Glass (packaging)	Electricity consumption (hives placement)	Transport—lorry (hives placement)
3	Transport—aircraft (distribution)	Transport—aircraft (distribution)	Glass (packaging)
4	Steel (packaging)	Transport—lorry (hives placement)	Transport—aircraft (distribution)
5	Transport—lorry (hives placement)	Steel (packaging)	Steel (packaging)
		HCT	
1	Electricity consumption (hives placement)	Steel (packaging)	Steel (packaging)
2	Steel (packaging)	Transport—aircraft (distribution)	Transport—lorry (hives placement)
3	Transport—aircraft (distribution)	Glass (packaging)	Transport—aircraft (distribution)
4	Glass (packaging)	Transport—lorry (hives placement)	Electricity consumption (hives placement)
5	Transport—lorry (hives placement)	Electricity consumption (hives placement)	Glass (packaging)
		TEC	
1	Electricity consumption (hives placement)	Transport—aircraft (distribution)	Transport—lorry (hives placement)
2	Transport—aircraft (distribution)	Transport—lorry (hives placement)	Transport—aircraft (distribution)
3	Transport—lorry (hives placement)	Glass (packaging)	Electricity consumption (hives placement)
4	Glass (packaging)	Steel (packaging)	Glass (packaging)
5	Steel (packaging)	Electricity consumption (hives placement)	Steel (packaging)

and TEC. Furthermore, they demonstrated that the "B_m" scenario reached the highest scores for more categories (IR, OFHH, OFTE, TEC, FEC, MEC, HCT, HNCT, LU, MRS and FRS), whilst "A" for GW, SOD, FPMF, TA, FEU, MEU and WC. Furthermore, a contribution analysis for the three most influenced impact categories showed that it was always the electricity consumption during the pre-storage of supers in refrigerator rooms (in the hives placement phase and before being used for each new annual cycle) to be the most impacting process for scenario "A". The electricity consumption was followed by the glass used for the jar, for WC; the steel used for the lid of the jar, for HTC; the transport by airplane during the distribution phase, for TEC. As far as scenarios "B_c" and "B_m" are concerned, electricity consumption lost some of its importance (due to the fact that supers need to stay for less time in the refrigerator rooms in the case of cherry-blossom honey). Indeed, with regard to "B_c",

Table 2 Contribution analysis: the five most impacting processes for WC of scenario "A"—extracted from SimaPro (Pré 2020)

Order of significance	Process	Quantity (m^3)
1	Electricity consumption (hives placement)	1.230
2	Glass (packaging)	0.235
3	Transport—aircraft (distribution)	0.142
4	Steel (packaging)	0.103
5	Transport—lorry (hives placement)	0.098

Table 3 Contribution analysis: the five most impacting processes for WC of scenario "B_c"—extracted from SimaPro (Pré 2020)

Order of significance	Process	Quantity (m^3)
1	Glass (packaging)	0.235
2	Electricity consumption (hives placement)	0.174
3	Transport—aircraft (distribution)	0.142
4	Transport—lorry (hives placement)	0.131
5	Steel (packaging)	0.103

Table 4 Contribution analysis: the five most impacting processes for WC of scenario “B_m”—extracted from SimaPro (Pré 2020)

Order of significance	Process	Quantity (m^3)
1	Electricity consumption (hives placement)	0.574
2	Transport—lorry (hives placement)	0.554
3	Glass (packaging)	0.235
4	Transport—aircraft (distribution)	0.142
5	Steel (packaging)	0.103

the most important processes were for WC: jar of glass, electricity consumption (hives placement); for HTC: lid of steel (packaging), transport by aircraft (distribution); for TEC: transport by aircraft (distribution), transport by lorry (in hives placement and in distribution). As far as “B_m” is concerned, the most significant processes were for WC: electricity consumption (hives placement) and transport by lorry (hives placement); for HTC: lid of steel (packaging), transport by lorry (hives placement); for TEC: transport by lorry (hives placement), transport by aircraft (distribution). The first five most impacting processes for the three most influenced impact categories per scenario can be found in Table 1 for parallel reading, whilst Tables 2, 3 and 4 contain the quantitative results for each of the scenarios regarding the most affected impact category (WC).

All in all, there are five processes that are mainly responsible for the environmental impacts of all three scenarios, i.e. electricity consumption and transport by lorries (in hives placement), jar of glass and lid of steel (in packaging) and transport by aircraft (in distribution). The only aspect that changes is actually their order of significance for the various categories.

3.2 Sensitivity analysis

As mentioned in Sect. 2.2.1, it was assumed for the base scenario that 30% of the production was for orange-blossom honey and 30% was for cherry-blossom honey. In order to understand whether and how such an assumption might influence the results presented in Sect. 3.1, a sensitivity analysis was performed for a series of scenarios. In addition to the other scenarios, the new ones included for both products the assumptions that the production of product “A” or product “B” was 0%, 10%, 20%, 40%, 50%, 60%, 70%, 80%, 90% or 100% of the total production of honey in Italy (corresponding to 9.5 million kg). For all these scenarios, the economic allocation between the value of honey and the one of the pollination service were calculated. The value of honey reflected the percentage of honey production with respect to the total production in Italy, whilst the value of the pollination service remained constant. Finally, another scenario per product was added, where 100% of the environmental impact was attributed only to honey (where the pollination service is not taken into consideration at all—“A_{np}” and “B_{np}”). A summary of all scenarios used in this sensitivity analysis along with the various percentages of allocation is shown in Table 5.

The results of the sensitivity analysis confirmed that higher percentages of honey production (“A” or “B”) with respect to the total honey production in Italy entail higher environmental impacts that are allocated to the product (honey), for all environmental categories. Indeed, higher percentages of honey “A” or “B” production entail lower

Table 5 Sensitivity analysis: the scenarios examined and their respective allocation percentages

Scenario name	Scenario description	Orange-blossom		Cherry-blossom	
		Percentage (%) of allocation to honey	Percentage (%) of allocation to pollination	Percentage (%) of allocation to honey	Percentage (%) of allocation to pollination
0%	Percentage of honey “A” or honey “B” production with respect to the total production of honey in Italy	0	100	0	100
10%		16.76	83.24	9.70	90.30
20%		28.71	71.29	17.68	82.32
30%		37.66	62.34	24.36	75.64
40%		44.61	55.39	30.04	69.96
50%		50.17	49.83	34.93	65.07
60%		54.71	45.29	39.18	60.82
70%		58.50	41.50	42.91	57.09
80%		61.70	38.30	46.21	53.79
90%		64.44	35.56	49.14	50.86
100%		66.81	33.19	51.78	48.22
NP	No pollination service	100	0	100	0

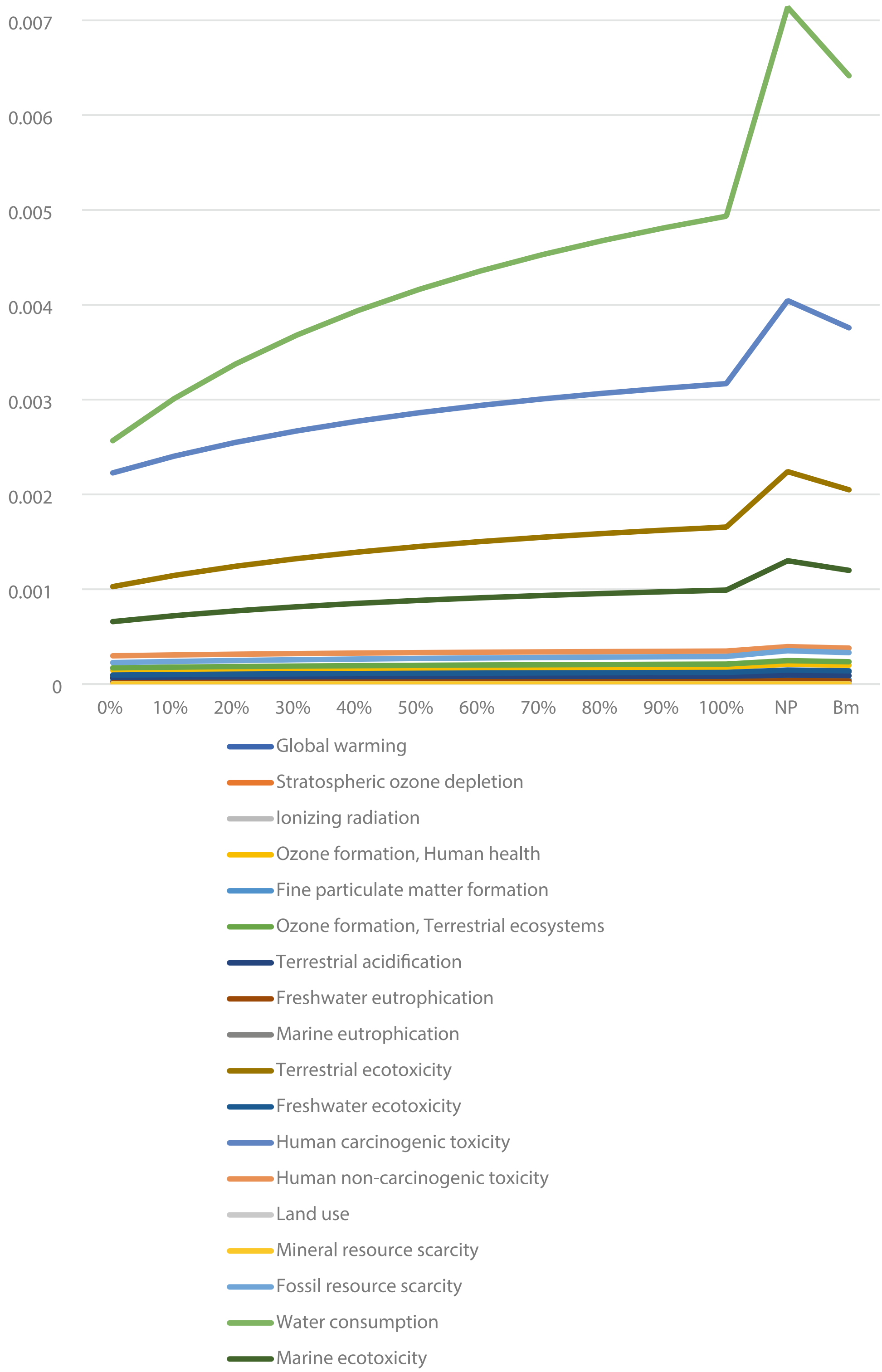


Fig. 4 Normalisation results for the various scenarios of the sensitivity analysis—extracted from SimaPro (Pré 2020)

unit values for the pollination service (whilst EVIP remains constant) and therefore lower percentages of allocation for the service, thus confirming the results of Arzoumanidis et al. (2019). Furthermore, the analysis confirmed a great increase in the total environmental impact when the pollination service (scenarios “A_{np}” and “B_{np}”) was not considered at all. For an example of the obtained results (for cherry-blossom honey), please refer to Fig. 4. Following “B_{np}”, scenario “B_m” reached higher scores for most of the impact categories with respect to every other scenario.

Table 6 Quantitative normalised results for B_c and B_m scenarios

Impact category	Scenario B_c	Scenario B_m
GW	9.9E-05	1.3E-04
SOD	5.7E-06	7.8E-06
IR	8.3E-06	1.2E-05
OFHH	1.6E-04	2.0E-04
FPMF	3.9E-05	5.0E-05
OFTE	1.9E-04	2.4E-04
TA	7.1E-05	8.9E-05
FEU	2.0E-05	3.3E-05
MEU	9.1E-07	1.4E-06
TEC	1.3E-03	2.0E-03
FEC	1.1E-04	1.4E-04
MEC	8.2E-04	1.2E-04
HCT	2.7E-03	3.8E-03
HNCT	3.2E-04	3.8E-04
LU	4.4E-06	4.8E-04
MRS	8.2E-09	1.1E-08
FRS	2.6E-04	3.3E-04
WC	3.7E-03	6.4E-03

3.3 Further insights

One of the novel aspects of this work is that it is one of the few to have modelled an apicultural system as multifunctional, by considering the pollination service as one of the co-products. With regard to the other two studies that used economic allocation, but only for calculating the CF (Kendall et al. 2013; Mujica et al. 2016), the results of this study appear to partially confirm them. It is to be noted, though, that both aforementioned studies excluded the distribution phase from their analysis. According to both studies, transport related to hives placement and electricity consumption during honey extraction were the hotspots of the life cycle. When it comes to the relevant GW impact category, the results of this study showed that the most contributing processes are electricity consumption in hives placement, glass in packaging and transport by lorries in hives placement (when the distribution phase was excluded). Nonetheless, the inclusion of the distribution phase in this study demonstrated its importance for the calculation of CF. Indeed, when such a phase was taken into account, the important processes changed, with transport by aircraft (distribution) being in the first place (0.459 kg CO_2 eq), followed by the others (electricity consumption at 0.275 kg CO_2 eq, glass at 0.131 kg CO_2 eq and transport by lorries at 0.073 kg CO_2 eq).

A parallel view of the two scenarios for cherry-blossom honey (please refer to Fig. 3 and Table 6) demonstrated that when the economic value of the pollination service was calculated based on the dependence of the fruit tree on it, the impact was much lower with respect to when the value reflected the market. This was because of the difference in the value of the pollination service between the two scenarios and of the fact that the market value does not take into consideration the dependence of the fruit tree upon pollination.

Another aspect that was examined was the difference in the dependence upon pollination of the two types of fruit trees. The higher DR of cherry trees entailed higher economic value for the pollination service, thus resulting in higher percentages being allocated for the pollination service (please refer to Table 5) with respect to the one of orange trees.

4 Conclusions

The beekeeping system is characterised by multifunctionality. Indeed, one of the functions of the system is the pollination service performed by honeybees, which is of fundamental importance for the nutrition of mankind. The discussion on including ecosystem services in the framework of the LCA methodology has opened; this article proposed an alternative way of considering ecosystem services in the specific case of a multifunctional system. Indeed, in an LCA implementation, this study applied economic allocation between the main product (honey) and the pollination service provided by domesticated honeybees to agricultural ecosystems. The consideration of the pollination service in two honey LCA case studies was examined. In order to do so, the economic values of the main product (honey) and the pollination service were estimated, and then, economic allocation was performed between them for both case studies.

After taking into consideration a series of different scenarios for both products (3 base scenarios and 12 scenarios for the sensitivity analysis), the results of the case studies confirmed that the environmental impact for the product (honey) obviously decreases when economic allocation is performed for all impact categories (given that a part of the impact was accounted for the pollination service). It is thus important to know how much environmental impact can be allocated to the pollination service, and thus reduce the overall environmental impact (see for example the difference between scenarios “B_c” and “B_m” in Table 6). With regard to the various life-cycle hotspots that were identified for these products, it was hives placement, packaging and distribution that were found to be the most responsible. More into detail, it was electricity consumption for the pre-storage of supers as well as the use of packaging materials (such as the lid of steel and the jar of glass) that were found to be the most impacting for both products, even if the electricity consumption was more important for orange-blossom honey. For this reason, an attempt should be made to reduce the impact of glass (for the jar) and steel (for the lid) by reducing their mass per unit as well as the electricity consumption for the refrigeration of supers. Another important aspect was found to be the transport by aircraft for the distribution of the product overseas, especially when it comes to cherry-blossom honey. Different options for distributing the product overseas should therefore be examined (e.g. by ship).

As far as the environmental impacts are concerned, it was found that when the economic value of the pollination service was calculated based on the dependence of the fruit tree on it, the impact was much lower with respect to when the value reflected the market. Water depletion was the most influenced impact category, followed by human carcinogenic toxicity and terrestrial ecotoxicity. The order of importance for the various impact categories was confirmed by the sensitivity analysis, as well.

Given that a social life cycle assessment (SLCA) has already been performed for the same product (D'Eusanio et al. 2018), future developments may include carrying out a life cycle sustainability assessment by identifying whether the hotspots of the LCA implementation could be similar—in which way and to what degree—to the ones of the SLCA. In that sense, the implementation of a life cycle costing would be appropriate in order to achieve a complete LCSA.

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