Εταιρεία Γεωργικών Μηχανικών Ελλάδος

Πρακτικά

10ου Πανελληνίου Συνεδρίου Γεωργικής Μηχανικής

«Η Συμβολή της Γεωργικής Μηχανικής στην Ανάπτυξη της Ελληνικής Γεωργίας»

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Περίληψη

Η Ανάλυση Κύκλου Ζωής (ΑΚΖ) χρησιμοποιείται όλο και περισσότερο για τη βελτίωση των περιβαλλοντικών επιδόσεων προϊόντων και υπηρεσιών, μεταξύ των οποίων τα συστήματα τροφίμων. Παρόλα αυτά, το μέλι φαίνεται να έχει αναλυθεί σπανίως. Ο ρόλος των μελισσών ως επικονιαστών είναι μια από τις λειτουργίες ενός μελισσοκομικού συστήματος και είναι υψίστης σημασίας για τα φυσικά οικοσυστήματα και τη γεωργία. Κατά την εφαρμογή μιας ΑΚΖ, η επικονίαση μπορεί να θεωρηθεί ως μια από τις λειτουργίες ενός πολυλειτουγικού συστήματος (με άλλες για παράδειγμα την παροχή μελιού και κεριού). Η παρούσα εργασία εξετάζει την οικονομική αξία της επικονίασης ως πιθανή βάση για τη διαχείριση της πολυλειτουργικότητας στη μοντελοποίηση των ΑΚΖ και την εφαρμογή της σε μια μελέτη περίπτωσης.

Λέξεις κλειδιά: Ανάλυση Κύκλου Ζωής, μέλι, επικονίαση, πολυλειτουργικότητα

ENVIRONMENTAL ASSESSMENT OF BEEKEEPING PRODUCTS AND SERVICES – A LIFE CYCLE ASSESSMENT CASE STUDY INCLUDING HONEY AND POLLINATION

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ABSTRACT

Life Cycle Assessment (LCA) has been increasingly used for the improvement of the environmental performance of products and services, amongst which food systems. Nevertheless, honey appears to have been rarely analysed. Furthermore, the role of honey bees as pollinators can be regarded as one of the functions of an apiculture system and is undoubtedly of utmost importance both for natural ecosystems and agriculture. When implementing an LCA of an apiculture system, the pollination service can be considered as one of the functions of a multifunctional system (other functions including, e.g., the provision of honey, beeswax, etc.). This paper explores the economic value of pollination and the proposed calculation methods, as a potential basis for managing multifunctionality in LCA modelling and its application in a case study.

Keywords: Life Cycle Assessment, honey, pollination, multifunctionality

1. INTRODUCTION

Life Cycle Assessment (LCA) has been increasingly used for the improvement of the environmental performance of products and services, amongst which food systems. Indeed, a great number of food LCA case studies and reviews of case studies have been published in the scientific literature. Nevertheless, amongst the food products, honey appears to have been rarely analysed. Honey is a natural product, which is considered to have a great range of benefits for human health. Besides that, the role of honey bees as pollinators can be regarded as one of the functions of an apiculture system and is undoubtedly of utmost importance both for natural ecosystems and agriculture. The importance of the pollination service cannot be underestimated for most of the crops worldwide (Klein et al., 2007; Crenna et al., 2015), even though most crops are able to produce yield to some extent even in the absence of insect pollination (Hanley et al., 2015). The benefits of this service are indeed significant (Southwick and Southwick, 1992). For example, in its absence, fertilisers and labour requirements would have to be higher (ibid.). The economic importance of the service was already acknowledged in the past, e.g., Cheung indicates the existence of hives rent contracts, in the United States, between beekeepers and farmers in order for the formers to offer the service to the latter (Cheung, 1973).

When implementing an LCA of an apiculture system, the pollination service can be considered as one of the functions of a multifunctional system (other functions including, e.g., the provision of honey, beeswax, etc.) and the issue of how to deal with multifunctionality in the modelling of that system should be carefully considered.

When it comes to addressing the multifunctionality issue, various approaches are available (please refer to ISO, 2006a). One of the most consolidated approaches, given its simplicity, is the use of allocation (even if it is not the first suggested option in the ISO standard cited above). The allocation can be performed either based on physical relations (e.g., mass, volume) or economic ones. In the case of a service (such as pollination) a physical relation cannot be appointed to it. Therefore, only economic allocation can be applied, by means of the economic values of the various products, among which the pollination service, generated by the relevant multifunctional process.

The main objective of this paper is to explore, by means of a literature review, the economic value of pollination and the proposed calculation methods, as a potential basis for managing multifunctionality in LCAs. Furthermore, the application of this multifunctional system in a honey-related LCA case study is addressed.

This paper is structured as follows: in Section 2 the economic value of pollination is explored both in terms of calculation methods used for it and of its own inclusion in LCA studies (or in life cycle-based approaches, in general). Section 3 describes the implementation of LCA in a honey case study and the inclusion possibilities of the pollination service methodologically. Finally, in Section 4 the main conclusions and future developments of this article are drawn.

2. ECONOMIC VALUE OF POLLINATION

In this study, the economic value of the pollination service, which may be much higher than that of honey itself (Eardley et al., 2006; Hein, 2009), was investigated both in terms of its measurement methods and its inclusion in life cycle-based approaches via two different literature reviews, as described hereafter.

2.1 Measurement methods

In order to evaluate the various methods that measure the economic value of the pollination service, a literature review was carried out. This included databases such as the inter-database EBSCO Discovery Service and Google Scholar, using keywords such as ("honey" OR "bee") AND "pollinat*" AND "economic value" (and their combinations) for the years 1990-2016. The results were then evaluated with regard to their relevance to the topic. The screening resulted in 11 scientific articles (Southwick and Southwick, 1992; Greanleaf and Kremen, 2006; Vaissière et al., 2008; Gallai et al., 2009; Hein, 2009; Garratt et al., 2014; Majewski, 2014; Munyuli, 2014; Champetier et al., 2015; Giannini et al., 2015; Hanley et al., 2015), which were reviewed.

Giving a monetary value to a natural service, which is not tradable, is somehow challenging (Munyuli, 2014). However, as it can be deduced by the papers found, several methods have been used or developed for such a task, which can generally be divided in market and non-market ones (Hanley et al., 2015). The output of a crop depends on various inputs (e.g., labour hours, pesticides etc.), as well as on pollination services and stochastic factors, such as rainfall and temperature (ibid.). Commonly, the market value of pollination services reflects how a reduction in them can influence yields (Garratt et al., 2014). The non-market methods may include the consumers' Willingness To Pay (WTP) for environmental improvements or in order to avoid loss of pollinators (Hanley et al., 2015). The market-based methods are presented briefly hereafter.

2.1.1 Dependence Ratio

For a number of crops, production depends on the pollination service at a different degree for each crop (dependence ratio). This widely used method measures the proportion of crop output lost without pollination services (Gallai et al., 2009; Giannini et al., 2015; Hanley et al., 2015). Nonetheless, this method fails to include the marginal benefits of pollination or to account for all economically significant crop outputs that are affected by pollination, all inputs or producer costs (Hanley et al., 2015). In Gallai and Vaissière (2009) the dependence ratio (DR) is used for the calculation of what they propose as the Economic Value of Insect Pollinators (EVIP), using the following equation:

$$EVIP = TVC * DR \qquad \text{(Eq. 1)}$$

where, TVC is the total value of crop, calculated as the product of the unit producer price (economic value/mass) times the production (mass) and DR reflects the dependence ratio of that crop upon pollination.

2.1.2 Yield Analysis

Yield Analysis (YA) assesses the per-hectare benefits of pollination based on comprehensive field studies that report the effect of market quality benefits, cultivar variations and storage life (Hanley et al., 2015). This method lacks the linking information between marginal changes in pollination services and output changes (ibid.).

2.1.3 Replacement Cost(s)

The Replacement Costs (CR) method examines the costs avoided by the presence of pollinators by estimating the costs of replacing them, e.g., manually (Hein, 2014; Hanley et al., 2015). In the case of wild pollinators, another way of calculating the replacement cost, apart from hand pollination, could be through the cost of bringing in managed bees (Hein, 2014). Nevertheless, hand pollination has demonstrated to be rather ineffective on several crops (Hanley et al., 2015) and is not widely conducted in the world (Hein, 2014).

2.1.4 Consumer Surplus

The Consumer Surplus (CS) method measures economically the excess of price that the public are theoretically willing to pay over the price that is actually paid for a good (Southwick and Southwick, 1992; Hein, 2009; Hanley et al., 2015). The econometric analysis required for this method has proven to be rather data-intensive and complex, in terms of trade effects (Southwick and Southwick, 1992; Hanley et al., 2015). The CS can be calculated through the equation proposed by Southwick and Southwick (1992):

$$CS = \int_{Q_0}^{Q_1} [P(demand) - P_1] dQ \qquad \text{(Eq. 2)}$$

where, Q_0 and Q_1 are the quantities the consumer buys before and after the pollination service is introduced, P(demand) represents the demand function, whilst P_1 is the price after the introduction of the pollination service.

2.1.5 Producer Surplus

The Producer surplus (PS) echoes "the amount of welfare a producer gains at a certain level of production and for a certain market price" (Hein, 2009; p.75). In other terms, this can be summarised as the gross revenues for the producer minus their production costs (ibid.). Munyuli (2014), in his study on coffee, suggested the following equation using PS in order to calculate the total value generated by pollination services:

$$W = S * \Delta q * (p - c) \qquad \text{(Eq. 3)}$$

where, W is the welfare to producer or PS, S is the area under production, Δq reflects the increase in productivity as a consequence of the service, p is the farm-gate price of the crop and, finally, c are variable costs related to crop harvest.

2.1.6 Hybrid Seeds (sunflowers)

In this case, the pollination economic value is given by the proportion of pollinated florets (seeds per unit area divided by available florets) multiplied by the total value of the hybrid seed production industry (Greenleaf and Kremen, 2006).

2.1.7 Combinations

Finally, combinations of the DR, CS, RC and YA exist as well, as for example in the calculation of the economic value of the pollination service in the production of watermelons (Hanley et al., 2015).

2.2 Environmental Life Cycle Approaches and the economic value of the service of pollination

The second literature review was performed in order to identify the inclusion, if any, of the economic value of the pollination service in Environmental Life-Cycle-based studies. This included databases such as the inter-database EBSCO Discovery Service and Google Scholar, using keywords such as ("honey" OR "bee") AND ("lca" OR "life cycle assessment" OR "carbon footprint" OR "life cycle") for the years 1990-2016. The results were then evaluated with regard to their relevance to the topic. The review resulted in 2 scientific articles, both concerning the Life cycle-based approach of carbon footprint (Kendall et al., 2013; Mujica et al., 2016), but not the full LCA methodology.

In order to deal with the multifunctionality issue in the carbon footprint studies, the two peer-reviewed articles use different methods. In Kendall et al. (2013), the percentages (for honey and the pollination service) of the total income related to beekeeping is taken into account for the use of economic allocation. These data were obtained from the beekeepers through the use of questionnaires. In the other article, Mujica et al. (2016) also propose the use of subdivision between the main product (honey) and pollination services. However, in order to deal with the hive management phase, they investigated two different hypothetical scenarios: one where the phase could be attributed 100% to honey and 0% to the pollination and one where the percentages are applied *vice versa* (ibid.).

Given the lack in honey LCA case-studies that take into account the pollination service, which was identified in the scientific literature, this paper examines the case of orange-blossom honey.

3. CASE STUDY

The case study presented here was performed with the aid of the SimaPro LCA software (Pré, 2017) and following the ISO 14040:2006 international standards (ISO, 2006b).

3.1 Goal and Scope Definition

The aim of the study was to identify the most critical phases of the life cycle of orange-blossom honey from an environmental point of view as well as the environmental impacts mostly affected by the product system examined. The intended audience of this study would be scientists, beekeeping companies and consumers. The Functional Unit (F.U.) was defined as a 250-g jar of honey including its primary, secondary and tertiary packaging. Furthermore, the system boundary included the following life cycle stages: honey collection, processing, packaging, distribution, and waste treatment. It can thus be called a "cradle-to-grave" analysis. For the flow chart of the life cycle of honey under study please refer to Fig. 1.

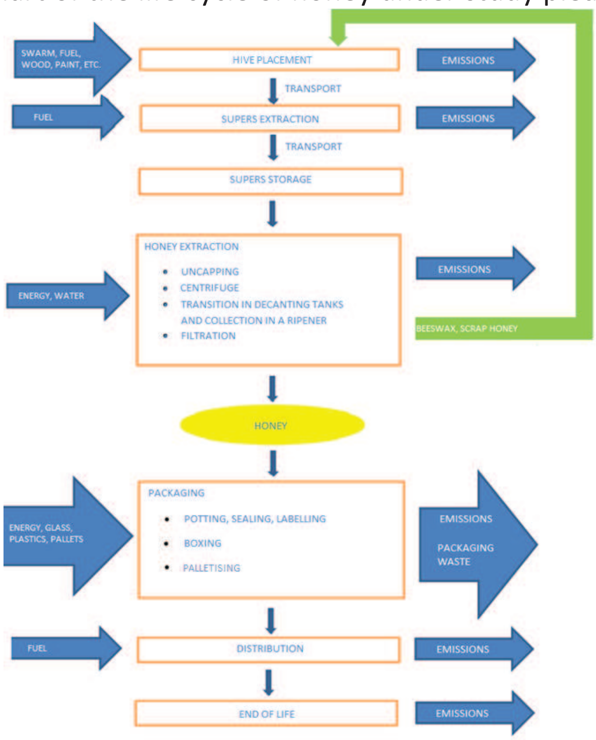

Figure 1. Life cycle flow chart of the product under study (orange-blossom honey).

As regards the multifunctionality issue the various functions of the system were identified as follows: production of honey and beeswax (the latter being returned as an input to the system, in the "hive placement" phase) and provision of the pollination service. This issue was attempted to be dealt with via economic allocation (please refer to Section 3.2).

3.2 Life Cycle Inventory (LCI)

The LCI data were collected on-site at the firm *Finocchio* situated in Tornareccio, in the Italian region of Abruzzo. The hives containing the honeybees (*Apis mellifera*) are initially transported and placed in the region of Apulia at a distance of 180 km. The data for all necessary inputs and the relevant processes, such as transport-related fuel consumption, wood and paint for the hives structure, bee-specific medicines, etc., and their respective packaging and transport, where applicable, were collected on-site or carefully selected from the Ecoinvent 2.2 database (Ecoinvent Center, 2017), which is integrated in the software used. As far as the medicines are concerned, the relevant processes were selected on the basis of the different ingredients. One ingredient, namely oxalic acid, had to be excluded from the calculations since it was not found in the software database.

It is the first phase in the product life cycle where the pollination service occurs, as well. As described in Section 3.1, it was decided to apply an economic allocation. Given that the two products of this phase were honey and the pollination service, their economic value *per* F.U. had to be calculated. The market value of honey was obtained directly by the beekeeping company. On the other hand, the economic value of the pollination service had to be calculated from scratch. This was performed using (Eq.1), as defined in Section 2.1.1 for the DR method. As regards the calculation of TVC for Italy: (a) for the producer price per mass unit, given that no data were found for Italy, based on Gallai and Vaissière (2009) data from the FAO statistics website (FAO, 2017a) were acquired for Spain (the most important producing country of the relevant world region), calculating the average for the year 2013; (b) the Italian production of oranges in 2013 was obtained through the same source. As far as DR is concerned, the dependence upon animal pollination for oranges was taken from the tool (FAO, 2017b) proposed by Gallai and Vaissière (2009). (Eq.1) thus gave: EVIP = TVC * DR = [246.5 (US$/t) * 1,700,778 t] * 0.05 = US$ 20,945,081 or € 19,279,440 (exchange rate: 12/05/2017). In order for EVIP to be transformed as *per* F.U. and with the assumption that all orange pollination for that year derived from domesticated honeybees, the total orange-blossom honey production in Italy (or from citrus fruit, in general) had to be obtained; however, no specific data have been found. In order to calculate it, the total honey production in Italy for 2013 - that is 9,500,000 kg (OSN, 2017) - was considered. Furthermore, in a case study concerning an Italian region, the average percentage of citrus fruit honey was reported as 30% (Strano et al., 2015). Nonetheless, since the sample of firms taken into account in the cited case study was not specified, assuming the above percentage in calculations could introduce uncertainty in the results and their interpretation. In order to address that issue, a sensitivity analysis was carried out on the assumed percentage of 30%. According to this, nine scenarios were taken into consideration for different percentages: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% (0% and 100% were excluded because, in fact, these cannot be applicable in Italy). For each one of the scenarios, the calculations were made as follows: as the percentage of oranges in citrus fruit in Italy was calculated as 62.67% (ISTAT, 2014), the economic value of the pollination service per F.U. (i.e., per jar) could then be calculated as well. The economic allocation was therefore performed for the two values: one for honey and one for the pollination service.

In the next step of the life cycle, the beekeepers bring the hives back to the apiculture firm for the supers' extraction phase and their storage. Here, primary inputs such as the necessary gloves, lab coats, uniforms and internal transport (via forklifts) were included. No issues were encountered with finding the entries in the software.

The honeycombs are then uncapped in the successive phase. Here, energy consumption (electricity) due to machines, such as the uncapping machine, a press, a centrifuge and a chain and inputs regarding the filtration sub-phase, was included. At the end of the uncapping sub-phase, a specific amount of beeswax is obtained, which, after being processed at the premises of a firm in the region of Piedmont, returns to the beekeeping company as an input for the first stage (as aforementioned). These inputs were easily introduced in the software.

Once the honey is obtained, it is packaged using a glass jar, a plastic/aluminium lid, a paper label (as primary packaging), a cardboard box and adhesive tape (as secondary packaging) and a plastic film and pallets (as tertiary packaging). The relevant entries in the software were found without any obstacles.

The product is then distributed to its consumers, who reside both in Italy and abroad (e.g., the USA and France). The last phase includes the waste management of the final product, i.e., its packaging, since the product itself is consumed via the human metabolism.

Finally, regarding the quality of the data used in this study, the method used following the ILCD Handbook data quality indicators (European Commission, 2010) resulted in a "basic quality" score (Di Cesare, 2016).

3.3 Life Cycle Impact Assessment (LCIA)

For this LCA case study, the calculations were performed using the ReCiPe Midpoint (H) method (Goedkoop et al., 2009). Therefore, the environmental impact categories taken into consideration were the ones selected by this method. In this part, the classification, characterisation and normalisation (calculated per European citizen) phases of LCIA were carried out. An example of the results (for the 30%-scenario) of the characterisation step is shown in Fig. 2, as they were exported from the software. The impacts for the various environmental impact categories are shown for the different life cycle phases, honey production (including hive placement, supers' extraction & storage, honey extraction and packaging), distribution and waste management. These demonstrated that the production phase is the most impacting one for all categories. A deeper examination of the results showed that the most responsible aspect within the production phase was the use of electricity during the storage of supers in refrigerator rooms before they are used for each new cycle.

Regarding the normalisation results, the most affected environmental impact category appeared to be natural land transformation, followed by marine ecotoxicity, freshwater eutrophication and human toxicity (see Fig. 3).

3.4 Sensitivity Analysis

The nine scenarios were analysed in order to identify the importance for this case study of the percentage of citrus fruit honey within honey production in Italy. The results (see Fig. 3) showed that higher percentages mean higher environmental impacts allocated for the product (honey) for all environmental categories. This can be explained by the fact that higher percentages mean lower prices for the pollination service per kg (whilst the EVIP value is constant), which result in lower allocation percentages for the pollination service.

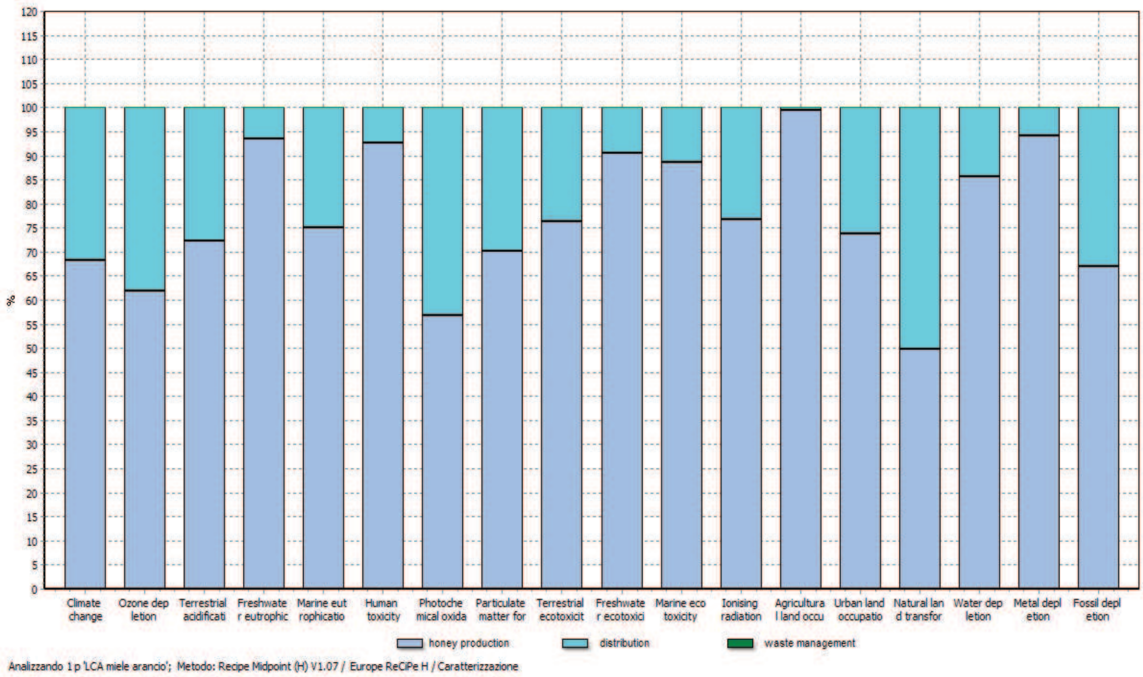

Figure 2. Characterisation results.

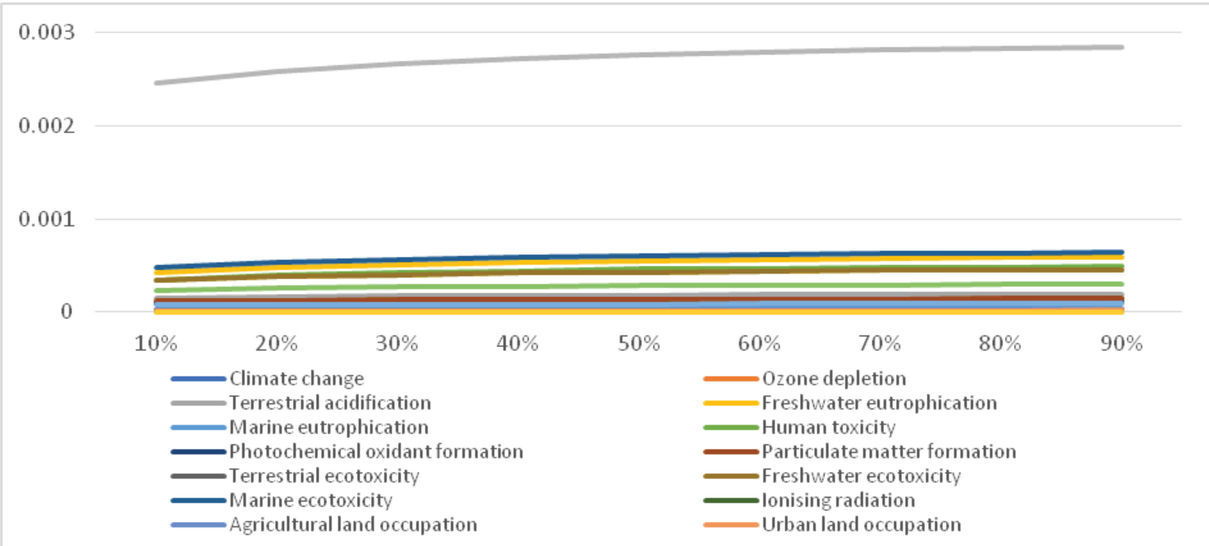

Figure 3. Normalisation results for the various scenarios (elaborated from SimaPro).

4. CONCLUSIONS

This article tackled the inclusion of the pollination service in honey LCA studies, as one of the functions of the system. The two literature reviews carried out showed that this issue has been rarely addressed so far, only in life cycle-based approaches (i.e., carbon footprint), but never in full LCAs and that there are several methods for the economic evaluation of the pollination service. Given the multifunctionality of the beekeeping system, an attempt was made to include the pollination service in an LCA case study in Italy. In order for this issue to be dealt with, the use of economic allocation was decided between the main product (honey) and the pollination service. An attempt was then made for the economic value of pollination to be calculated using the DR method (found in the literature review).

At the end, an accurate implementation of this hypothesis was not feasible, because not all the necessary data for the transformation of the EVIP value per jar were available at the time of drafting this article. The sensitivity analysis for the missing datum showed that the order of importance of the various environmental impact categories did not depend on it; yet, in order for more reliable quantitative results to be obtained, an accurate calculation is required. Future developments may include the implementation of economic allocation for this and other types of honey, in order for robust conclusions to be drawn with regard to these methodological hypotheses.

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