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Evaluation of the Pollination Ecosystem Service of the Honey Bee (*Apis mellifera*) Based on a Beekeeping Model in Hungary

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Abstract: Apiaries must be ecologically and economically sustainable to provide pollination as a unique ecosystem service. Pollination as an ecosystem service is economically, socially, and environmentally irreplaceable. Therefore, it is essential to improve the profitability of beekeeping activities, which are mainly carried out in rural areas. With this in mind, the main objective of this article is to assess pollination as one of the ecosystem services provided by bees, based on the specificities of Hungarian honey production. The authors' analysis is based on a Hungarian apiary with 300 colonies active in migratory beekeeping. The model farm produces a wide variety of honey thanks to its migratory beekeeping, visiting several bee pastures during the beekeeping season. This paper presents an approach to quantify the ecosystem services provided by honey bees (*Apis mellifera*) using two economic valuation methods (productivity change and surrogate market goods) belonging to the family of cost-based valuation. The results of the monetary valuation of the ecosystem services provided by bees can provide a starting point for further research to help decision-makers and farmers to calculate a fair "pollination fee" for beekeepers, which will significantly help beekeepers to maintain beekeeping, an important and beneficial activity for all of us.

Keywords: honey bees; ecosystem services; productivity changed method; replacement goods/services method; sustainability

Citation: Feketéné Ferenczi, A.; Szűcs, I.; Bauerné Gáthy, A. Evaluation of the Pollination Ecosystem Service of the Honey Bee (*Apis mellifera*) Based on a Beekeeping Model in Hungary. *Sustainability* **2023**, *15*, 9906. https://doi.org/10.3390/su15139906

Academic Editor: Lucia Rocchi

Received: 28 April 2023
Revised: 16 June 2023
Accepted: 19 June 2023
Published: 21 June 2023

1. Introduction

1.1. Role of Pollinators

Most animal pollinators are insects (bees, flies, butterflies, wasps, beetles, and thrips). However, there are also vertebrate pollinators (birds, bats, other mammals, and lizards). Bees are the most important group of pollinators. There are over 20,000 described bee species worldwide, of which about 50 are kept [1]. About 12 species play a significant role in pollinating crops, such as the western honey bee (*Apis mellifera*), the eastern honey bee (*Apis cerana*), some bumble bees, melipona (stingless), and solitary bees [2,3]. Of these, *A. mellifera* is the most commonly kept bee in the world [4]. Honeybees and beekeeping produce many benefits, with three closely interrelated dimensions: environmental, socio-economic, and socio-cultural [5]. The United Nations Food and Agriculture Organization (FAO) estimates that 71 of the 100 species of crops that account for 90% of the world's food production are pollinated mainly by bees [6]. In Europe alone, 84% of the 264 crop species are pollinated by animals, and more than 4000 species of vegetables are known to be pollinated by bees [7]. The honey bee (*A. mellifera*) is the most economically valuable pollinator of large-scale monocultures (e.g., sunflower and rapeseed) worldwide. It may be the most economical method of pollination [8].

In most agricultural areas, pollination is provided by a combination of managed honey bees and wild insects. Many publications have tried to valuate the pollination of honey bees, while fewer studies have attempted to valuate wild pollinators. Although honey bees are widely known as economically valuable pollinators, studies have shown that wild pollinators are often plentiful as bees on crop inflorescences [9]. Wild pollinators found in Hungary include the ground bumblebee (*Bombus terrestris*), the bumblebee (*Bombus pascuorum*), the pit bee (*Andrena*), the artist bee (*Megachile sculpturalis*), and the wall bee (*Osmia cornuta*, *Osmia rufa*) [10]. Crops that depend to some extent on animal pollination account for 70–80% of the world's leading crops [6,11,12]. Pollinator-dependent crops are estimated to be 15–35% of total agricultural yields [6,13]. One cause for concern is that the number of pollinating insects is declining worldwide. They are seriously threatened by pesticide use, intensive agricultural production (land use changes), pathogens, parasites, and climate change. In addition, honey adulteration and low purchase prices are future challenges for beekeepers [14].

Pollination of crops by animal pollinators is an important ecosystem service for which there is currently no generally accepted valuation method [4]. Many socio-ecological analyses have been carried out on this topic [15–17]. Several methods can be applied separately or in parallel to each other for the monetary valuation of natural resources. Only 2% of global food production comes from crops entirely dependent on pollinators. The yield loss due to their scarcity would be around 3–8%, in addition to other impacts on the diversity of agricultural production [18]. Cereals, including wheat, rice, and maize, are either wind pollinated, or their seed production does not require fertilisation [19]. Many other crop species (e.g., apple, cherry, peach, raspberry, almond, and some coffee species) would not yield well without pollinators. There are also some crop species whose yield or yield quality is significantly improved by pollinators (e.g., rapeseed, sunflower, cotton, soybean, strawberry, pepper, tomato, and grapes). Beekeepers offer the ecosystem services provided by their bees for free as a positive externality. Farmers in some countries hire them to pollinate [20]. There is already a market for pollination services in many countries where beekeepers are paid to make their bees available, for example, in the United States, Canada, Australia, New Zealand, Germany, and Thailand [8]. However, there is typically much less information available on these ecosystem service-based markets than on other agricultural markets.

1.2. Relationship between Pollination and Sustainability Goals

Research by [21] shows that bees can contribute to 15 of the 17 UN sustainable development goals (SDGs) in addition to their role in pollination. Within the ecosystem services provided by bees, pollination contributes significantly to the following eight SDGs: No poverty SDG1—Keeping bees as an income or supplementary income can help livelihoods, especially for rural populations [22–24]. Zero hunger SDG2—Pollinating bees increase yields and enhance the nutritional value of fruits, vegetables, and seeds [6,25–28]. Good health and well-being SDG3—Beekeeping products can also be used for medicinal purposes, and pollination by bees contributes to the maintenance of biodiversity, which directly contributes to, for example, improving air quality [22,29–33]. Affordable and clean energy SDG7—Pollination by bees improves the yield and quality parameters of oilseeds, for example, increasing sunflower and rapeseed biofuel potential [34–36]. Decent work and economic growth SDG8—Improved agricultural production through bee pollination can contribute to gross domestic product (GDP). Beekeeping can diversify livelihoods for men and women in rural areas and support nature-based tourism initiatives [24,37–40]. Responsible consumption and production SDG12—Pollination by bees can help reduce food waste by improving food's visual aesthetics (shape, size, and colour) and increasing shelf life [41,42]. Climate actions SDG13—Environmental use of bees and apiculture products can contribute to a better understanding of the effects of climate change and, as an indicator species, scientists can also monitor the impact on the environment by studying populations [43,44]. Life on land SDG15—Bees contribute to biodiversity by pollinating flowering trees and plants, and beekeeping can contribute to forest conservation [28,45–48].

1.3. Main Characteristics of the Hungarian Beekeeping Sector

(In this study we use the term bee colony. The term hive is also used.) Compared to previous years, the number of bee colonies and apiaries in Hungary has slightly decreased since 2017, but before that, the trend was upwards. The decline in hives has accelerated in recent years, with 46,886 hives in 2017–2019 and 43,236 bee colonies in 2019–2020, according to national beekeeping organisation (OMME—Hungarian Beekeeping Association) data [49] (Figure 1). This means the number of bee colonies decreased by the same amount in one year as in the previous two years. As a result, bee density decreased from an average of 13.44 bee colonies/km^2 in 2017 to 12.5 bee colonies/km^2 in 2020 [49], still the highest by European standards.

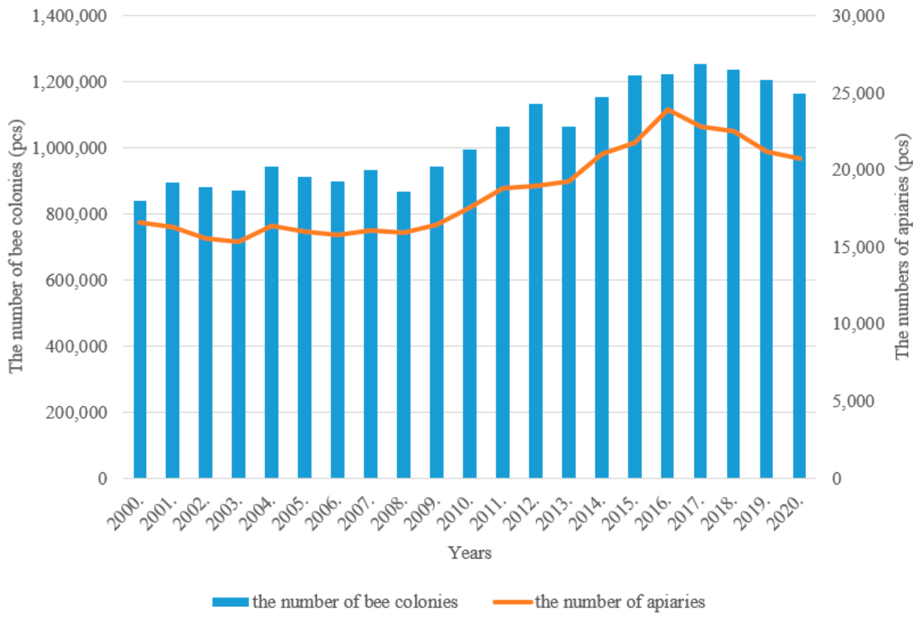

Figure 1. Trends in the number of bee colonies and apiaries in Hungary (2000–2020).

A specific feature of the Hungarian sector is that there are relatively few beekeepers with at least 150 bee colonies. In 2017, 6.8% of beekeepers and 6.82% in 2018 had at least 150 bee colonies, about 30% of the Hungarian bee population [50]. In Hungary, beekeepers typically consider beekeeping a hobby if they have less than 20 hives. Above 20 hives, beekeeping is used as a source of additional income (74.4% of beekeepers in Hungary fall into this category) [51]. In this sector, as in other agricultural sectors, it is essential that the agricultural enterprise managers and beekeepers are highly motivated to engage in honey production.

Moreover, the beekeeper must have a wide range of agro-technological, economic, and marketing knowledge to manage the enterprise. This type of work requires a complex knowledge of different fields [52]. Aiming to attain higher yields, around 70% of beekeepers migrate to different bee pastures [53].

Rural depopulation is one of the biggest problems in developed and developing countries. Furthermore, beekeeping positively contributes to the development of the local economy, as it is one of the labour-intensive sectors that help maintain the population in rural areas. It is essential to retain sectors that offer local employment opportunities for young people [54]. Traditional agricultural sectors' roles and maintenance in rural areas are critical [55].

1.4. The Economic Valuation of Pollination Services

A starting point for the monetary valuation of pollination as a bee ecosystem service was found only in the international literature [3,4,56,57]. The total economic value (TEV) of an ecosystem is the sum of the components of the value element derived from that ecosystem, which can be divided into two main groups: use-related and use-independent values [56] (Table 1). These so-called primary valuation studies are usually costly and time-consuming. Benefit transfer methods have been developed, which, under certain conditions, allow the transfer of information (values) from existing studies [56,58,59].

Table 1. Components of Total Economic Value.

Total Economic Value					
Use Value			Non-Use Value		
Direct use	Indirect use	Option	Altruism	Bequest	Existence

The most commonly used methods to assess the value of pollination services are the production value method, which focuses on the crop production value attributable to pollination, and the substitution value method, which involves estimating the cost of using an alternative technology or organism to achieve the same function. Other methods used to assess economic value include crop price measures, pollinator-managed prices, dependency ratios, partial and general equilibrium models, and stated preferences [4,9,60].

Methods for assessing the effects of pollinators and pollination gains and losses can range from very simple to very complex at several levels. Economic valuation highlights the economic contribution of pollinators to various benefits to the agricultural sector and society. Furthermore, economic valuation can assess the impact of changes in pollinator populations on the economic well-being of different groups of people, such as farmers or consumers [3]. Some methods use "willingness to pay" (WPT) as a measure of the value of goods and services, based on direct statements or any observable information [61–63].

To determine the total economic value (TEV), we used cost-based valuation methods for productivity change and substitute market goods, partly based on the state statistical database and partly on our data collection. Cost-based methods are suitable for identifying values directly related to use, and their use is supported by the fact that a monetary value can be obtained relatively quickly using price information available in the market. The underlying assumption of these methods is that the value of a natural resource and the benefits it provides to people are equal to the costs of conserving/restoring it [64]. Costs can take many forms, for example, a reduction in the level of service provided by a natural asset (e.g., a reduction in bee population due to a lack of pollination, resulting in a reduction in crop yield). In this case, the cost is indicated by a reduction in benefits and productivity. The replacement market goods/services method is based on the idea that the degradation of the natural environment leads to the disappearance or decline of a particular ecosystem service. In this case, the beneficiaries of the ecosystem service have to replace it with other forms (e.g., artificial pollination). The money spent on this replacement is the basis for valuing ecosystem function [64].

This study explores the potential of bee pollination as an ecosystem service through the economic modelling of a large-scale beekeeping operation in Hungary. This paper presents an approach to quantify the ecosystem services provided by honey bees (*Apis mellifera*) using two economic valuation methods (productivity change and surrogate market goods) belonging to the family of cost-based valuation.

2. Materials and Methods

The research includes both primary data collection and secondary data analysis. In addition to processing relevant literature on the subject, we obtained the data used in the analysis from the Hungarian National Beekeeping Programme [50] and the Hungarian Central Statistical Office databases [65–69]. The research results were based on the 2021 HUF/EUR exchange rate (HUF 358.52/EUR) published by the Central Bank of Hungary [70]. The primary research involved personal farm visits to develop the parameters of the sample farm, which involved collecting data and information from two professional bee farms. Using statistical data and the technological characteristics of individual apiaries, personal visits to apiaries, and interviews, an economic model was developed to determine the conditions for honey production in Hungary.

The focus is on the monetary valuation of the ecosystem services bees provide through pollination as a yield and quality enhancer (SDG2) and as a substitute for honey as a product (SDG3). Rapeseed and sunflower are self-pollinating, but pollinating insects are necessary for better yield quality and higher yields [36]. Based on the production conditions of the model farm and the honey varieties produced, the case of rapeseed (*Brassica napus* L.) and sunflower (*Helianthus annuus* L.) pollinated by insects was investigated. Hungary's most important arable crops (such as sunflower and rape) are concentrated in the Great Plain [65]. The economic importance of pollination of these crops is mainly regional. No sources or calculations were found in the Hungarian literature. According to the literature, 2–4 bee colonies [71] or 3 bee colonies [72] are needed for one hectare of sunflower, while rapeseed requires 1.5–3 bee colonies [73,74]. Based on discussions with our interviewees, considering the factors in Hungary (e.g., the state of the soil, climatic conditions, sunshine duration, precipitation amount), an optimum bee density of 3 hives/ha was defined. Using a value of 3 bee colonies per hectare for the model farm under study, we based our calculation on the pollination of 100 hectares of sunflower and rape crops by 300 bee colonies. Note that when deploying, it should be considered that the flight radius of the bee colonies should be within 2.5 km of the bee pasture [73], with no other migratory apiaries in the vicinity in the direction of the bee colonies, and, of course, with the land owner's consent.

As pollinating insect populations have declined significantly worldwide, the presence of beekeepers and their bees in the vicinity of rapeseed or sunflower fields is significant. Among the pollinating insects, the visitation of honey bees is the most intense in rapeseed and sunflower. However, other insect species are also present [36,75–78].

2.1. Technological Characteristics of the 300 Bee Colonies Modelled Farm

Based on the economic analysis, a model beekeeping farm is presented based on the average production indicators in Hungary. The farm is larger than the average one in Hungary relying solely on honey production. The model described in this study reflects Hungary's honey production and beekeeping environment. It provides a starting point for the size of the bee population needed to pollinate the crops produced in the defined area under study. For example, a study [79] used data from secondary sources to estimate mathematically the maximum capacity of honey bees to meet optimal pollination service demand. Another study [80] estimated the economic value attributed to insect pollination based on modified formulas from previous research [81]. Based on the specific yields of migrating colonies (rapeseed honey 10 kg/bee colony; acacia honey 21 kg/bee colony; mixed flower honey 10 kg/bee colony; sunflower honey 19 kg/bee colony), the annual honey production is 18,000 kg. A good bee colony is essential for honey production, and natural stands of plants with large surface areas, many flowers, and cultivated crops are essential.

Of the honey-producing forest trees in Hungary, the acacia occupies the most prominent area (about 455,000 hectares according to 2019 data [66]. It provides the primary source of honey for beekeepers. In addition to the quality of the bee colonies, the role of the weather is also decisive, influencing the regular foraging work of bees and the nectar production of honey plants [51]. Rapeseed and sunflower are Hungary's most essential bee pastures among cultivated crops.

Beekeepers mostly purchase queen bees from Hungarian bee breeders. This serves to preserve the genes of the native Pannonian bee, which has excellent production and behavioural traits suitable for exploiting Hungarian bee pastures [82]. After the acacia harvest, bee colonies carry pollen and nectar from wildflowers and other floodplain flowers. During the intervening few weeks, oxalic acid can be used to control *Varroa destructor* infestation under constant control. Removing the male brood is also a method to isolate *Varroa destructor* infections.

Before bees visit sunflowers, the queen bees should be rechecked and, if necessary, replaced. Depending on external factors (weather, crop protection), migration to early- and late-flowering sunflowers may occur. At this time, honey is no longer taken from bee colonies, as late summer and autumn flowering usually does not produce nectar.

Control of *Varroa destructor* with the persistent carrier can be started and removed in the first days of November. At the end of the month, depending on the weather, the final treatment is either oxalic acid soaking or sublimation. Considering the weather forecast, winter blankets should be applied as late as possible to prevent further oviposition.

2.2. Monetary Valuation of the Ecosystem Services Provided by Honey Bees

Due to the specificity of the sector under study, we used cost-based economic valuation methods to quantify the ecosystem services provided by honey bees (*Apis mellifera*) within the activities of the model farm. Another possibility of cost-based monetary valuation methods is the replacement goods/services method, which also gives a relatively underestimated value. Many comprehensive studies have been carried out to quantify the dependence of essential crops on animal pollination. Their review shows that sunflower and rapeseed are moderately dependent, with yield increases over a wide range (Table 2).

Table 2. Effect of pollination on yield.

Yield Increase of Sunflower (*Helianthus annuus* L.)	Yield Increase of Rapeseed (*Brassica napus* L.)	Reference
10–30%	-	[83]
28%	-	[84]
26%	-	[85]
30–40%	-	[86]
10–40%	10–40%	[6]
-	50%	[87]
-	10.6%	[88]
-	46%	[89]
-	18%	[75]
40%	-	[78]
-	29–37.5%	[36]
-	20%	[77]
-	30%	[90]
27–34%	10–15%	[91]

Variation in values may be due to the study methods, pollinator composition (diversity, density), numbers, and dependence on animal pollinators, which may vary between plant species and regions [77]. The most crucial pollinating insect in the studies reviewed was the honey bee (*Apis mellifera*). It should be noted that honey bee visitation is significant when the plants are honey-producing, i.e., providing good nectar and pollen. The benefits of pollination on crop yields are also influenced by soil fertility (plant condition), i.e., insect pollination was found to increase crop yields when the soil was more fertile [92].

3. Results and Discussion

3.1. The Productivity Change Method

Of the monetary valuation options for ecosystem services, the first cost-based method we used in our calculations represented the productivity change method. The starting point of the method was to treat the bee population (in terms of pollination function) as an input to the production activity (in this case, crop production). To valuate the pollination function of the bee population (natural capital) in the production activity under consideration (the quantity of sunflower and rapeseed harvested), we calculated the extent to which the benefits of the natural capital are reduced if the pollination function of the bee population is impaired or eliminated by an external effect.

The monetary value of the surplus yield of insect pollination in the modelled farm using the productivity change method was determined as follows:

Average yield per hectare (in kg) × purchase price (kg/EUR) × 100 ha (modelled farm size) × yield share (%).

Consequently, the productivity and quality of both arable crops will be reduced. In a broader sense, it will lead to a loss of benefits for society (lower yields and deterioration of quality parameters are expected). In 2021, Hungary's total sunflower seed yield was 1,698,000 tons [67], and the area sown was 663,491 hectares [65]. The area sown to rapeseed in 2021 was 261,266 hectares [65], and the yield was 722,000 tons [67]. The average yield per hectare in 2021 was 2.56 tons for sunflower and 2.76 tons for rapeseed in Hungary.

The purchase price of sunflowers increased in 2021, in line with international trends, despite the higher harvest, and was 45% higher than in the previous year at 0.491 EUR/KG [68]. Given the current uncertain economic situation, we incorporated a +20% increase in the purchase price in our calculations, with 5% increments (thus, we started from the 2021 price of 0.491 EUR/kg and worked up to 0.589 EUR/kg). We also considered ecosystem services on a scale of 5% for the proportion of yield attributable to pollination. The increase in the yield share was calculated from 10% to +40%, as published in the literature. Most of the literature estimates the yield to be 30–40% due to the pollination activity of the bees. Considering the purchase prices in 2021, the 300 bee colonies of our model farm are worth between EUR 37,700–50,270 for sunflowers, contributing to the result. In other words, if pollination were not carried out, the change in productivity would be reflected in this value, and such a loss would be incurred in economic terms. The findings by Kamler [85] confirm our results that colonies foraging on sunflowers resulted in increased honey production and better colony development in the following year. Based on the results in Table 2, we set the yield increase of sunflowers in our model at 30–40%. Previous studies reported that pollination services provided by different honey bee species for sunflowers significantly increased seed size [78,93]. Table 3 shows the monetary value associated with the pollination activity of bees in relation to the different purchase prices and pollination yield shares.

Table 3. The monetary value of the surplus yield of sunflower by insect pollination (yield share in thousand EUR).

	in %	**kg/100 ha**	**Purchase Price of Sunflower (EUR/kg)**				
			0.491	**0.516**	**0.541**	**0.563**	**0.589**
The extra yield of pollination	+10	71	12.57	13.20	13.82	14.45	15.08
	+15	107	18.85	19.79	20.74	21.68	22.62
	+20	143	25.13	26.39	27.65	28.90	30.16
	+25	179	31.42	32.99	34.56	36.13	37.70
	+30	214	37.70	39.59	41.47	43.36	45.24
	+35	250	43.99	46.18	48.39	50.58	52.78
	+40	286	50.27	52.78	55.30	57.81	60.32

The table shows the monetary value calculated due to the yield share due to pollination and the purchase price increase in steps of 5%, from dark grey to light grey.

The average purchase price of rapeseed in January–November 2021 was 0.485 EUR/kg, which was 39% higher [68] than in the same period in 2020 [65]. For rapeseed, we also incorporated a +20% increase in the purchase price in our calculations, with 5% increments (thus, we started from the 2021 price of 0.485 EUR/kg and worked up to 0.583 EUR/kg), taking into account the uncertain economic situation. For the yield share attributable to pollination, we also considered the ecosystem service in steps of 5%, so we calculated the yield share from 10% to +40%, as reported in the literature.

According to most previous studies, although rapeseed is self-pollinating, the pollination activity of bees determines at least 20–40% of the yield (see Table 2), so that, taking into account the purchase prices in 2021, the 300 bee colonies of our model farm contribute between EUR 27,000–54,000 to the yield from 100 ha of rapeseed. If the bees did not pollinate, the productivity change and yield loss would be this large. Table 4 shows the exact monetary value associated with the pollination activity of bees in terms of the different purchase prices and pollination yield shares.

Table 4. The monetary value of the surplus yield of rapeseed by insect pollination (yield share in thousand EUR).

	in %	kg/100 ha	Purchase Price of Rapeseed (EUR/kg)				
			0.485	0.510	0.533	0.558	0.583
Extra yield of pollination	+10	77	13	14	15	15	16
	+15	115	20	21	22	23	24
	+20	154	27	28	29	31	32
	+25	192	33	35	37	39	40
	+30	231	40	42	44	46	48
	+35	269	47	49	52	54	56
	+40	308	54	56	59	62	64

The table shows the monetary value calculated due to the yield share due to pollination and the purchase price increase in steps of 5%, from dark grey to light grey.

Applying the cost-based valuation method for productivity change, we determined the value of pollination as an ecosystem service for our model farm at 50,270 EUR/year for sunflower and 54,000 EUR/year for rapeseed, based on current market prices. Due to the particularities of the method used, the results obtained can be considered a significant underestimate. The calculation does not consider, for example, that pollination results in higher yields for farmers and improved crop quality (e.g., oil content, size).

In their study of the UK, Breeze et al. [79] concluded that the area sown to rapeseed is increasing and will continue to increase due to the growing demand for alternative uses (e.g., biofuels, animal feed). As a result, the proportion of beekeeping areas will also increase. In Hungary, on the other hand, there has been a slight decrease in the area sown to rapeseed [65]. For this reason, the additional yield from pollination is also paramount, as demonstrated by [36,94].

The limitations of the method used are partly due to this. Pollination has various yield-enhancing values based on different sources and methods. In addition, the cost-based valuation method results in only one component of TEV, the direct use value element. Therefore, the result may result in underestimating honey bees' essential pollination services. This valuation is mainly focused on the benefits to farmers. Furthermore, the effects of climatic conditions (e.g., temperature, precipitation) have not been considered.

In order to quantify the proportion of total rapeseed and sunflower yields attributable to insect pollination, a cross-tabulation analysis was carried out based on the yields from 100 ha of rapeseed and sunflower associated with 300 bee colonies on the model farm. In our calculation, we incorporated the yield share attributable to pollination as reported in the literature and its market price in 2021 for both sunflower and rapeseed to express pollination's value in monetary terms.

3.2. Replacement Goods/Services Method

In the case of natural honey, as a product produced by bees, one of the substitutes available on the market that can be used as a sweetener to replace honey for this function is granulated sugar. However, refined granulated sugar does not have the other valuable properties of natural honey (natural origin, rich in vitamins and minerals, properties of different types of honey). It is used in quantities about one-and-a-half times higher than honey. (The high sweetness of honey is due to the fructose content, 7 spoonfuls of fructose sweeten as much as 10 spoonfuls of cane sugar or beet sugar [91]. Thus, the sugar/honey ratio is about 1.5.)

The monetary value of the surplus yield of insect pollination in the modelled farm using the replacement good/services method was determined as follows:

Quantity of honey produced (kg/modelled farm) × average consumer price (granulated sugar EUR/kg).

The annual honey production of our model farm with 300 bee colonies is 18,000 kg, and the average consumer price of granulated sugar in 2021 was 0.669 EUR/kg [69]. A consumer price increase of +20% with 5% steps was also included. We therefore estimate the replacement value at 18,000 EUR/year.

Table 5 shows the replacement value of natural honey for granulated sugar as an alternative for different consumer prices and honey yields. In a study in the USA, where a market for pollination services is already in place, Winfree et al. (2011) [4] showed that the results of their exchange value method ruled out a possible future increase in the cost of hiring honeybees. They identified ongoing bee health problems as the reason for this. We underline that the assumed decline in honey production is also reflected in the loss of income for beekeepers from selling honey.

Table 5. Changes of the replacement value of natural honey based on the modelled farm yield data (replacement value in thousand EUR).

	in %	kg/100 ha	The Average Consumer Price of Sugar (EUR/kg)					
			0.669	0.703	0.736	0.770	0.803	0.837
Honey yield	0	50	18	19	20	21	22	23
	+5	53	19	20	21	22	23	24
	+10	55	20	21	22	23	24	25
	+15	58	21	22	23	24	25	26
	+20	60	22	23	24	25	26	27
	+25	63	23	24	25	26	27	28

The table shows the replacement value calculated due to the increase in honey yield and the average consumer price of sugar in steps of 5% from dark grey to light grey.

The substitution market goods/services approach was also applied to the substitution of bee pollination, with studies showing that artificial pollination results in higher rates of rotten fruit, which ultimately reduces the profitability of producers [95]. Furthermore, in determining the economic value of the ecosystem service provided by honey bee pollination, Popak and Markwith (2019) highlighted that each individual producer prefers pollination by honey bees, which avoids yield losses [96].

4. Conclusions

We have evaluated the ecosystem services provided by the 300 bee colonies' beekeeping-model activity using a cost-based method adapted to Hungary and applied in the present framework to represent the monetised value of the pollination service provided by the bee population. For the valuation of ecosystem services, the monetary value of bee pollination as an ecosystem service in direct use was expressed using the method of productivity change and the replacement goods/services method presented in this study for TEV. In the case of the model farm, the value of insect pollinators as an ecosystem service was determined by the cost-based valuation method of productivity change at 50,270 EUR/100 ha/year for sunflowers and 54,000 EUR/100 ha/year for rapeseed. Another approach, the replacement goods/services method, investigated the possibility of substituting natural honey with granulated sugar as an alternative sweetener. According to our calculations, the replacement value of the honey (18,000 kg) produced by the model farm in one year would be about 18,000 EUR/year under the production conditions outlined. In both cases, due to the specificity of the methods used, these can be considered as significant underestimates, as they do not consider, for example, that pollination not only results in higher yields for farmers but also higher quality (e.g., oil content, size). In addition to the sweet taste of natural honey, it contains many ingredients beneficial to health and the immune system.

Based on the three pillars of sustainability and in line with the UN's sustainability objectives (SDGs), beekeeping is a positive externality for environmental sustainability [5,97]. Beekeeping contributes significantly to pollination and ecological balance, which are essential for agriculture. Beekeepers recycle the beeswax they produce (beeswax sheets) and maintain many tools (hive, spinner, scrubber, storage tools) for long-term use. The main economic objective of honey and other beekeeping production is to provide income and livelihood opportunities for beekeepers (about 20,000 people in Hungary) and generate significant export revenues, as most of the honey is exported abroad, thus playing a role in developing macroeconomic indicators. In addition, providing society with healthy, high-quality food is increasingly essential. All this contributes to strengthening the rural population's capacity to maintain and sustain itself and stabilising family farms based on beekeeping.

Our results can provide a starting point for beekeepers to calculate a fair "pollination fee". As bee density is high in Hungary, farmers are not yet interested in offering beekeepers such a payment. Several studies have already demonstrated that pollination as an ecosystem service is irreplaceable from an economic, social, and environmental point of view (e.g., [21–24]), so, if farmers are not willing, the state could play a role in financing the pollination fee, either directly or indirectly as subsidies. However, the profitability of beekeeping depends mainly on, for example, the weather, the bee health situation (bee diseases, poisoning by chemicals), and the conditions for selling bee products. In addition, input costs for beekeepers are increasing. These circumstances create unpredictability for the continuation of beekeeping activities. In addition, it is worth considering people's willingness to pay, which helps estimate the market value of the surplus for producers and consumers. Further research is needed on the structure of the calculation of the pollination fee (as subsidies or on a market basis), which could be of considerable help to beekeepers in maintaining an activity that is important and beneficial to all.

Author Contributions: Conceptualization, I.S. and A.B.G.; methodology, I.S. and A.B.G.; software, A.F.F.; validation, A.B.G.; formal analysis, A.F.F.; investigation, A.F.F. and A.B.G.; resources, A.F.F.; data curation, A.F.F.; writing—original draft preparation, A.F.F. and A.B.G.; writing—review and editing, A.F.F. and A.B.G.; visualization, A.F.F.; supervision, I.S. and A.B.G.; project administration, A.F.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

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