






## Article

# Direct Economic Impact Assessment of Winter Honeybee Colony Losses in Three European Countries

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**Abstract:** Honeybees are of great importance because of their role in pollination as well as for hive products. The population of managed colonies fluctuates over time, and recent monitoring reports show different levels of colony losses in many regions and countries. The cause of this kind of loss is a combination of various factors, such as the parasitic mite *Varroa destructor*, viruses, pesticides, management practices, climate change, and other stress factors. Having in mind that the economic aspect of honeybee colony losses has not been estimated, a pioneer effort was made for developing a methodology that estimates the economic impact of honeybee colony losses. Winter loss data was based on 2993 answers of the COLOSS standard questionnaire survey of honeybee winter colony losses for 2016/2017. In addition, market and financial data were used for each country. In a comparative analysis, an assessment on the economic impact of colony losses in Austria, Czechia, and Macedonia was made. The estimation considered the value of the colonies and the potential production losses of the lost colonies and of surviving but weak colonies. The direct economic impact of winter honeybee colony losses in 2016/2017 in Austria was estimated to be about 32 Mio €; in Czechia, 21 Mio €; and in Macedonia, 3 Mio €. Economic impact reflects the different value levels in the three countries, national colony populations, and the magnitude of colony losses. This study also suggests that economic losses are much higher than the subsidies, which underlines the economic importance of honeybees for the agricultural sector.

**Keywords:** *Apis mellifera*; economic assessment; methodology; colony losses

## 1. Introduction

Honeybees are economically important managed pollinators for crops and wild plants [1–5]. Though they are not solely responsible for the pollination of cultivated crops, their exact economic contribution to agricultural production is difficult to estimate [6]. Still, losses of honeybee colonies have extensive economic consequences. Next to pollination, the honeybees' economic importance lays in the production of hive products such as honey, pollen, beeswax, propolis, bee venom, and royal jelly. Honeybee colonies, nucs, and packages are important trade products too [7]. Honey is by far the most important product

and is globally traded [8]. In Europe, most beekeepers are backyard or sideline beekeepers producing for the local market, but there are also a few professional beekeeping operations making a regular income from beekeeping and hive products [9,10].

In temperate climates, winter is a critical period for honeybee colonies. With no forage available, a colony relies on food reserves hoarded in the hive for thermoregulation and brood rearing. Though there can be a natural baseline mortality assumed, winter colony losses due to colony mortality or queen failure vary greatly among winters and from region to region. For example, an overall loss rate of 20.9% was recorded in the winter of 2016/2017 according to the COLOSS study conducted in many European and some non-European countries [11]. There are similar reports of loss rates of managed honeybee colonies from other continents [12–17]. The COLOSS survey performed in spring 2017 recorded losses of production colonies of 23.4% in Austria, 15.0% in the Czech Republic, and 22.5% in the Republic of Macedonia [11].

In the European subspecies of the Western honeybee, *Apis mellifera*, the parasitic mite *Varroa destructor* hampers winter survival by reducing the longevity of worker bees [18,19]. By feeding on bee tissues, varroa is also a vector of honeybee viruses [20]. A clear association between mite infestation levels in autumn and honeybee winter colony losses has been demonstrated in Austria by Morawetz et al. [21]. Other factors, such as further pests and pathogens, hive management by beekeepers, loss of forage, and pesticides impact colony health [22–27]. A pan-European epidemiological study demonstrated that honeybee colony survival greatly depends on beekeeper education and disease control [28]. One possible explanation for the variation of colony losses between different winters are the prevailing weather conditions, not only during winter, but also before, that influence growth and development of the honeybee colony, and hence also of the varroa mite population [29].

Honeybee colony losses can be compensated, which results in rather stable or even increasing numbers of colonies managed in certain regions, though decreasing honeybee populations have also been reported [17,30,31]. Such compensations in colony numbers are achieved by beekeepers splitting colonies. Such splitting, in turn, is accompanied by financial expenses. Achieving economically sustainable colony levels and the role of economic factors in the long-term decline of honeybee stocks in the United States has been studied in the Rocky Mountain region by Jones Ritten et al. [32]. In this study, we aim to estimate the direct economic impact of winter honeybee colony losses on the apicultural sector of three European countries, Austria, Czech Republic, and the Republic of Macedonia. While focusing on the costs directly affecting beekeeping, the indirect costs—e.g., through lost pollination of agricultural crops—were not examined in this study, as this was already established for Europe, the United States, and the world [2,33,34]. The honeybee colony numbers of the three countries are in the midfield of the European apicultural sector [10], and the loss rates of winter 2016/2017 [11] were used for analysis.

## 2. Materials and Methods

### 2.1. Data Collection

The data on winter honeybee colony losses were collected by the citizen science crowdsourcing concept in Austria (AT), Czech Republic (CZ), and Republic of Macedonia (MK) in spring 2017. Beekeepers voluntarily participated in this survey coordinated by COLOSS. These standardised annual surveys among beekeepers on colony losses are well-established in all three countries [11,25,30,35–38]. The survey is promoted via various channels, including websites and beekeeping magazines, and is open for every beekeeper, even anonymously. The questionnaire included questions on the number of wintered colonies, colony losses, and weak colonies after winter. In MK, the COLOSS questionnaire was supplemented with questions referring to market and financial data. For AT and CZ, the average honey production, and the average market price per kilogram of honey for the calculations were based on the average national data from referenced or official sources [39,40]. For MK, honey production and its market price were obtained for the different geographic regions from the questionnaire.

## 2.2. Economic Estimation

The value of the total losses is a sum of the value of losses as a consequence of the lost colonies and as a result of the weak colonies (Equation (1)).

$$VTL = VLLc + VLwc, \quad (1)$$

where

$VTL$  = Value of total losses;

$VLLc$  = Value of losses as a result of lost colonies;

$VLwc$  = Value of losses as a result of weak colonies.

The value of the losses as a consequence of the lost colonies ( $VLLc$ ) was calculated as a sum of the value of the lost honeybee colonies (their number multiplied by the price per colony) and the value of the lost production that could have been obtained from these colonies (the number of lost colonies multiplied by the average honey production per colony and the price of the honey—Equation (2)):

$$VLLc = Lc \times Pc + Lc \times Hc \times Ph, \quad (2)$$

where

$VLLc$  = Value of losses as a result of lost colonies;

$Lc$  = Number of lost colonies;

$Pc$  = Price per colony;

$Hc$  = Honey yields per colony;

$Ph$  = Price per one kg honey.

The value of the losses as a result of the weak colonies ( $VLwc$ ) is estimated only on the basis of the value of the lost honey production (Equation (3)). The calculations are made based on the presumption that there are no differences between the lost honey yields from a strong and a weak colony.

$$VLwc = Wc \times Hc \times Ph, \quad (3)$$

where

$VLwc$  = Value of losses as a result of weak colonies;

$Wc$  = Number of weak colonies;

$Hc$  = Honey yields per colony;

$Ph$  = Price per one kg honey.

The average economic losses per one lost colony were calculated by dividing the total value of the losses, as a consequence of the lost colonies, with the total number of lost colonies. Economic losses per one weak colony were calculated by dividing the total value of the losses because of the weak colonies with the total number of weak colonies. The economic losses per one colony before winter start were calculated by dividing the value of the total losses with the total number of colonies before winter, i.e., the total number of colonies in the sample.

In our calculations, we only included the costs beekeepers are confronted with. In the evaluation, we did not include the parameters about protection, feeding, and working hours per beehive because of their extreme variations and complexity. We also did not include any indirect costs deriving from colony losses, e.g., due to loss of crop yield by reduced pollination, but we exclusively focused on the direct costs the beekeepers are facing. By multiplying the average financial losses per one colony before the beginning of the winter with the total number of colonies in each country, the total value of economic losses was extrapolated to the national level. Where possible (MK and CZ), a comparison between the data from the economic losses and the state subsidies was made.

### 3. Results

In total, our survey covered 1656 beekeeping operations from AT, 1191 from CZ, and 320 from MK. Atypical beekeeping operations with more than two times standard deviation from the mean of the total value of losses within a class were excluded from the sample. This means that data from 1570 beekeepers with 31,096 colonies were left for economic loss assessment in AT, which covers 8.8% from the total 354,080 colonies [39] in the country before winter 2016/2017. In CZ, data from 1118 beekeepers with 22,701 colonies were analysed, which covers 3.3% from the total 693,069 colonies in 2016 (official data on request from the Ministry of Agriculture of the Czech Republic). In MK, data from 305 beekeepers with 17,348 colonies were analysed with a coverage of 17.1% of the total number of 101,669 colonies before winter 2016/2017 [41]. For the analysis, the sample was stratified based on the size of beekeeping operations, i.e., the number of colonies per beekeeping operation in six classes. Each class was individually analysed for normal distribution of the total value of the losses. The size classes of beekeeping operations in the three countries are shown in Table 1.

**Table 1.** Number of analysed beekeeping operations from the survey according to the number of colonies per operation in Austria (AT), Czechia (CZ), and Macedonia (MK).

Number of Colonies Per Beekeeping Operation	AT	CZ	MK	Total
Up to 10 colonies	821 (52%)	529 (47%)	33 (11%)	1383 (46.3%)
11 to 20	381 (24%)	284 (25%)	32 (10%)	697 (23.2%)
21 to 50	265 (17%)	224 (20%)	107 (35%)	596 (20.0%)
51 to 100	67 (4%)	53 (5%)	91 (30%)	211 (7.0%)
101 to 150	19 (1%)	17 (2%)	29 (10%)	65 (2.1%)
More than 150 colonies	17 (1%)	11 (1%)	13 (4%)	41 (1.4%)
Total	1570 (100%)	1118 (100%)	305 (100%)	2993 (100%)

This estimation considers colony mortality during winter 2016/2017, the value of the lost colonies, and potential honey production losses from the lost and weak colonies. The values used for the calculations are shown in Table 2.

The results of the economic analysis showed that the total financial losses for the sampled population of beekeeping operations in AT were about 2.8 million € (2,813,052 €) in 2017 (Table 3). Around 2.0 million € (2,085,444 €) or 74% of total economic losses were from the lost colonies and circa 0.8 million € (727,608 €) or 26% of economic losses derived from the weak colonies. Total economic losses in CZ amounted to 0.7 million € (700,955 €). The losses from the lost colonies exceeded 0.5 million € (533,133 €), or 76%, from the total losses and near 0.2 million € (167,823 €), or 24%, were from the weak colonies. For MK, the total losses exceeded 0.5 million € (518,507 €). Most of them came from the lost colonies, or 0.4 million (422,696 €). This is 82% of the total financial losses, whereas the odd 18% were from the weak colonies estimated at around 0.1 million (95,811 €).

**Table 2.** Values used for calculations according to the number of colonies per beekeeping operation in Austria (AU), Czechia (CZ), and Macedonia (MK) based on the data from the COLOSS survey for 2016/2017.

Number of Colonies Per Beekeeping Operation		Up to 10	11 to 20	21 to 50	51 to 100	101 to 150	>150	Average
AT	Average no. of lost colonies per beekeeping operation	1.23	3.17	6.64	13.46	18.84	77.47	4.18
	Average no. of weak colonies per beekeeping operation	0.79	2.46	4.47	8.91	10.05	45.35	2.76
	Average price of one colony in EUR				150.00			
	Average honey yields in kg per colony				14.00			
	Honey price EUR per kg				12.00			
	Number of colonies in country (2016)				354,080			
	Loss rate 2016/2017 (%)				21.1			
CZ	Average no. of lost colonies per beekeeping operation	0.54	1.45	3.93	8.43	15.00	23.82	2.28
	Average no. of weak colonies per beekeeping operation	0.42	1.02	2.07	3.66	5.94	13.00	1.27
	Average price of one colony in EUR				90.88			
	Average honey yields in kg per colony				15.12			
	Honey price EUR per kg				7.84			
	Number of colonies in country (2016)				693,069			
MK	Average no. of lost colonies per beekeeping operation	2.55	4.53	10.07	13.75	24.48	19.54	11.54
	Average no. of weak colonies per beekeeping operation	1.55	3.00	6.28	6.88	17.24	11.15	6.85
	Average price of one colony in EUR	77.17	77.63	72.31	78.43	74.90	83.56	76.16
	Average honey yields in kg per colony	9.49	8.39	8.27	8.43	7.06	10.95	8.29
	Honey price EUR per kg	5.29	5.61	5.52	5.44	5.26	4.90	5.38
	Number of colonies in country (2016)				101,669			
	Loss rate 2016/2017 (%)				20.3			

**Table 3.** Value of the economic losses. EUR per country stratified by beekeeping operation size, based on the sample data from the COLOSS survey for 2016/2017.

Number of Colonies Per Beekeeping Operation	AT (EUR)	CZ (EUR)	MK (EUR)
Up to 10 colonies	430,848	86,661	13,261
11 to 20	542,046	121,030	22,606
21 to 50	758,760	239,376	157,711
51 to 100	387,132	116,648	184,223
101 to 150	145,932	65,397	98,089
More than 150 colonies	548,334	71,845	42,616
Total losses from lost colonies	2,085,444	533,133	422,696
Total losses from weak colonies	727,608	167,823	95,811
Total losses	2,813,052	700,955	518,507

The average economic losses per beekeeping operation size class were different in all three countries. In AT, they ranged between 525 € for the category of beekeepers with up to 10 colonies and 32,255 € for beekeeping operations with more than 150 colonies. In CZ, the average economic losses per beekeeping operation varied between 164 € and 6531 €, and in MK, they amounted from 402 € to 3278 € (Table 4).

**Table 4.** Average economic losses per beekeeping operation in EUR per country stratified by beekeeping operation size based on the data from COLOSS survey for 2016/2017.

Number of Colonies Per Beekeeping Operations	AT	CZ	MK
Up to 10 colonies	525	164	402
11 to 20	1423	426	706
21 to 50	2863	1069	1474
51 to 100	5778	2201	2024
101 to 150	7681	3847	3382
More than 150 colonies	32,255	6531	3278
Average losses per beekeeping operation based on the loss rates for 2016/2017	1792	627	1700

In AT, we calculated the economic losses per lost colony to be 318 € and per weak one to be 168 €. In CZ, economic losses per colony are 209 € per lost colony and 119 € per weak colony, while in MK, the average economic losses are 120 € per lost colony and 46 € per weak colony, respectively (Table 5). Based on this, and the number of colonies in each state (Table 2), the total national economic losses are estimated. This is about 32 Mio € in Austria, 21 Mio € in Czechia, and 3 Mio € in Macedonia (Table 5).

**Table 5.** Average economic losses per colony and country and estimated total national economic losses for Austria (AT), Czechia (CZ), and Macedonia (MK) in EUR for 2016/2017.

Type of Economic Losses	AT	CZ	MK
Losses per one lost colony	318	209	120
Losses per one weak colony	168	119	46
Losses per colony before winter starts	90	31	30
Estimated national total economic loss	32,031,305	21,400,401	3,038,741

#### 4. Discussion

Our study is the first to calculate the direct economic impact of winter losses of managed honeybee colonies. We used raw data of loss rates from the 2017 COLOSS investigation [11] and economic data originally surveyed from beekeepers (Macedonia) or obtained from official national documents (Austria, Czech Republic). Scientific studies on beekeeping economics so far mostly considered the honey market [8,17], consumer preferences [42,43], pollination services [5,44–46], or queen trade [7]. Only very little research has been done on the impact of honeybee diseases on beekeeping economics and the economic sustainability of beekeeping [32,47]. For treatment of honeybee colonies against the parasitic mite *V. destructor*, a number of different methods are available [48,49]. Sound analysis of the economics of different varroa treatments (including decision support systems [50]) or monitoring tools for the economic accounts of stock [51] have only become available recently. To better illustrate the importance of economic and efficient hive management and the financial loss for the apicultural sector, we estimated the direct economic costs of honeybee winter colony losses in three European countries based on real 2016/2017 colony-loss rates collected from almost 3000 beekeepers. We included the price of honeybee colonies, honey production, and prices and financial losses from surviving but weak colonies, which were assumed to produce no honey the following year.

Surprisingly, few data on regional parameters required for our analysis, such as average honey yield or price of honey, are available from scientific sources, probably because the market of bee products is not regulated or properly examined. Therefore, data collection via questionnaires or consultancy of authoritative documents are needed, just like we did in this study. The assessment of economic parameters is further complicated,



for example, by regional variations in honey prices, not to speak about different prices of different honeys depending on quality or floral origin [51,52]. Having in mind the variation in the prices, yields, and colony losses, and that these variations are correlated with the size of the beekeeper operation, it is recommended to incorporate economic data as an integrated part of the international COLOSS questionnaire or similar surveys in order to enable more precise assessments of the economic losses of the apicultural sector in the future. For example, in MK, we noticed a variance in average colony price (from 74 to 80 € per colony), average honey yield (8 to 11 kg per colony), and average honey prices (5 to 6 € per kg) between the classes according to the size of the beekeeping operation, i.e., the number of colonies per beekeeping operation. Our study, therefore, set the parameters needed for the extension of our economic estimations to other countries or larger entities such as the European Union. We also want to note that extension of our method to other countries with different structure of the apicultural sector (larger beekeeping operations, different degrees of professional beekeeping) may need separate attention [10]. In our study, backyard and sideline beekeeping prevailed, though especially in MK, a notable number of larger beekeeping operations also exist that responded to our data collection (Table 1). Again, one of the most critical points is the availability of the different data types (good estimates of colony numbers, colony loss rates, prices for bees and bee products, honey yield) that need to be integrated into economic estimations. In that manner, building capacity and motivation of beekeepers to perform regular bookkeeping and record-keeping can significantly contribute towards a more precise impact assessment of honeybee colony losses.

The results from the extrapolation on a national level showed that in AT, the estimated economic losses were 32,031,305 €; in CZ, 21,400,401 €; and in MK, 3,038,741 € (Table 5). As the information about the national structure of the beekeeping operations according to operation size was deficient, we were not able to perform any analysis of sample representativeness. Additionally, while the highest share of the sample in AT and CZ were small beekeeper operations with less than 20 colonies (77% and 73%, which reflects previous studies [9,30]), in MK, the highest portion (65%) of surveyed beekeeping operations manage between 51 and 100 colonies. Additionally, the average economic losses per colony before the start of the winter vary between different beekeeping operation sizes and at the same time, between countries (Table 5). The highest value in AT can be explained by the high prices for honey and honeybee colonies (Table 2). In their study focusing on the United States, Rucker et al. [53] suggested that colony collapse disorder has a surprisingly small economic impact because of adaptations such as increasing pollination fees. For Europe, and the presented countries, honey is the most important product, and no steep increase in honey price has been observed [8].

The economic impact assessment of winter honeybee colony losses can also be a useful tool for policymakers for planning and developing strategies and support measures for the beekeeping sector. It becomes evident from our analysis that the economic losses are higher than the national support measures. For MK, the estimated national losses of 3,038,741 € were almost 1 million euro higher than the financial payment of 130,435,200 MKD or 2,120,898 € for the registered surviving winter colonies in 2017 [54]. The situation is even more pronounced in the case of CZ, where the total subsidy paid was 105,000,000 CZK or 4,038,461 € for wintered colonies, which is more than five times lower than the estimated losses of 21,400,401 € in the following winter [55]. For AT, the estimated losses were 32,031,305 €, but due to the absence of data on subsidies, no comparison was made.

Our methodology should be further extended to assess other consequences from colony losses, such as direct impact on economic losses from the potential loss of yields from other bee products (royal jelly, pollen, wax, etc.) or pollination fees, additional extra costs (labour, feeding, etc.) and losses from beekeeper's practices (splitting as compensation for the lost colonies), but also impact to indirect losses, primarily from the pollination role of the bees.

The direct costs of honeybee colonies reported in this study very likely make up only a small portion of the real economic impacts of honeybee colony losses. We did not include any economic impacts from a possibly reduced pollination service provided by the honeybees [2,5,6,34]. However, our estimated costs are the minimum costs that certainly affect beekeepers. In the end, if we take into consideration the indirect losses, primarily from the pollination of agricultural crops and wildlife biodiversity, we can conclude that economic losses from honeybee colony losses are quite beyond the results presented in this paper, which supports investments in colony health to reduce loss rates. Another example for a loss we have not included, and which is probably difficult to measure economically, is the loss of valuable breeding stock.

In the three countries, a large proportion of beekeepers are hobbyist or sideline beekeepers. Each year they re-establish the colonies lost during winter on their own expenses, by making colony splits, breeding queens, etc. [30]. The economic effect of labour for doing this was not included in our estimations, hence, further research is required to picture the economic magnitude of colony losses more precisely for society. Our study also confirms that reducing colony losses by efficient treatments against diseases or other actions greatly lowers the economic pressure on beekeeping operations [47,50]. This could impede the recession of honeybee colonies, and active beekeepers, in many Western countries [17,31,56]. Measures to reduce economic losses from colony losses include enhancement of extension capacities for beekeeper education and spreading good apicultural practice [28,36,57,58], raising awareness for the use of native or locally adapted honeybee stock [59–61], encouraging honeybee breeding initiatives and programs for genetic improvement by considering the relevance of local adaptation [62], considering colony vitality and varroa resistance as imperative breeding goals [63–65], and propagating best-practice varroa treatments that are tailored for the local conditions [66,67]. Though these actions and practices are also costly [68], subsidies could be used to facilitate these, and revenue would strengthen the apicultural sector. Another opportunity to safeguard economically sustainable beekeeping is the increase in revenue from hive products through higher prices [8].

## 5. Conclusions

Our pilot study on periodic costs of losses of managed honeybee colonies brought the first estimation of the economic importance of the apicultural sector as part of the agricultural economy. The applied model is relatively simple, but nevertheless provides first values of national economic impacts and differences among countries, mainly based on the different value levels in the three countries, national colony populations, and the magnitude of the colony loss rate. Following our pilot effort to estimate the direct economic impact of winter colony losses of managed honeybees, further research and broadening to more countries where COLOSS data is available is recommended, including temporal series to detect long-term trends. To set the economic losses reported in this article in relation to the economics of the apicultural sector, a thorough analysis of the economics of the whole sector is required. Policymakers may act in reducing economic impact of honeybee colony losses by supporting known factors contributing to colony survival and further research to improve colony health.

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