Environmental implications of honey production in the natural parks of northwestern Spain

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Abstract

Honeybees, considered an indicator of ecosystem integrity and biodiversity, have experienced a significant decline due to industrialized agricultural practices and the threat of pests and invasive species, such as the Asian wasp (*Vespa velutina*). Beekeeping practices should be reviewed to ensure the viability of the colony and the protection of the environment. The objective of this study is to analyse the possible environmental impacts associated with honey production in terms of carbon footprint and normalized impact index. In total, 11 beehives from 3 Galician natural parks have been analysed. As for the carbon footprint, all producers obtained values lower than 1.66 kg CO_2/kg of honey, except for two producers, who obtained 5.96 and 3.20 kg CO_2 eq/kg of honey. The transport and production of metal lids have been shown to be the main hot spots in the process. Furthermore, in this study, the influence of scale is very important, because producers have to frequently monitor the integrity of the hive. With the target of reducing the environmental impact associated with honey production, different actions could be implemented, such as more efficient modes of transport, other environmentally friendly packaging or remote pest control systems, which ensure early detection of the invasive wasp.

Keywords: climate change, life cycle assessment, sustainable production, carbon footprint, natural park

1. Introduction

In recent years, human activities related to the development of an industrial society have compromised biodiversity and the provision of ecosystem services that are basic to the preservation of the environment [1]. Habitat loss, introduction of invasive species, overexploitation of resources, desertification, climate change and pollution have all reached such a magnitude that both ecosystem integrity and human well-being are vulnerable. Although global warming is making headlines today as a major environmental impact, biodiversity loss is turning into a serious environmental risk. Pollinating species are especially vulnerable to these threats, specifically honey bees (*Apis mellifera*). The vital importance of these insects in our current production chain is demonstrated by the fact that one third of the global food production relies on insect pollination, of which an estimated 80% is provided by honey bees [2].

A major effort has been made in recent decades to implement honeybee monitoring programmes, which have shown worrying rates of colony losses in Europe and North America [3,4]. Threats that pose the greatest risk to the bee population include land-use change, intensive agricultural management and pesticide use, environmental pollution, invasive species, pathogens and climate change as direct drivers [5]. Although it is difficult to establish a direct connection between these drivers and the reduction of honeybee communities, specific case studies have suggested that these factors have a relevant effect [6]. In particular, Climate Change could affect honeybees at different levels as it may alter the quality of the floral environment, which could cause a reduction of the harvesting capacity and development of the colony. Another consequence of Climate Change is the direct influence on the behaviour and physiology of honeybees [7].

Honeybees play an important role in agriculture since bees pollinate both wild and cultivated flowers, resulting in better production yields of fruits and seeds [8]. In fact, bees can fly and search for nectar and pollen in an area of 28 km^2 around the apiary. Moreover, honey production can contribute to Europe's sustainability goals, since, unlike other sweeteners such as sugar, honey production requires neither the occupation of agricultural land or the use of mineral fertilisers and irrigation for crop cultivation [9].

Although Spain is not a major honey producer, the total Spanish production in 2016 was 31.018 t; with more than 31.527 beekeepers, of which about 18% are professionals who handle more than 150 hives [10]. The number of apiculture farms in Spain has increased by around 40% in the 2010/2018 period. The spread of honey production in Galicia (Northwest Spain) seems to be able to have a positive impact in its natural resources.

Galician honey production faces several challenges, including the use of insecticides, the proliferation of predators and climate change. In fact, the asian wasp (*Vespa velutina*) is causing great damage to honeybees in Spain and other European countries and its impact is increasing on a yearly basis [8]. The constant presence of these Asian wasps close to bee colony forces worker bees to defend the hive entrance, decreasing the time for foraging. If this situation continues, pollen reserves are depleted, leading to mortality of developing bee larvae, endangering the colony [8].

In a broader and more global context of agricultural activity in Galicia, there has been an increase and intensification of agricultural activities to the detriment of low-intensity agriculture, which in many cases is accompanied by loss of environmental diversity, soil degradation and biodiversity. Moreover, the abandonment of agricultural activity in mountain areas sometimes leads to reforestation with monoculture tree species or simply to an increase in the area of scrubland. On the contrary, it is important to take into account the enormous potential of the region, characterized by having a significant extension of protected areas. In the territory of Galicia there are six declared natural parks: i) Fragas do Eume, ii) Complexo dunar de Corrubedo e Lagoas de Carregal e Vixán, iii) O Invernadeiro, iv) Serra da Enciña da Lastra, v) Baixa Limia – Serra do Xurés and vi) Monte Aloia. Each territory has adopted territorial strategies to favour ecosystem integrity and biodiversity, in particular, there is an intensive monitoring programme aimed at establishing and applying policies that help each territory to achieve these goals. In particular, these natural parks guarantee conditions of greater ecological protection than any other area. In this way, all kinds of activities are carefully planned and managed, with the objective of ensuring environmental protection, the cultivation of native species against monocultures and the promotion of less industrialized agriculture and livestock. The production of valuable products such as honey is also compatible with this figure of protection, provided that sustainable agricultural practices are carried out in these areas, which also offers a good opportunity for economic growth in rural areas.

The main objective of this study is to analyse the possible environmental impacts associated with honey production in 3 Galician natural parks, focusing mainly on the normalized impact index and the carbon footprint, as a quantitative indicator of the environmental impact associated with climate change. This study also proposes the identification of critical points in the environmental profile of the process under study, prior to its development and marketing of the product and the co-products obtained.

2. Materials and methods

2.1. Goal and scope and system boundaries

The main goal of this study is to obtain the environmental performance of honey production in 3 different Galician natural parks: Fragas do Eume; Complexo dunar de Corrubedo–lagoas de Carregal–Vixán and Baixa Limia – Serra do Xurés. A total of 11 producers were evaluated, whose main products was centrifuged honey, although other co-products such as wax and propolis are also produced. The secondary goal is to identify the main hotspots in the entire life cycle. The result of this study can help beekeepers and honey processors improve their environmental performance by identifying the main hotspots in the production process.

The functional unit (FU) is a measure of the function of the system and provides a reference to which the inputs and outputs can be related. In this study, the production and packaging of 1 kg of honey ready for distribution has been chosen as FU. The system under study includes all the processes necessary for honey production, as well as the production of all the necessary materials and the disposal of the waste generated. To this end, a cradle-to-gate life cycle assessment (LCA) has been performed in accordance with ISO standards [11]. In more detail, the production system has been classified in three different subsystems: SS1 – Hive management; SS2 – Honey extraction; SS3 – Final packaging. The subsystems and system boundaries under consideration are illustrated in the flow chart of Figure 1.

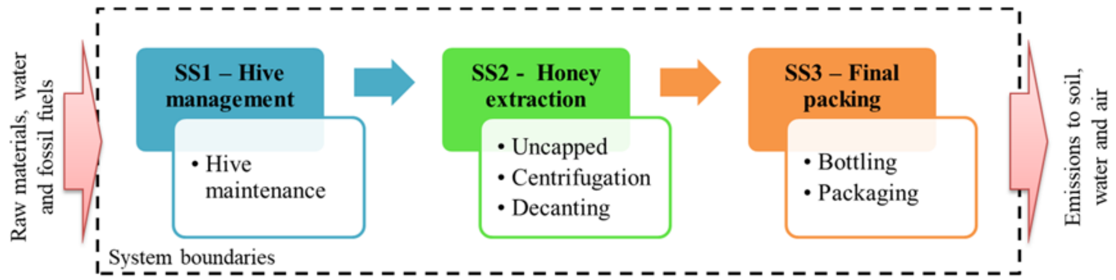

Figure 1. System boundaries of the environmental assessment of honey production

The first stage of honey production is the management of the hives, which are composed mainly of wood, sheet steel and wire. Due to the location of the beehives within the natural parks, the apiaries are placed in areas that ensure that within a radius of 3 km the sources of nectar and pollen are essentially organic crops or, where appropriate, wild vegetation or managed forests or crops that have only been treated with low environmental impact methods. The management of the hives ensures the use of natural methods for reproduction. For this reason, cloning and embryo transfer as well as treatments with hormones or similar substances to induce or control reproduction are not considered.

The number of honeycombs per hive can vary and also their yield in terms of the amount of honey produced in each unit. A periodic visit to the apiaries by the producers is necessary to ensure the greatest efficiency of production and to preserve the integrity of the hive from the potential attack of the Asian wasp. The frequency of these visits varies significantly between systems (18-360 visits/year), as well as the travel distance to the areas where the apiaries are located (0.5-75 km/visit). The visits are made by car with a fuel consumption ranging between 5-12 L per 100 km traveled. At each visit, the producers are responsible for checking the correct operation and maintenance of the hives, including food supplements such as a mixture of water and sugar in equal proportion of 1:1. The use of phytotherapeutic products and rodenticides (only in traps) can be applied as a protection measure of the honeybee. In case of infection with Varroa destructor, formic acid, lactic acid, acetic acid, oxalic acid, menthol, thymol, eucalyptol or camphor may be used.

In some cases, during the visit to the hives, producers may need to use a smoker. The main function of these smokers is to control the bees to move away from the hive and allow manual operations of the beekeeper. Smoke is generated from different sources, such as pellets, straw, grass or cardboard. The consumption of water and fuel can also be recorded due to the cleaning tasks carried out on the land where the hives are located, mainly associated with the use of brushcutting machinery. The waste generated in this first stage is mainly wood and steel plate from the hives and is properly managed before final disposal.

The honey is extracted between 1 and 3 times a year, between the months of June and September. At the beginning of this stage, the honeycombs of the hive are transported by car (5-12 L per 100 km) to the processing facilities. Once there, the uncapping task allows to separate the wax and other wastes thanks to the application of heat supplied by a boiler fed with butane. The removed wax is replaced by virgin wax, while the remaining residual wax is used as fertilizer in agricultural soils. The honey is separated by means of stainless steel centrifuges with a power of 150-600 W. Finally, the honey is decanted for clarification and the residues generated in this step are used as an attractant for the Asian wasp, so that it is used as a trap serving as a defense against the harmful effects of this invasive species. Sometimes it is necessary to use water and bleach in the periodic cleaning tasks.

Finally, glass and plastic containers are used in the packaging phase. Glass containers with a weight of 300 g and a capacity of 1 kg are combined with 15 g metal lids. However, the capacity of plastic containers is variable (350 g - 20 kg), also used in combination with 15 g plastic lids. In some facilities, 25 kg food-grade plastic tanks are used to store honey prior to final packaging. In some cases, it is necessary to wash the containers, either by hand or in a dishwasher, with the consequent consumption of electricity and water. Finally, all containers are labelled with paper labels (2 g) and stored in cardboard boxes of 6-12 jars.

2.3. Life cycle inventory

Most of the inventory data were collected through surveys of the different honey producers (primary data), including information on the characteristics and land occupied by the hives, the equipment used in the different phases and their specifications (material, electricity consumption, diesel and butane), transport activities (type of transport, fuel consumption, distances and frequencies) and the consumption of additional inputs (water, chemical products and packaging materials), as well as the products and co-products obtained and the waste generated.

However, some data must be estimated due to the absence of primary data. Therefore, a useful life of approximately 15 and 30 years was assumed for the food-grade plastic and stainless steel centrifuges, respectively. Furthermore, the Ecoinvent® database was used to calculate the production of the different inputs used in each of the systems studied [12–16]. The main inventory data relating to the different subsystems involved in honey production are shown in Tables 1-3.

Table 1. Life cycle inventory of Subsystem 1. Hive management

Inputs/Outputs	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Units
Inputs from Environment												
Land occupation (parcels)	7500	9500	1500	2500	2000	33300	10000	2300	3000	6200	7500	m^2
Land occupation (hives)	246	13.6	166	62.7	2.16	7.80	36.0	18.0	228	696	605	m^2
Inputs from Technosphere												
Materials												
Wood (hives)	37.8	13.6	28.0	8.80	2.40	10.4	6.00	8.00	29.1	116	152	kg
Wire (hives)	0.35	0.14	0.33	0.10	0.03	0.12	0.07	0.09	0.37	1.35	1.47	kg
Steel sheet (hives)	4.72	1.70	3.50	1.10	0.30	1.30	0.75	1.00	3.64	14.5	15.8	kg
Dry material (smoker)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	kg
Diesel (brushcutting machinery)	-	4.80	0.40	2.40	0.40	1.60	0.40	5.00	0.80	2.00	2.00	kg
Water (cleaning tasks)	60.0	-	-	-	30.0	30.0	-	30.0	-	-	-	L
Sugary mixture												kg
Water	208	34	70	44	12	26	30	40	160	580	632	L
Sugar	208	34	70	44	12	26	30	40	160	580	632	kg
Transport												
Car	1080	521	1825	1440	12.2	3911	26.1	261	626	4172	3911	km
Outputs to Technosphere												
Products												
Tables with wax and honey	312	272	630	198	48	117	120	160	800	2900	3158	number
Waste												
Wood (hives)	37.8	13.6	28.0	8.80	2.40	10.4	6.00	8.00	29.1	116	152	kg
Steel sheet (hives)	4.72	1.70	3.50	1.10	0.30	1.30	0.75	1.00	3.64	14.5	15.8	kg

Table 2. Life cycle inventory of Subsystem 2. Honey extraction

Inputs/Outputs	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**Units**
Inputs from Technosphere												
Materials												
Stainless steel (centrifuge)	1.33	1.67	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	kg
Butane	62.5	18.8	12.5	6.25	12.5	25.0	6.25	25.0	-	-	-	kg
Water (cleaning tasks)	-	100	300	100	100	300	100	100	-	-	-	L
Bleach (cleaning tasks)	-	15.0	15.0	1.00	15.0	-	10.0	5.00	-	-	-	L
Transport												
Car	-	5.0	-	-	-	25.0	-	5.00	6.00	40.0	75.0	km
Energy												
Electricity	9.00	1084	79.2	99.6	74.7	1082	360	-	54.4	86.4	72.0	kWh
Outputs to Technosphere												
Products												
Centrifuged honey	728	680	1050	220	180	390	225	400	1600	5800	6316	kg
Co-products												
Propolis	-	-	-	-	-	-	-	-	3.00	-	-	kg
Wax	50.0	20.0	60.0	4.00	20.0	20.0	10.0	5.00	25.0	60.0	60.0	kg
Waste												
Residual wax	-	-	-	-	-	-	-	2.00	5.00	-	10.0	kg
Stainless steel (centrifuge)	1.33	1.67	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	kg

Table 3. Life cycle inventory of Subsystem 3. Final packing

Inputs/Outputs	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Units
Inputs from Technosphere												
Materials												
Food-grade plastic	1.39	1.30	-	0.40	0.30	0.70	0.40	0.80	-	11.0	12.0	kg
Glass	109	102	315	33.0	27.0	58.5	33.8	60.0	480	870	947	kg
Plastic containers	25.0	23.3	-	7.54	6.17	13.4	7.71	13.7	-	199	217	kg
Metal (lids)	5.46	5.10	15.8	1.65	1.35	2.93	1.69	3.00	24.0	43.5	68.0	kg
Plastic (lids)	15.6	3.40	-	0.08	0.07	0.15	0.08	0.15	-	2.18	2.37	kg
Paper (labels)	2.80	0.71	2.10	0.23	0.19	0.41	0.24	0.42	3.20	6.10	9.30	kg
Cardboard	-	1.25	0.60	1.20	0.60	0.60	1.10	0.60	0.60	-	-	kg
Water (cleaning tasks)	-	125	100	100	100	350	100	100	-	-	-	km
Energy												
Electricity	-	3.75	-	-	-	10.5	-	3.00	-	-	-	kWh
Outputs to Technosphere												
Products												
Packed honey	728	680	1050	220	180	390	225	400	1600	5800	6316	kg

2.4. Life cycle impact assessment: methodology

SimaPro 8.5.2 [17] has been the software used for the implementation of the Life Cycle Inventory. To analyze the inputs and outputs of the Life Cycle Inventory, the Classification and Characterization guidelines defined by ISO were followed. The environmental results have been presented in terms of carbon footprint and the normalized impact index of the ReCiPe methodology [18].

According to the Intergovernmental Panel on Climate Change (IPCC) [19], the carbon footprint (CF) is defined as the total sets of greenhouse gas (GHG) caused during the entire life cycle of a process, product or service and expressed as kg of CO_2 equivalent. The CF has become a widespread indicator and is used by governments and companies throughout the world. The CF not only quantifies direct GHG emissions, but also takes into account indirect emissions.

The normalized impact index (NI) reflects the results of environmental burdens in the form of different impact categories, offering a global view of the environmental performance of the product. To obtain this index, the normalization stage is performing after the classification and characterization stages. The normalization phase allows to unify all the impact categories in the same units. The considered impact categories from the ReCiPe methodology are shown in Table 4.

Table 4. Impact categories included in the normalized impact index

Impact Categories	Acronym	Units
Climate Change (Carbon Footprint)	CC	kg CO_2 eq
Ozone Depletion	OD	kg CFC-11 eq
Terrestrial Acidification	TA	kg SO_2 eq
Freshwater Eutrophication	FE	kg P eq
Marine Eutrophication	ME	kg N eq
Human Toxicity	HT	kg 1,4-DB eq
Photochemical Oxidant Formation	POF	kg NMVOC
Particulate Matter Formation	PMF	kg PM10 eq
Terrestrial Ecotoxicity	TET	kg 1,4-DB eq
Freshwater Ecotoxicity	FET	kg 1,4-DB eq
Marine Ecotoxicity	MET	kg 1,4-DB eq
Ionising Radiation	IR	kg U_{235} eq
Agricultural Land Occupation	ALO	m^2a
Urban Land Occupation	ULO	m^2a
Natural Land Transformation	NLT	m^2
Water Depletion	WD	m^3
Metal Depletion	MD	kg Fe eq
Fossil Depletion	FD	kg oil eq

3. Results and discussion

Table 5 shows the LCA results of the honey production from 11 producers. The contribution of each single subsystem has been computed and expressed in the corresponding units for the carbon footprint (kg CO_2 equivalent) and the normalized impact index (points). As shown in Table 5 and Figure 2, the environmental results are very different, both in the final result and in the relative contribution of each subsystem to the environmental burdens.

Table 5. LCA results of honey production.

Producer	CF (kg CO_2 eq)			NI (points)		
	Hive management	**Honey extraction**	**Final packing**	**Hive management**	**Honey extraction**	**Final packing**
P1	0.595	0.085	0.483	0.009	0.001	0.022
P2	0.324	0.838	0.446	0.005	0.010	0.022
P3	0.689	0.087	0.631	0.009	0.001	0.042
P4	2.505	0.248	0.437	0.033	0.003	0.022
P5	0.090	0.279	0.435	0.002	0.003	0.022
P6	4.068	1.458	0.434	0.047	0.017	0.022
P7	0.141	0.955	0.562	0.003	0.011	0.037
P8	0.293	0.062	0.434	0.005	0.001	0.022
P9	0.115	0.039	0.370	0.003	0.001	0.002
P10	0.162	0.023	1.214	0.004	0.000	0.023
P11	0.145	0.015	0.501	0.004	0.000	0.031

Regarding the environmental results obtained in the carbon footprint, all producers obtained values lower than 1.66 kg CO_2 eq/kg honey, with the exception of Producer 6 (5.96 kg CO_2 eq/kg honey) and Producer 4 (3.2 kg CO_2 eq/kg honey). In both cases, hive management was the subsystem that most contributed to GHG emissions (68% and 79% respectively). With respect to the normalized impacts index, the results follow the same trend as the carbon footprint ones. Producer 6 is again the one with the greatest environmental impact (0.086 pts), not only due to the management of the hive management (55%), but also to honey extraction (20%) and final packaging (25%). The producer with the second highest environmental impact is Producer 4 (0.057 pts), but in this index, the difference with the rest of producers is not so high (Producer 3: 0.053 pts; Producer 7: 0.051 pts). Unlike the CF results, in all cases, except for Producers 4 and 6, Subsystem 3: Final packing is the main factor contributing to the environmental impact. This is related to the use of metal for the manufacture of covers for the glass containers. This material causes an important impact on the MD category and, at the same time, this category has a relatively high normalization factor. Below, the subsystems are analysed separately in order to understand the causes of the environmental impacts produced in each case.

Regarding Subsystem 1. Hive management, it is important to highlight that this subsystem accounts for 51%, 49%, 79% and 68% of the impacts produced in the CF for Producers 1, 3, 4 and 6. If this subsystem is analysed in detail, it can be observed that transport is the main source of GHG emissions, contributing between 85% and 99% of the impacts produced in this subsystem, especially due to emissions derived from fuel consumption. In addition, this subsystem also has a significant burden on the impacts produced in the NI for Producers 4 and 6, with contributions of 57% and 55% of the impacts respectively, mainly due to transport. These results can be explained by the number of weekly trips to the hive. On the other hand, the honey production of each honeycomb is a very important factor, since a low productivity magnifies the impacts by relativizing them with the functional unit (i.e., for each kg of honey). The impacts produced in Producer 6 are the highest since the producer has to visit the apiary 3 times a week, covering a distance of 25 km and the annual production of honey is only 400 kg.

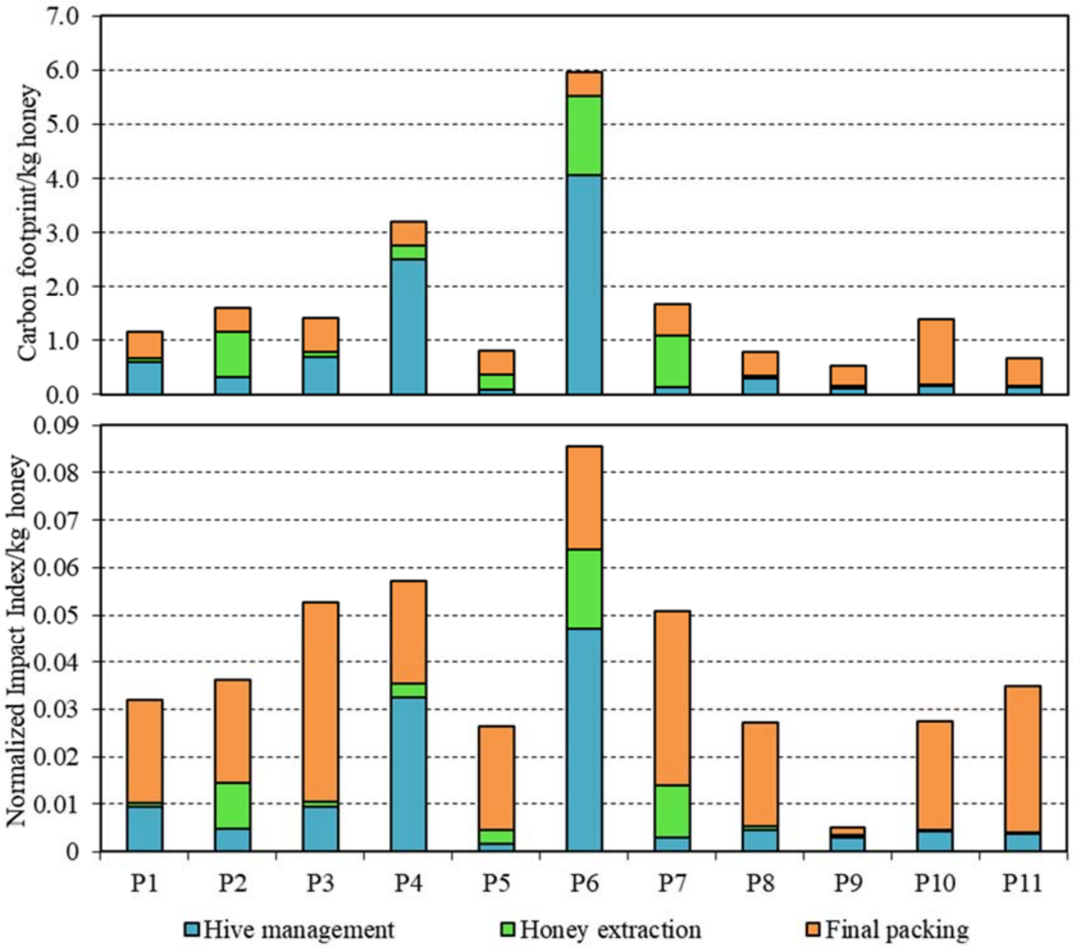

Figure 2. Environmental results for the carbon footprint and normalized impact index of honey production

For both CF and NI, the honey extraction subsystem plays an important role in the environmental profile of Producers 2, 6 and 7. Contributions range from 24% to 58% of the impacts in HC, and from 11% to 27% in NI, while for the other producers it does not exceed 8%. For both indicators, the environmental impacts are mainly produced by electricity consumption (between 70% and 89% in CF and between 79% and 90% in NI).

As for the packaging process, the importance of this subsystem contribution is different in the indicators. For CF, contributions reach a maximum of 58% in the case of Producer 7, while in the case of NI, contributions are between 60% and 88% for 8 of the 11 producers under study. Analyzing the processes involved in this subsystem, it is observed that the environmental impacts are associated with the production of the jars. In the case of CF, the impacts are divided between metal production (72%) and plastic production (26%). However, in the case of the NI, most of the impacts are attributed to metal production (<93%). It is important to emphasize at this point that the study has been carried out from a cradle-to-gate perspective, and that the use and possible recycling of the jars has not been included in the analysis.

The threat caused by the Asian wasp causes a major impact on the environmental performance. Not only does it increase the frequency with which producers must visit the apiary, but it also reduces annual productivity. The productivity of the honey of each apiary plays a fundamental role since it has a direct effect on the functional unit. The reduction in productivity due to these wasps magnifies these impacts when the results per functional unit (i.e. per kg of honey produced) are relative.

4. Conclusions

The carbon footprint of honey production and processing ranges from 0.5 to 6 kg CO_2 eq/kg of processed honey, mainly due to transport and container production. However, the influence of the scale is very important, as all producers have to move two or three times a week to the hive to protect them from Asian wasps. Therefore, in this case small-scale production is a clear disadvantage in terms of the environmental performance.

Transport is one of the main hot spots in the process in both indicators (CF and NI) due to direct GHE emissions from diesel combustion. One possible method of reducing emissions and energy consumption is to minimize transport distance and use more efficient modes of transport. As far as NI is concerned, Subsystem 3 is of great importance mainly due to the production of glass and metal for the manufacture of the jars. Therefore, a possible improvement action would be the use of another type of packaging with a lower environmental impact. In this way, the product can be more attractive to consumers, as it is a product from a natural park and environmentally friendly. Finally, in such a seemingly simple system, beekeepers also demand technology. In this way, it would be very beneficial to have remote pest control systems that ensure the early detection of the velutin wasp and, therefore, allow the apiary to be protected. Additional protective measures, such as barrier systems, could also be introduced to allow the passage of bees but prevent the much larger invasive species from accessing the hive.

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