With or without pollination?

Environmental impacts of Swedish beekeeping systems considering pollination services

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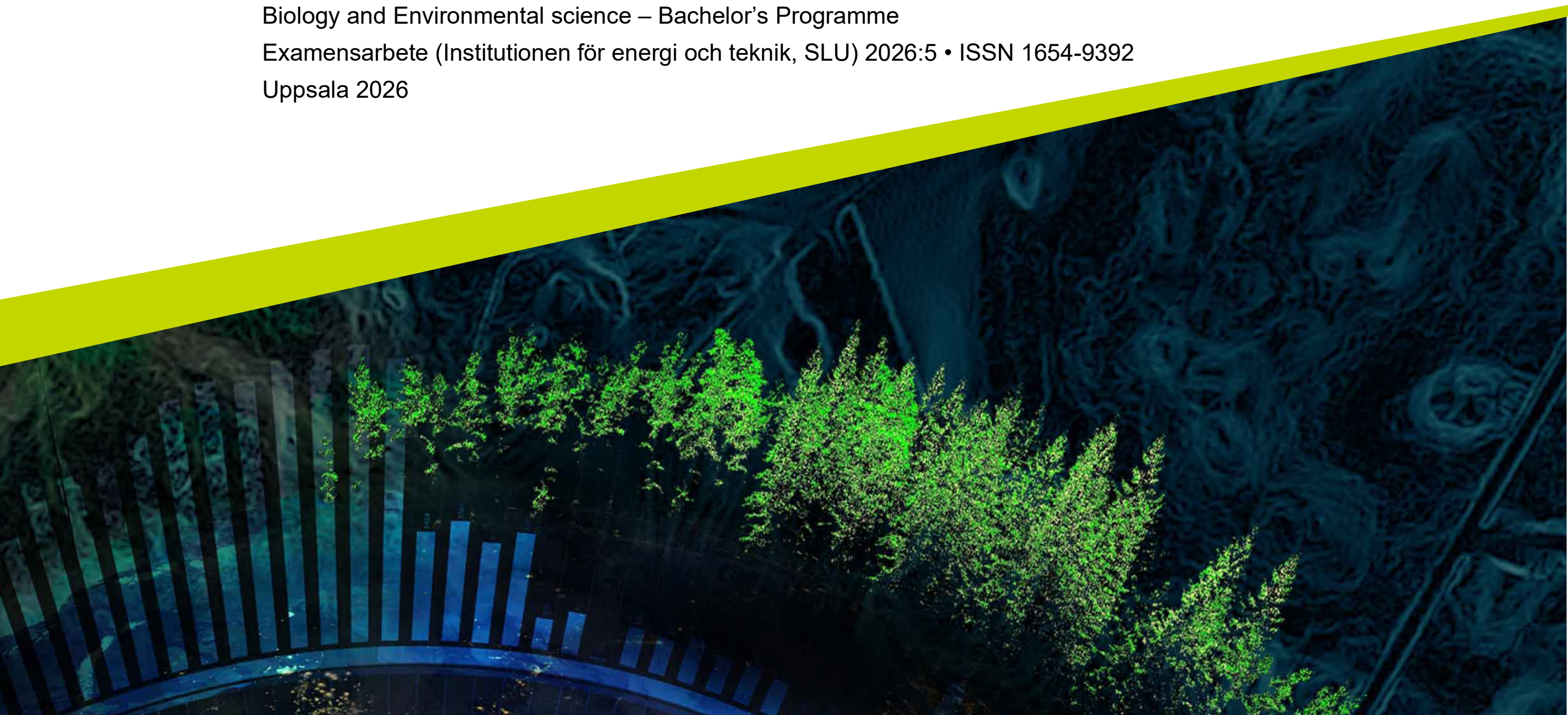

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Med eller utan pollinering? Miljökonsekvenser av svenska biodlingssystem med hänsyn till pollinering

Filippa Höglund

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Abstract

Beekeeping serves a broader function than only producing honey, it is a multifunctional system that also provides pollination services. Pollination is often difficult to include in life cycle assessments (LCA) since it is a nonphysical product. Ecosystem services that are provided by beekeeping are important for agricultural yield. This study therefore analysed the environmental impact of Swedish honey ready for distribution. It also evaluated how the inclusion of pollination affected the results using three scenarios. In the first scenario, $Honey_{baseline}$, environmental impact of honey production was quantified without considering pollination services. In the second scenario, $Honey_{system}$, system expansion was used to include pollination as a co-function through increased yield in oilseed rape. Lastly, in $Honey_{economic}$, economic allocation was applied to divide economic impact between honey and pollination based on their economic value.

In the $Honey_{baseline}$ scenario the total impact was 0.66 kg carbon dioxide equivalents (CO_2-eq) and 0.28 m² annual crop equivalents (a crop eq) per functional unit (*500g of honey ready for distribution)*. The largest contributions originated from maintenance and packaging. In the $Honey_{system}$ scenario the results were -3.7 kg CO_2-eq and -11.4 m²a crop eq per functional unit. In the $Honey_{economic}$ scenario, 73% of the impact was allocated to honey and 27% to pollination, reducing the environmental impact of honey to 0.48 kg CO_2-eq and 0.21 m²a crop eq per functional unit. The results show that the inclusion of pollination has a considerable effect on the assessment of honey, particularly when using system expansion and accounting for the environmental credit. The environmental benefits of honey are not captured when pollination is excluded from the system. Thus, pollination should be considered in LCAs of apicultural systems to better represent the multifunctionality of the system and the importance of bees as pollinators.

Keywords: Apis mellifera, Honey, Apiculture, Climate impact, Ecosystem services, Life cycle assessment

Table of contents

Abbreviations

a crop eq	Annual Crop Equivalent
CO_2-eq	Carbon Dioxide Equivalent
FU	Functional Unit
GWP	Global warming potential
LCA	Life Cycle Assessment
LCI	Life cycle inventory
pcs	Pieces
SLU	Swedish University of Agricultural Sciences

1. Introduction

Honeybees (*Apis mellifera*) are highly important for pollination, especially for the 35% of global food production that depends on pollination from insects. Most crops can produce some yields without insect pollinators, but 84% of crops still depend partly on animal pollination (Klein et al. 2007). Without animal pollination, the land required for crop production would be greater (Aizen et al. 2009). There are 600 000 beekeepers in the EU, together they have 17 million beehives producing approximately 240 000 tonnes of honey every year (European Parliament 2018). In Sweden, the estimated amount of honey produced in 2022 was 4400 tonnes. The pollination services provided by the beekeeping system can for some beekeepers contribute to their income (Adolfsson 2023).

Pollination by honeybees not only accounts for higher yields but also contributes to increasing biodiversity when pollinating wildflowers. Pollination is therefore a crucial function of the apicultural system (Genersch 2010). Yet only a few LCA studies on honey currently include ecosystem services such as pollination (Arzoumanidis et al. 2019). It is challenging to capture the multifunctionality within the LCA framework which is often optimized for single functional systems. According to Arzoumanidis et al. (2021) LCA can still be used to assess the multifunctional systems of honey production if the modelling of the system is done carefully.

1.1 Objective

The aim of this study is to investigate the effects of including pollination as a co-function when assessing environmental impacts of Swedish honey production. To do so, global warming potential and land use change are quantified using life cycle assessment. The study also aims to evaluate how different approaches to handling multifunctionality influence the results and interpretation of the assessment, by comparing a base scenario with system expansion and economic allocation.

2. Background

2.1 The beekeeping system

Beekeeping and apiculture are common words to describe the management of honeybee colonies in artificial hives that produce honey or other apicultural products. The beekeeper can choose to have a stationary system where the bees stay in one place or a migrating system where they can be moved. The migrating system is important for agriculture where crop production is intensified, and insect pollination together with wild pollination are insufficient. By moving hives to specific crops during different flowering periods, the beekeeper can support the pollination while also producing honey from selected flowers. (Wafullah & Munene 2024)

The income from pollination can for some beekeepers be greater than the income from honey production. In Sweden (Österlen), fruit farmers have rented approximately 5000 honeybee colonies per year to ensure sufficient pollination and receive high yields. Pollination services also occur for crops such as clover and oilseed rape. (Mattson 2009)

A Swedish beehive is made from stacked boxes on top of each other together with a lid and bottom (Mattson 2009). The beehives are mainly made of cellular plastics (Environmental impacts of beekeeping 2026) due to insulating properties and low weight (Mattson 2009). To maintain the apicultural system, it is common for the beekeeper to use protective gear such as a full body suit and gloves. During the summer and high season, it is common to visit the colonies every other week and less during the winter season. For the winter it is important to ensure that the bees have supplementary feed after taking their honey, for each hive it is recommended that they have access to at least 20kg of sugar. To extract the honey from the frames a honey extractor is needed (Mattson 2009). In some cases, a smoker can also be used to calm the bees before removing the frames or other activities related to apicultural maintenance (Kankare 2017).

2.2 Life cycle assessment

LCA is a framework used to evaluate environmental impacts between products for the whole life cycle of a product. When a system has more than one output they are referred to as co-products (Matthews et al. 2014). For pollination it is more complicated to use LCA since pollination is a nonphysical system, it is therefore challenging to link to a flow. (Arzoumanidis et al. 2021) According to the LCA ISO standard (14044: 2006) (see Curran 2017): if possible, the multifunctionality of a system should be avoided, if unavoidable, the following hierarchy is recommended: subdivision of multifunctional processes as first choice; followed by system expansion (including substitution); and lastly allocation to distribute the burden between different co-products (Curran 2017).

2.2.1 System expansion

One of the suggested methods to handle multifunctionality in LCA is system expansion. Within system expansion the co-product is modelled and becomes a part of the system (Matthews et al. 2014). Using this method, credit will be granted for avoided production, it is therefore essential to understand what is being substituted (Curran 2017). The usage of system expansion can result in negative values. If negative values occur, they should be interpreted with high caution (Matthews et al. 2014).

2.2.2 Allocation

The last recommendation in the hierarchy for multifunctional systems is allocation (Curran 2017). The method distributes outputs based on different flows using an allocation factor. The factor can for example be made from mass or economic value. The factor is then multiplied by the impact to give the allocated flow from the total impact. Therefore, the relationship represented by the allocation factor is important, and the choice of method can highly affect the results (Matthews et al. 2014).

2.2.3 Previous studies

In earlier studies assessing the environmental impacts of honey with pollination included as a co-product, the majority has used economic allocation to handle the multifunctionality (Arzoumanidis et al. 2019; 2021; Nguyen 2025).

In Arzoumanidis et al. (2019) The economic value for honey was set based on the selling price of orange-blossom honey and the dependency ratio for pollination, 59% was allocated to honey and 41% to pollination. In a later study by Arzoumanidis et al. (2021) The production cost was used for honey, and 3 different scenarios were applied for pollination:

- Scenario A: Dependence ratio method for orange blossom-honey allocating honey 38% and 62% to pollination
- Scenario B_{market}: pollination service market value for cherry-blossom honey allocating honey 84% and 16% to pollination
- Scenario $B_{calculated}$: Dependence ratio method for cherry-blossom honey allocating honey 24% and 76% to pollination

In Nguyen (2025), The economic values were based on selling price of honey and an estimated market price for the pollination. The allocated impact was 88% to honey and 12% to pollination.

2.3 Correlation between yield in oilseed rape and honeybees

Oilseed rape was chosen as a model crop due to its significance as an oil crop in Sweden. It has been cultivated in Sweden for a long time, with especially high yields between the 1970s and the 1990s (jordbruketisiffror 2021). Record yields were recorded in 2022 (jordbruketisiffror 2023a), though it decreased in the following year (jordbruketisiffror 2023b).

The pollination of Oilseed rape (*Brassica napus*) can occur through insect pollination, wind pollination and self-pollination. The crop carries multiple traits that are highly interesting for insect pollinators: flowers are open, yellow and can in some cases produce large amounts of nectar and pollen (Ouvrard & Jacquemart 2019). According to Klein et al. (2007) oilseed rape is moderately dependent (10-40%) on insect pollination. In the study of Ouvrard and Jacquemart (2019) that rewired the dependency of insect pollinators for oilseed rape, the results stated that the importance of pollinators can variate between regions and cultivars. The findings also show that field-based studies are in general more realistic compared to experiments on caged plants.

A Swedish field study by Lindström et al. (2016) compared the yield of oilseeds rape when adding honeybees to fields with two different types of cultivars: Open pollinated and hybrid cultivars. The study was performed over 2 years on 43 fields. For open pollinated oilseed rape the presence of honeybees increased the yield by almost 11%, resulting in +448kg/ha. For hybrid cultivars the study showed no correlation between yield and honeybees. On the studied fields honeybees accounted for 68% of insect's visits.

The recommended number of beehives for oilseed rape in Sweden are two beehives per hectare. In comparison 4 colonies per hectare are recommended for apples and 10-20 for strawberries. Two factors explain the relatively low number of hives used in oilseed rape fields: winds plays a large part in the pollination of this species, and honeybees experience a high attraction to the flowers of this species. (Mattson 2009)

3. Method

To determine the environmental impacts of honey ready for distribution a life cycle assessment (LCA) was performed. The system boundary was defined as cradle-to-gate, including the stages construction, maintenance, extraction and packaging (Figure 1). The excluded processes were distribution to retail and waste from hive construction and frame replacement. Parts of the system that could be reused and produced within the system were also excluded, these processes were starting bee colonies, production colonies, and beeswax. Within the system one co-function from beekeeping was included for 2 scenarios.

The included co-function was pollination defined as increased yield in oilseed rape. To assess the multifunctionality of honey production, three different scenarios were modelled and included in the analysis:

1. $Honey_{baseline}$: The studied system without the inclusion of the pollination services.
2. $Honey_{system}$: The studied system with system expansion that includes pollination as a co-function.
3. $Honey_{economic}$: Economic allocation is applied to divide environmental impact between the produced honey and the pollination services.

In the $Honey_{system}$ scenario, open-pollinated oilseed rape is used as a modelling crop. The values for increased yield were based on literature (Lindström et al. 2016). In this scenario, the increased crop yield due to the pollination services were calculated as an environmental credit. The credit represents the avoided environmental burden associated with producing the same amount of crop without the additional yield from managed honeybee pollination. In the $Honey_{economic}$ scenario, the economic values used to divide the impact were based on the income to the beekeeper for 1kg of honey and the price received for pollination service. The honey price was set to 12 €/kg, and the pollination value was set to 300 €/ha based on survey answers from one beekeeper.

500 grams of honey ready for distribution was set as the functional unit (FU). To analyse the impact two environmental impact categories were used, global warming potential (kg CO_2-eq) and land use (m^2a crop eq). The software for modelling the system was SimaPro version 10.3.0.4. The databases used for materials were "Ecoinvent 3 allocation, cut-off by classification" and "Industry Data 2.0". For data linked to sugar and oilseed rape "Agri-footprint economic allocation" was used (see Appendix 1). ReCiPe 2016 (H) midpoint was then used within the software to calculate environmental impact.

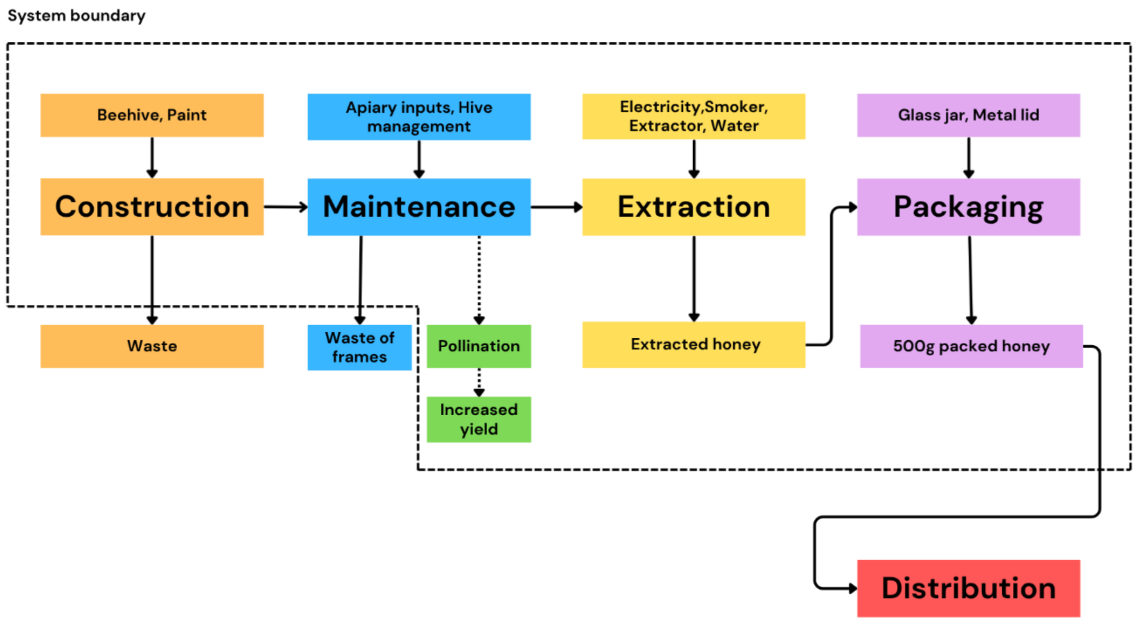

Figure 1: Flowchart for the Inputs and outputs in Swedish honey system for each stage. The system includes the stages hive construction, apiary maintenance, honey extraction, and packaging. The excluded stage is distribution, and the excluded outputs are waste from construction and frames. From the maintenance stage pollination is shown as an output and is interpreted as the co-function within the system.

An unpublished survey within the EU project BEE-GUARDS was used for primary data. A total of 6 answers from active Swedish beekeepers were used in the study. (Environmental impacts of beekeeping 2026) If the data from the survey were text based the most common answer was selected. For numbers the average was calculated and outliers were excluded. No set value for the outliers was done. When the data from the survey were not enough to complete the model, data from manufactures or suppliers were used. All assumption and proxies for each stage are described in 3.1.1 to 3.1.3.

A sensitivity analysis was performed to account for the variation and uncertainty of values presented on the dependency of honeybees to oilseed rape for pollination (Klein et al. 2007; Lindström et al. 2016; Ouvrard & Jacquemart 2019).

3.1 Life cycle inventory

The combined data from survey responses, manufactures and literature values were calculated to the functional unit (*500 g honey ready for distribution*) for all life cycle stages. The inventory is categorised according to the life cycle stages. For materials reused within the system a lifetime was set and presented in Table 1. Supporting results are available in Appendix 1.

Table 1 : Lifecycle inventory for all materials in each lifecycle stages including Inputs/outputs and lifetime for all materials or items. The data is presented per functional unit.

Stage	Material/Item	Input/output	Lifetime(years)	Amount per FU	Unit
Beehive Construction	EPS	Input	15	8.5×10^{-3}	kg
	Wood	Input	4.2	9.5×10^{-2}	dm^3
	Paint	Input	15	1.6	ml
Hive Maintenance	Polyester (65%), Cotton (35%)	Input	3.4	0.25	g
	Gloves (rubber)	Input	1	1.7×10^{-2}	g
	Strimmer	Input	-	5	m^2
	Transport	Input	Yearly	0.36	km
	Feed protein	Input	Yearly	7.3×10^{-3}	kg
	Feed sugar hard	Input	Yearly	1.5×10^{-2}	kg
	Feed sugar syrup	Input	Yearly	0.26	kg
	Medicine (Oxalic acid 3.2%)		Yearly	0.44	ml
	New frames	Input	Yearly	4.6×10^{-2}	dm^3
	Queen	Input	-	1.46×10^{-4}	pcs
	Pollination	Output	Yearly	3.3	kg
Extraction	Smoker	Input	7.6	3.4×10^{-4}	kg
	Extractor	Input	15	1.9×10^{-3}	kg
	Electricity	Input	-	3.73×10^{-3}	kwh
	Water	Input	Yearly	0.73	litre
	Extracted honey	Output	-	0.50	kg
Packaging	Glass	Input	-	220	g
	Metal	Input	-	14	g

3.1.1 Beehive construction and frames

The type of beehive and material used for construction were selected based on the survey responses. A low normal (*låg normal*) hive was chosen since this was the most common answer among the respondents. Within the low-normal category, the Nacka model was used as the representative hive model, since the supplier stated that this was their most sold model within this category (Lpsbiodling n.d.c). The assumed number of boxes per hive was set to 3. In addition to the boxes the calculation also included a lid and a bottom. To calculate the amount of material used for each hive, information was retrieved from the supplier (Lpsbiodling n.d.a; (Lpsbiodling n.d.a; n.d.d; n.d.e). To ensure correct density of the hive material the purchasing manager was consulted via email communication (Pettersson 2026). The estimated lifetime for one hive was assumed to be 15 years. The supplier states a lifetime of 30 years when painted (Lpsbiodling n.d.c). For respondents the highest possible answer was "more than 10 years" and was the answer of the majority. Some respondents still stated a lifetime between 7-10 years hence the lifetime of 15 years.

All respondents state the use of paint for hive construction in the survey. The amount needed for one hive was estimated on a supplier of beehive paint (Biredskapsfabriken n.d.a). The paint used for beekeeping was not available in any of the included databases, therefore an available paint process was used as a proxy (see appendix 1). The lifetime was assumed to be the same as for beehives (15 years) with no repainting needed.

When constructing a beehive, frames are used. The number of frames used within each hive were established from the survey. The frames are replaced more often than the beehive. The lifetime for frames was calculated based on the yearly replacement rate of 24% (average for all respondents). The material was assumed to be pine wood (Biredskapsfabriken n.d.b). The standard dimensions for frames used in the low normal hives was used to calculate the size (Lillabi n.d.).

3.1.2 Maintenance

For the beekeeping suit the weight and material was received from the retailer (Lpsbiodling n.d.b). The lifetime was set to 3.4 years based on survey results. For the polyester in the suit, nonwoven polyester was used as a proxy.

Approximately 70% of the respondents stated the use of gloves and the most common lifetime was 1 year. To calculate the weight measurements from the retailer was used. Data for type of material was also retrieved from the retailer (Lpsbiodling n.d.f). The included database did not include the material, and a proxy of synthetic rubber was used instead (see Appendix 1).

The use of a handheld strimmer and the time used to maintain grass was reported through the survey. To use the answers from the survey in SimaPro the time had to be to be converted to square meters (canberradiamondblade 2022). A lawn mower processes was the closest available process to the handheld strimmer and therefore used as a proxy.

Annual treatment with oxalic acid was used among all respondents. To model the treatment in SimaPro, a recipe of sugar, water and oxalic acid were modelled using a total of 30 ml mixed substance per hive (Van den brink 2021).

Data from the survey shows that the used feed is sugar syrup, protein supplement, and sugar candy. The amount of all types of feed was established from the survey. For syrup the most common answer was to use sugar from beet. According to Mattson (2009) the syrup is made of two parts of water and three parts of sugar. The recipe was then modelled in SimaPro. Only 3 respondents stated the type of protein supplement, all different brands hence one was randomly picked. For the protein supplement a proxy was used. According to Mattson (2009) bees normally use protein obtained from pollen. The proxy was a protein made from sugar since no process on pollen was available in used databases. For the sugar candy apifonda was the most common brand. To model the sugar candy, it was assumed to be pure sugar from beet.

The rearing of queens included one frame with food: each frame was assumed to hold 20 queen cells (Mattson 2009). The yearly input of approximately 3 queens per year was estimated based on the survey.

The distance between homes and beehives varied widely among the respondents. The chosen vehicles varied with distances. Thus, an average value was calculated and the vehicle reported by most respondents used. The modelled vehicle in SimaPro was a passenger car fuelled by diesel.

3.1.3 Extraction and packaging

A smoker used in beekeeping consist mainly of stainless steel. No weight was available for the smoker hence the measurements from the manufacture was used (Lindhagens Biredskap n.d.b). To calculate the final mass the density of stainless steel was used. The average lifetime was retrieved from the survey. The fuel for the smoker was excluded due to limited data on use and quantity.

The extraction process contained data of water use from the survey. Remaining data on material, electricity use and size was retrieved from the supplier (Lindhagens Biredskap n.d.a). An assumption was made for the lifetime considering the durability of the product and was set to 15 years. It was also assumed that there was no loss of honey from the extraction process to the finished packaging.

The selected packaging was made to match the functional unit and hold 500 grams of honey. The selection of a glass jar and metal lid were retrieved from the survey. Masses for the materials were retrieved from the manufactures (apromera n.d.; etivera n.d.).

4. Results

4.1 Impacts for Honey without pollination

The total environmental impact for the **Honey$_{\text{baseline}}$** scenario was 0.66 kg CO_2-eq per functional unit (500 g honey ready for distribution). For land use the total impact was roughly 0.28 m²a crop eq per FU. The maintenance stage accounted for the largest contribution in GWP and land use. Packaging was the second largest for GWP followed construction and lastly extraction. For land use the second largest was construction followed by packaging and extraction. The extraction process contributed only marginally to GWP and land use (Figure 2 & Table 2).

Within the maintenance stage, feed was the largest contributor for GWP followed by transport. For land use the feed was largest contributor followed by new frames. Other inputs contributed with less than 10^{-2} CO_2-eq or 10^{-2} m²a crop eq (Table 3). Supporting results are available in Appendix 2 in the form of flow diagrams from SimaPro.

Table 2: The environmental impacts of global warming potential and land use for Honey$_{baseline}$, presented for each lifecycle stage per functional unit.

Life cycle stage	Global warming potential (kg CO_2-eq/FU)	Land use (m²a crop eq/FU)
Construction	3.6×10^{-2}	7.3×10^{-2}
Maintenance	3.4×10^{-1}	1.9×10^{-1}
Extraction	1.2×10^{-2}	5.3×10^{-4}
Packaging	2.8×10^{-1}	1.9×10^{-2}
Total	**0.66**	**0.28**

Table 3: The environmental impacts of global warming potential and land use within the maintenance stage for Honey$_{baseline}$, presented per functional unit.

Maintenance	Global warming potential (kg CO_2-eq/FU)	Land use (m²a crop eq/FU)
Feed	0.19	0.15
Transport	0.13	< 0.01
New frames	< 0.01	3.4×10^{-2}
Other inputs	< 0.01	< 0.01

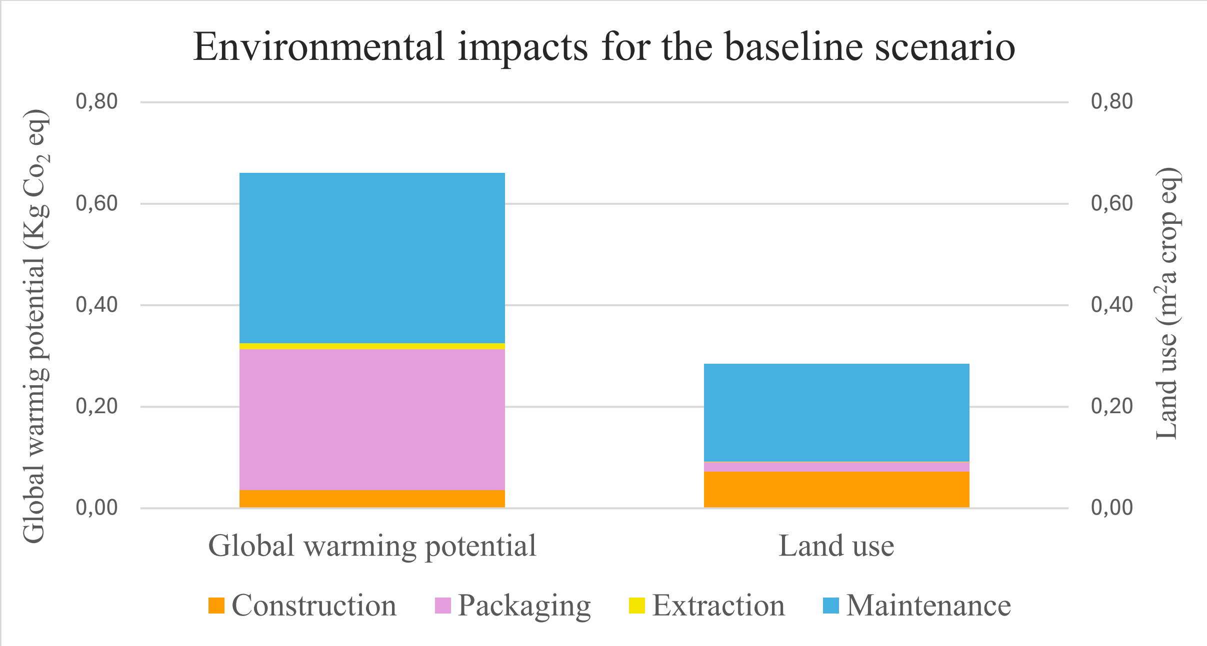

Figure 2: Environmental impacts of global warming potential and land use for Honey$_{baseline}$, presented in stacked bars for each life cycle category per functional unit.

4.2 Impacts for Honey using system expansion

The inclusion of pollination in the **Honey$_{\mathbf{system}}$** scenario resulted in environmental credit from pollination due to the increased yield. The total impact for Honey$_{system}$ were -3.7 kg CO_2-eq for GWP and -11.4 m^{2}a crop eq for land use. (Figure 3) The modelled pollination alone contributed with -4.4 kg CO_2-eq for GWP and -11.6 m^{2}a crop eq for land use (Table 6) Supporting results are available in Appendix 2.

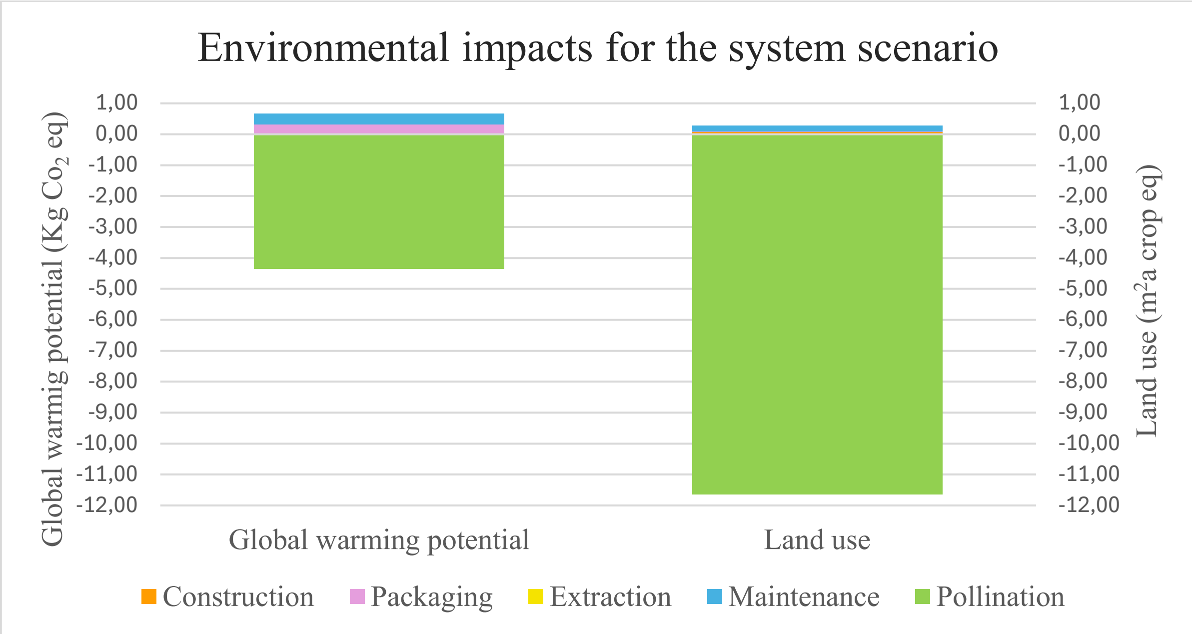

Figure 3: Environmental impacts of global warming potential and land use for Honey$_{system}$, presented in stacked bars for each life cycle category including pollination per functional unit. The negative values are the environmental credit from pollination.

4.3 Impacts for Honey using economic allocation

In the **Honey$_{economic}$** scenario the share for honey is 73% and 27% for pollination. The output of honey generated from 1 hectare of oilseed rape was calculated to approximately 69 kg (Table 4). The allocated result was 0.48 kg CO_2-eq and 0.21 m²a crop eq/ha for honey. The impact assigned to pollination was 0.17 kg CO_2-eq and 0.08 m²a crop eq/ha. (Table 5).

Table 4: Economic shares between honey and pollination showing the total value per hectare in Honey$_{economic}$.

Product	Unit	Quantity (per ha)	Economic value (€)/ ha	Share (%)
Honey	12 €/kg	69 kg	823	73
Pollination	300 €/ha	-	300	27

Table 5: Allocated impact for global warming potential and land use in Honey$_{economic}$ between honey production and pollination services.

Product	Allocated impact GWP (kg CO_2-eq)	Allocated impact Land use (m²a crop eq/ha)
Honey	0.48	0.21
Pollination	0.17	0.08

The 3 different scenarios lead to different results. The largest difference when pollination was included occurred for land use. A relatively large difference was also observed for GWP (Table 6).

Table 6: Comparison of environmental impacts assigned to honey production and pollination services for the 3 different scenarios: $Honey_{baseline}$, $Honey_{system}$, and $Honey_{economic}$.

Scenario	$Honey_{Baseline}$ (kg CO_2-eq)	$Honey_{System}$ (kg CO_2-eq)	$Honey_{Economic}$ (kg CO_2-eq)	$Honey_{Baseline}$ (m²a crop eq/ha)	$Honey_{System}$ (m²a crop eq/ha)	$Honey_{Economic}$ (m²a crop eq/ha)
Honey	0.66	0.66	0.48	0.28	0.28	0.21
Pollination	-	-4.35	0.17	-	-11.64	0.08

4.4 Sensitivity analysis

The results from the sensitivity analysis on changes in yield for oilseed rape demonstrated that the environmental impacts of yield changes were greater than the emission from honey when pollination is excluded. A yield increase of approximately 3% led to an environmental credit of 0.95 kg CO_2-eq and 2.5 m²a crop eq/ha (Table 7).

Table 7: The increased yield expressed in kg and converted to functional unit showing the impact of pollination for GWP and land use depending on assumptions for yield.

Increased yield(kg) /ha	yield (kg) /FU	Global warming potential (kg CO_2-eq) / FU	Land use (m²a crop eq/ha) / FU
350 (8%)	2.55	-3.40	-9.1
448 (11%)	3.26	-4.35	-11.6
550 (13%)	4.01	-5.35	-14.3

5. Discussion

5.1 The Swedish system

This study is one of the first LCAs on Swedish honey ready for distribution using primary Life cycle inventory data from Swedish beekeepers. The study, therefore, gives an important first indication on potential hotspots within the Swedish beekeeping system. The results suggest that the environmental impacts for GWP mainly come from maintenance including transport and feed. Construction and extraction had the lowest impact (Table 2). The results support that yearly inputs or items with a short lifetime will generally have the largest impact for GWP. For land use the lifetime of a product did not affect the results. Instead, the highest impact occurred from wood material in frames and feed based on sugar. To validate the results of the baseline scenario ($Honey_{baseline}$), they were compared with Northern region GWP results from Nguyen (2025). The result aligns well with this study, only differentiating 0.4 kg CO_2-eq. To lower the impact from Swedish beekeeping it is relevant to review the amount of feed given to the bees, due to the large impact in both environmental impact categories. Moreover, this could be a difficult category to change since it is important that honeybees have enough feed (Mattson 2009). For GWP the packaging materials contribute substantially therefore have a potential to lower the impact with changed material choices. An earlier study by Nguyen (2025) also supports the high impact from glass packaging.

5.2 System expansion to model pollination services

When pollination was included through system expansion, the environmental credit from pollination was greater than the environmental impact from honey production (Figure 3). When negative values occur, it is essential to do the interpretation with caution (Matthews et al. 2014), hence the conclusion on claiming honey production to be climate positive should be done with caution. Rather, the negative result shows that the avoided environmental burden from increased crop yield exceeded the impacts from hive construction, maintenance, extraction and packaging within this specific system expansion scenario.

The modelling of pollination service for the $Honey_{system}$ scenario is based on Lindström et al. (2016). In their study the results report a trend, and the study did not fully reach significant results (P-value of 0.07). Ouvrard and Jacquemart (2019) also illustrated that pollinator dependency in oilseed rape can differ. This is important to consider as it influences the results in this study. Thus, a sensitivity analysis was performed on assumed yield for the $Honey_{system}$ scenario. The sensitivity analysis showed that the environmental impact credits from pollination changed drastically with the assumed yield increase (Table 7). The difference in environmental impact between the tested yield values was greater than the total climate impact of honey production without pollination ($Honey_{baseline}$). This indicates that the $Honey_{system}$ result is strongly dependent on the assumed relationship between honeybee pollination and crop yield.

Another uncertainty in $\text{Honey}_{\text{system}}$ is the link between the functional unit and the pollination service. To connect pollination with the functional unit an assumption was necessary on the honey maintained per hive from pollination oilseed rape field. A strength in this study is the correlation of that it is certain that 2 hives were added to each hectare in the study by Lindström et al. (2016). Nonetheless, the conversions are based on research-derived values and should be taken into consideration.

5.3 Economic allocation to model pollination services

In the $\text{Honey}_{\text{economic}}$ scenario economic allocation was used. 73% of the impact was assigned to honey and 27% to pollination (Table 4). The economic value was based on selling price for honey and market value of selling pollination services. Since most of the impact is still assigned to honey the results are relatively close to the baseline scenario where pollination is excluded. In Nguyen (2025) economic allocation was also performed using selling price and market value. In their study the pollination received a smaller impact than this study, assigning approximately 12% to pollination. In Arzoumanidis et al. (2021) (scenario B_m) pollination also got a smaller share than this study used and 16% was allocated to pollination. Ultimately, this study assigns a larger share of the environmental burden to pollination than previous studies with the same method or similar methods. When the dependence ratio is used for pollination in Arzoumanidis et al. (2019) together with selling price of honey the impact assigned to pollination was 41%. In Arzoumanidis et al. (2021) using dependence ratio method and selling price, pollination got 62%. When comparing the present results with previous studies, it confirmed that the economic definition of pollination strongly affects the result. This suggest that it is possible that the full agricultural value from pollination is not captured by market values for the service provided by the beekeepers, in the same way is covered by the dependence ratio method that accounts for how dependent a crop is on pollination. This highlights that the economic allocation approach for pollination services depends strongly on crop price assumptions and method used to assigning the value.

In this study the crop connected to the pollination payment was unknown and estimated to 300 €/ha. With an estimate price of 5 SEK/kg for oilseed rape (Wahlberg 2025), a pollination service market value of 300 €/ha, and a yield increase of 11%, the end result would be a net loss. It is therefore unlikely that the payment came from oilseed rape even though it was used to model $\text{Honey}_{\text{system}}$. During the last 4 years oilseed rape has drastically dropped from 7 SEK/kg to 5 SEK/kg. This demonstrates the uncertainty in using economic values for crops due to their instability and quick changes.

5.4 Inclusion of pollination

The study aimed to investigate the effect on inclusion of pollination to the Swedish apicultural system. The results change considerably depending on the chosen scenario. The results from the $Honey_{system}$ scenario stood out the most since the environmental credit from pollination was larger than the direct burdens from honey production. Assumptions on crop types, hives per hectare, honey production per hectare etc. must be made to be able to include the pollination either through economic allocation or system expansion. Based on this and other studies (Arzoumanidis et al. 2019; 2021; Nguyen 2025) these assumptions influence the size of pollinations impact. Pollination is still an important function from the apicultural system and gives a large credit that should not be neglected. Ultimately, pollination is relevant to include in LCAs of apicultural systems, but the results should be interpreted in relation to the specific scenario and assumptions used.

5.4.1 Comparing methods

When using economic allocation pollination can only receive a share of the impact. The method does not show the environmental benefit created by increased crop yield. This is important for land use, since increased yield can reduce the land area needed to produce the same amount of crop. The avoided land use will therefore not be noticed when economic allocation is used. System expansion, on the other hand, includes the avoided environmental burden associated with the additional crop yield from pollination. This makes it possible to show the potential benefit of pollination. The issue with the method is that the result becomes strongly dependent on assumptions.

5.5 Limitation and future outlook

This study is one of the first LCAs of honey produced in Sweden using primary life cycle inventory data from Swedish beekeepers. The use of survey data improved the relevance of the model and provides an important contribution to the understanding of environmental impacts from Swedish honey production. The study also demonstrates that the inclusion of pollination services substantially changes the results. Since this is a relatively unexplored field and a multifunctional system, several assumptions had to be done, and the use of proxies were necessary to complete the inventory and should be considered when interpreting the results.

Honeybees normally obtain protein from pollen (Mattson 2009) and the proxy used in this study was based on protein made from sugar. The protein feed only had a small contribution to the system and should therefore not have interfered too much with the results. Other proxies were for example, synthetic rubber instead of nitrile rubber, a lawn mower process instead of a strimmer, alternative textile processes for the beekeeping suit. All the proxies were necessary to complete the inventory, but they may not fully represent products used within the agricultural system.

Transport is one output where the answers from the survey varied widely and contributed to 20% of GWP when using the average value. The high variability means that the impact could be much lower or higher depending on the distance each beekeeper has to their apiary.

Equipment lifetime is another uncertain parameter since it may variate depending on use. A strength of this study is that most lifetimes were based on survey responses rather than claims from manufactures. For answers that were not only based on survey answer a relatively low estimation was set. However, they still had a low contribution to the system. Ultimately the beehive and extractor are likely to have a lower impact than presented in the study.

For future analyses the relationship between increased crop yield from honeybee pollination should be investigated further to better understand and quantify the effects. The assumption of the crop and its dependency on pollination is likely to influence the result when implementing system expansion for the honey system. Future studies should therefore investigate multiple crops and the correlation of hive density needed. To decrease the sensitivity to outliers and individual responses in survey data, a larger number of respondents would be fundamental to ensure reliable results.

5.6 Conclusions

The study demonstrates that the inclusion of pollination substantially influences the environmental assessment of apicultural systems. In particular, the results show that different multifunctionality approaches can lead to fundamentally different interpretations of the environmental role of honey production and pollination services.

Economic allocation only divided the existing environmental burdens between honey and pollination and therefore received a less extreme result. The results of $Honey_{economic}$ became dependent on how honey and pollination are valued economically. System expansion had a larger effect since it included the avoided burden from increased oilseed rape yield. Thus, these results became highly dependent on crop choices. If pollination is excluded, the study only illustrates the environmental burden of honey production. Since pollination is an important ecosystem service excluding it completely would give an incomplete picture of the apicultural system. At the same time, the inclusion of pollination must be done carefully to avoid overestimating its benefit in system expansion or underestimating it in economic allocation.

Ultimately, pollination should be included in LCAs of apicultural systems. To do so, system expansion is more suitable for showing the potential environmental impact honey production has to the environment. It is important to remember that no method is neutral and relies on assumptions made for each scenario. The results should therefore be interpreted as specific to each scenario rather than generally valid for all honey production.

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Appendix 1

Table 1A: list of all inputs/outputs within the modelled system

Database	Name	Unit	Waste type	Type	Category
Ecoinvent 3 - allocation, cut-off by classification - system	Alkyd paint, white, without solvent, in 60% solution state {RER}| market for alkyd paint, white, without solvent, in 60% solution state | Cut-off, S	kg	Paint	Material	Construction\Paints\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Packaging glass, white {GLO}| market for packaging glass, white | Cut-off, S	kg	Glass	Material	Glass\Packaging\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Oxalic acid {GLO}| market for oxalic acid | Cut-off, S	kg		Material	Chemicals\Acids (organic)\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Tap water {Europe without Switzerland}| market for tap water | Cut-off, S	kg		Material	Water\Drinking water\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Textile, woven cotton {GLO}| market for textile, woven cotton | Cut-off, S	kg	Textile	Material	Textiles\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Textile, nonwoven polyester {GLO}| market for textile, nonwoven polyester | Cut-off, S	kg	Textile	Material	Textiles\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Synthetic rubber {GLO}| market for synthetic rubber | Cut-off, S	kg	Rubber	Material	Plastics\Rubbers\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Protein feed, 100% crude {GLO}| molasses, from sugar beet, to generic market for energy feed | Cut-off, S	kg	Compost	Material	Agricultural\Animal feed\Market

Ecoinvent 3 - allocation, cut-off by classification - system	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, S	kg	Steel	Material	Metals\Ferro\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Transport, passenger, car, diesel, medium size, EURO 5 {GLO}| market for transport, passenger, car, diesel, medium size, EURO 5 | Cut-off, S	m		Transport	Road\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Mowing, by motor mower {GLO}| market for mowing, by motor mower | Cut-off, S	m2		Behandlar	Agricultural\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Sawnwood, lath, softwood, dried (u=10%), planed {Europe without Switzerland}| market for sawnwood, lath, softwood, dried (u=10%), planed | Cut-off, S	m3		Material	Wood\Products\Market
Ecoinvent 3 - allocation, cut-off by classification - system	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S	MJ		Energi	Electricity country mix\Low voltage\Market
Agri-footprint - economic - system	Sugar, from sugar beet, market mix, at regional storage {NL} Economic, S	kg	Compost	Material	Food\Sugar\Market
Agri-footprint - economic - system	Rapeseed, at farm {SE} Economic, S	kg	Compost	Material	Agricultural\Plant production\Oil-bearing crops
Industry data 2.0	Expandable polystyrene (EPS), white and grey/EU-27	kg	PS	Material	Plastics\Thermoplasts
Industry data 2.0	Steel tinplated {RER} | blast furnace route | production mix, at plant | 1kg, typical thickness between 0.13 - 0.49 mm. typical width between 600 - 1100 mm | LCI result	kg	Steel	Material	Metals\Ferro

Appendix 2

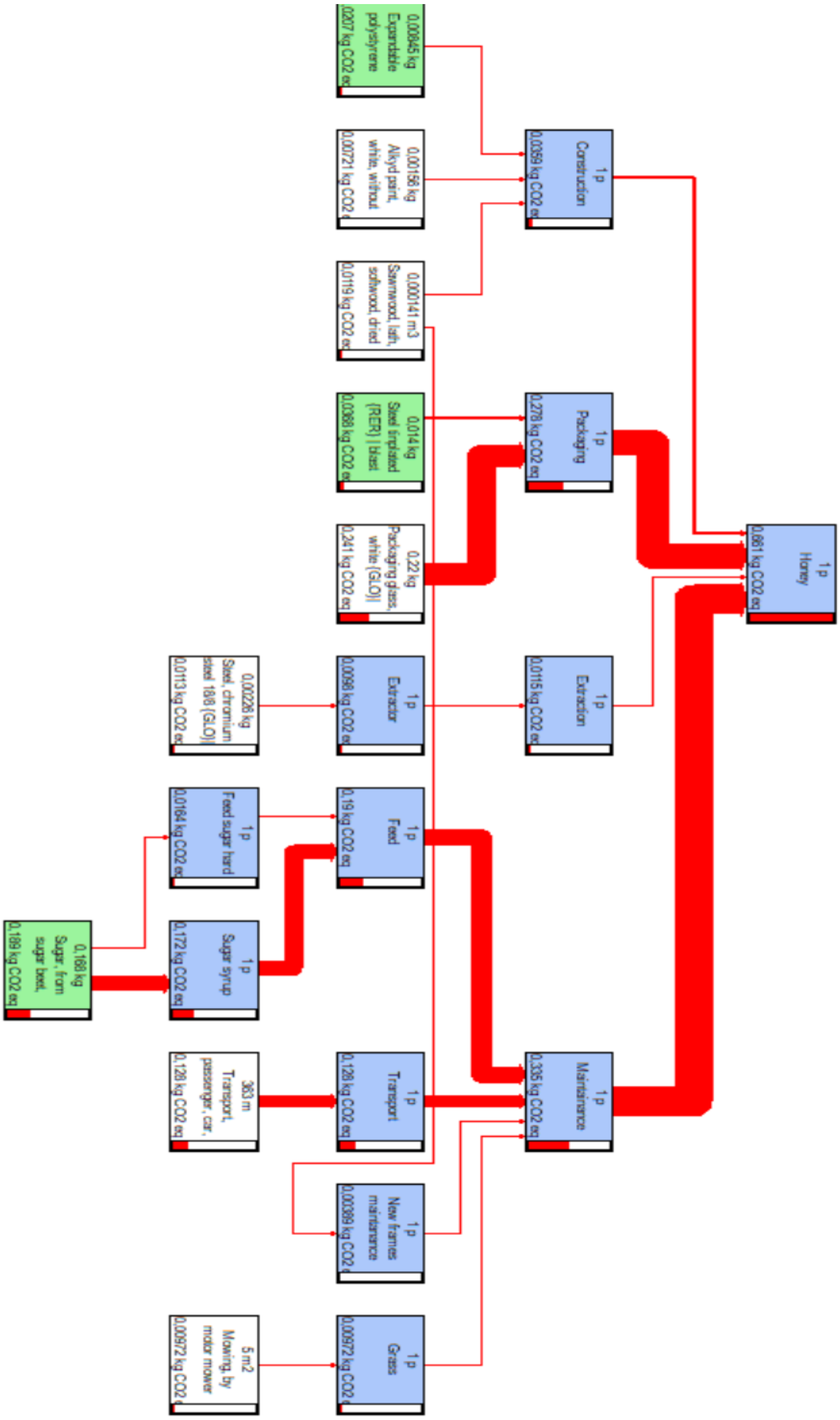

Figure 1A: SimaPro network simulation diagram for Honey$_{baseline}$. The diagram includes processes contributing over 0.5% to GWP, expressed per functional unit in kg CO_2-eq.

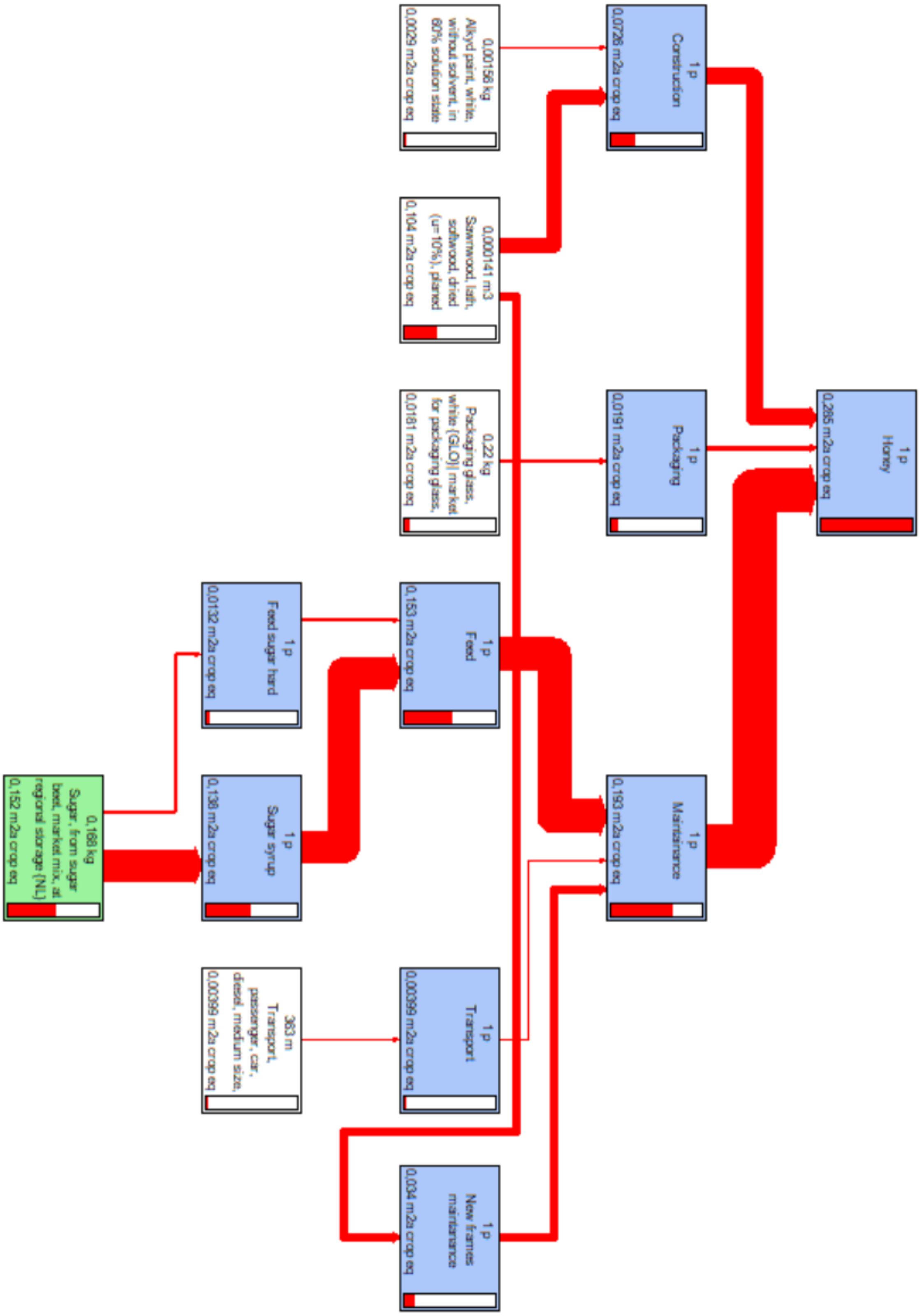

Figure 2A: SimaPro network simulation diagram for Honey$_{baseline}$. The diagram includes processes contributing over 0.5% to land use, expressed per functional unit in m²a crop eq.

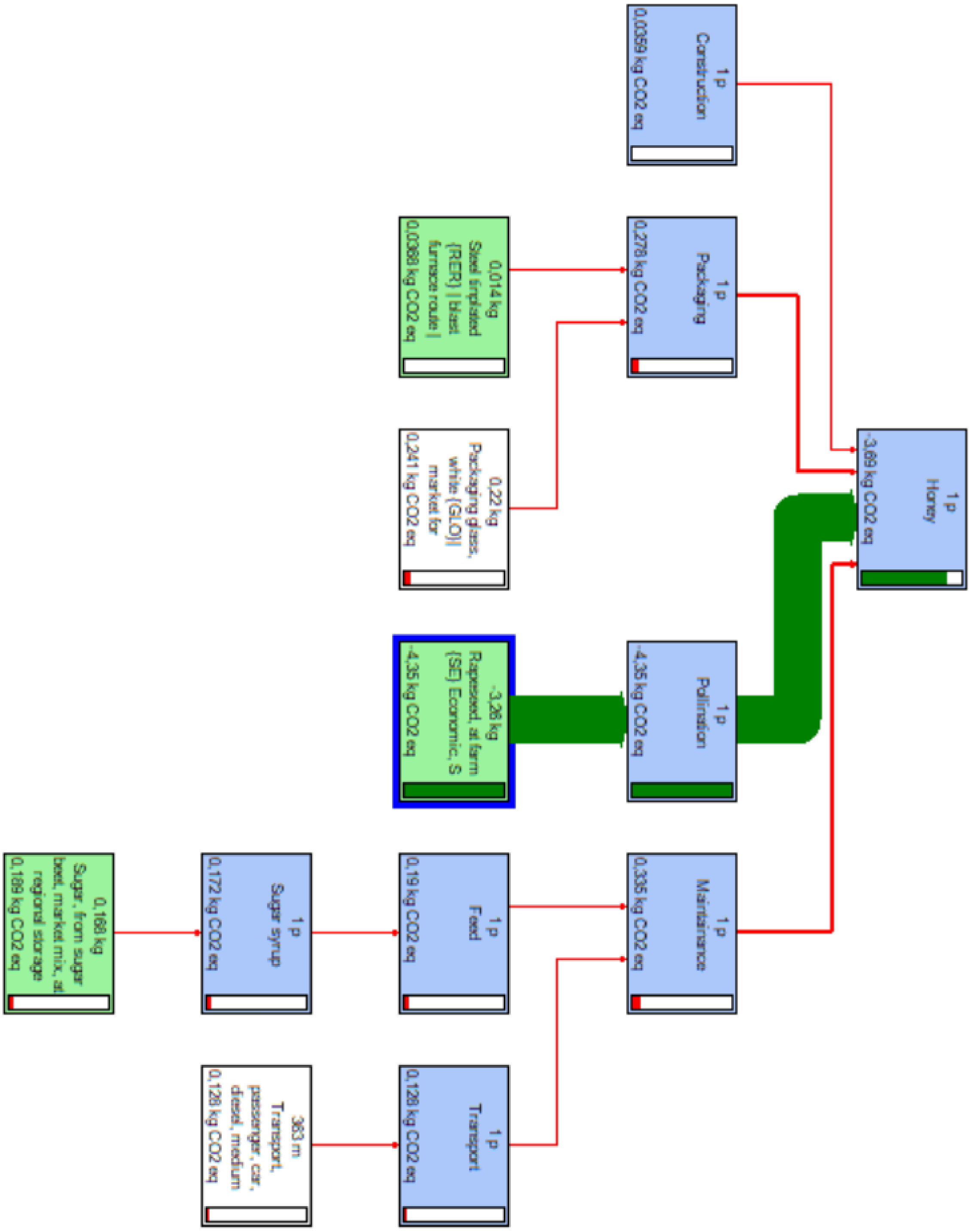

Figure 3A: SimaPro network simulation diagram for Honey$_{system}$. The diagram includes processes contributing over 0.5% to GWP, expressed per functional unit in kg CO_2-eq.

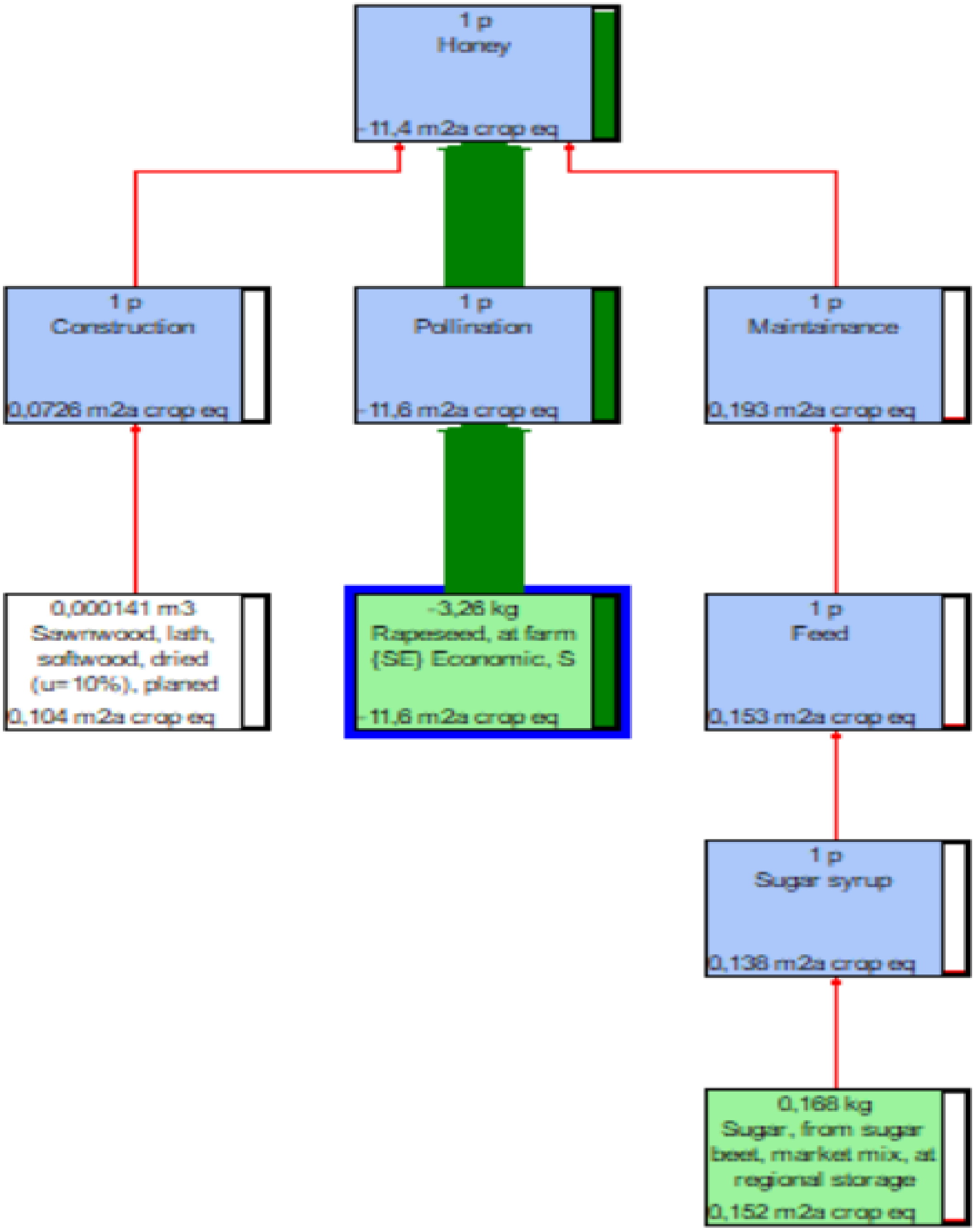

Figure 4A: SimaPro network simulation diagram for Honey$_{system}$. The diagram includes processes contributing over 0.5% to land use, expressed per functional unit in m²a crop eq.

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