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ANALYSIS OF THE ENERGY INPUT-OUTPUT OF HONEY PRODUCTION IN THE MOUNTAINOUS AREA OF ROMANIA

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Abstract

The paper offers information on the energy efficiency of the honey production in the mountainous area of Romania. The field research was carried out as a face-to-face interview in 2018, on a representative sample including 134 beekeepers. The main results of the analysis of the energy input–output are: input energy 754.9 MJ/hive, net energy -417.3 MJ/hive, efficient energy use 0.47 and specific energy 27.0 MJ/kg. From the total inputs, direct inputs and renewable inputs account for 38.1% and 5.1%, respectively. The apiaries with less than 50 hives have energy efficiency higher than the larger ones, but this phenomenon is adjusted when the size is over 150 hives. The highest energy output was obtained from the apiaries with a size of over 150 hives, but they are also the ones that involved the highest energy consumption as a result of the hives being moved in areas with high melliferous potential. Among the sources of input energy, the contribution of energy related to diesel fuel was the highest, followed by sugar. These inputs are needed both to ensure the mobility of the apiaries and to counteract the effect of unfavorable natural conditions. The regression analysis shows that compliance with the bee-keeping operations system, optimization of the transport distances and more frequent replacement of the queens with individuals with high genetic potential can lead to higher energy performance of Romania's apiaries.

Key words: energy efficiency, honey production, input-output energy, mountainous area

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1. Introduction

The sustainable development is based on values such as freedom, equality, solidarity, tolerance, respect for nature and shared responsibility (Shepherd et al., 2009), and the apiculture is an activity favourable for the natural environment where it takes place (Abrol, 2012; Beard, 2015), as well as for the wellbeing of the population (Mwakatob and Machum, 2010; Yap et al., 2015). On the other hand, the growing concern of beekeepers to increase production and profit may determine major ecological imbalances (Gupta, 2014), while the illegal deforestation, the contradictory governmental policy towards transforming traditional agriculture to the detriment of biodiversity (Benedek, 2018; Rusu et al., 2017; Ueawiwatsakul et al., 2018), as well as the effects of the less environmentally friendly tourism (Dumitrascu et al., 2017) lead to the increased vulnerability of bees (Draghici et al., 2017; Ianas and Germain, 2018; Petrisor, 2017). In addition to all these factors are the severe environmental conditions: floods (Sorocovschi and Pandi, 2002), hail (Burcea et al., 2016), water pollution (Muntean and Mihaiescu, 2016), air pollution (Dunea and Iordache, 2015; Florea et al., 2019), poor soils (Gheorghe and Tanase, 2013) and the climate changes (Spinoni et al., 2015).

The mountainous zone of Romania includes a total area of 71,381.48 km^2, representing 29.94% of Romania surface (Ungureanu, 2008), where there are 1994 apiaries with a total number of 48,044 hives (NIS, 2010). The honey production obtained in the

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year 2016 has reached 784 tonnes/year with an average of 16.3 kg/hive. The average number of bee families owned by a beekeeper was 24.1, with an annual honey production of 393 kg/apiary (NIS, 2018). The beekeepers are trading the honey from apiaries on the agri-food markets, within the branches of the Romanian Beekeepers Association and at other buyers.

The applied beekeeping management means a system that it is in the most part stationary (81.3%), only a small part (18.7%) of apiaries are moving to other zones with a high potential for honey production (Stefan et al., 2009). The high melliferous potential is represented by forests with predominant species such as *Robinia pseudoacacia L. and Tilia (tomentosa, cordata. europea)* and cultures such as *Helianthus annuus* and *Brassica rapa.* The beekeepers that are moving with their apiaries are using their own means of transport or they are benefiting from transportation services. The applied technology for honey production includes traditional techniques verified during the different generations of beekeepers, combined with modern techniques adopted from the meetings organized by the Romanian Beekeepers Association and the Beekeeping Research and Development Institute Bucharest. The apiary capital is in general reduced and includes: wooden hives, hand-operated centrifuge and some relatively simple tools. By applying for European funds, some beekeepers obtained electric honey extractors and some modern tools (Pocol et al., 2012; Popescu, 2010).

The environment protection and the sustainable development involves the most efficient use of resources such as melliferous potential (Jitariu et al., 2014; Pocol et al., 2012; Watson, 2017), capital resources and labour force (Al-Badri, 2017), expressed in energy inputs (Baishaya et al., 1990; Blaxter, 1962; Rafiee et al., 2010; Streimikiene et al., 2007). This aim is accordingly with the environment protection as well as with the increase of the beekeeping economic performances (Ceyhan, 2017; De Jonge, 2004; Farrar, 1993; Mujica et al., 2016; Verma and Attri, 2008).

The research aim consisted in the input–output energy analysis of honey production in the mountainous area of Romania. The beekeeping in the mountainous zone of Romania is important for the Romanian beekeeping because it takes place on an area representing almost 30% of the country's surface and it has particularities related to the development conditions and the productivity of bee families.

The paper objectives were: 1. Determination of the average size of energy inputs-outputs within the studied apiaries (MJ/hive); 2. Determination of the energy inputs-outputs structure (diesel fuel; drugs; human labour; electricity; sugar and track; indirect and direct; non-renewable and renewable); 3. Identification of the correlation and regression of the energy inputs-outputs (P, R^2, equations); 4. Determination of the main indicators of energy efficiency (productivity, energy use efficiency, specific energy and net energy).

2. Material and methods

The studied apiaries are located mainly in mountain rural settlements where they remain during winter; afterwards, some of them (with a part of or with all hives) are moving to zones with high potential for honey production in the south and south-eastern Romania (the counties Focșani, Buzău, Galați and Tulcea) and sometimes to some areas in the north and north-eastern Romania (the counties Vaslui, Suceava, Iași and Botoșani). The total distance of the apiaries circuit varies between less than 50 km to over 1,200 km. Because of the necessary conditions for practicing apiculture, the apiaries in the researched area are located in places with a southern exhibition, located on plateaus, terraces and at the foothills of the mountains. Beekeepers prefer the pastures from the forests or wind-free meadows. They usually avoid areas with excessive air humidity such as lowlands and river beds. The average altitude of the apiaries is approx. 530 m, with variations in the range of 600 - 800 m. The climatic peculiarities of the researched mountainous area are characterized by: abundant precipitations (800-1200 mm annually), annual average temperatures of 2 - 6°C, relatively strong winds, average number of days with frost 160, average number of tropical days (temperatures above 30°C) of 0.7 (NMA, 2008) .

The apiaries organization is made by using a distance between beehives of 40-70 centimetres on overwintering courts and of 10-50 centimetres in the pastoral period, for the beehives from beekeeping pavilions or for the beehives placed on soil. The main bee subspecies owned by the beekeepers from this area are *Apis mellifera and Apis carnica* (Table 1).

The access of other subspecies or crossbreeds is limited by the beekeeper's perception that their additional performances do not support the price difference in relation with the local ecotypes.

The number of beehives varies from less 50 beehives to apiaries with more than 150 beehives, thus being established a stratification with a share of 50 beehives (0-50, 51-100, 101-150, over 151), respectively 28.9%, 31.0%, 22.7% and 17.4% of total sample. The beehives are made from wood using 10 - 12 frames of honeycombs with 30x47 centimetres or 21x47 centimetres. Usually, they are foreseen with storages of same material with frames of 21x47 centimetres or 14x47 centimetres. The honey extraction is performed within the households or in the beekeeping pavilions and consists in the uncapping of honeycombs with manual knives and the extraction with manual, sometimes electric, centrifuge. The work temperature of beekeepers varies between -5°C during the apiaries winter inspection and 35°C during the honey harvesting proceedings, with an average work time of 1-12 h during a period of max. 300 days/year, according to the number of beehives. The feeding with sugar takes place with syrup in concentrations of 66% in order to complete the wintering food and 50% for the spring-autumn stimulations. The used medications have as active substance: amitraz and tau-fluvalinate.

The main melliferous plants from the investigated mountain area are represented by: *Robinia pseudacacia L.*, *Rubus idaeus L.*, *Picea abies (L.) H. Karst.*, *Trifolium repens L.*, *Fagus sylvatica L.*, *Pinus sylvestris L.*, *Acer pseudoplatanus L.*, *Corylus avellana L.*, *Trifolium pratense L.*, *Medicago sativa L.*, *Epilobium angustifolium* and other species of fruit trees and meadows (Antonie, 2017; Iordache et al., 2007). The system of operations applied for honey production in the studied area is in accordance with the recommendations of the Romanian Beekeepers Association (Table 2).

However, some of these operations are being neglected in many of the apiaries: hygiene of the beehive box, treatments for *Varroa jacobsoni*, checking the presence of the queen, assessing the level of development of the hives in autumn time, organizing the nest for harvesting etc.

The field research consisted in face-to-face interview during the first quarter of the year 2018 on a representative sample of 134 beekeepers, with questions about the apiaries consumptions and productions obtained in 2017. The sampling has used the Neyman method, deviation criterion 5% and a confidence level of 95%. The energy input-output analysis was carried out by using energy indices such as: energy productivity, energy use efficiency, net energy and specific energy.

Table 1. Practices and operations for honey production in the mountainous area of Romania

Practice/operation	***Description***
Bee subspecies	Mellifera, Carnica and their crossbreeds
Location of the hives establishment	stationary - mountain area: forests with *Robinia*, *Picea* and meadows with *Trifolium*, *Medicago* and *Epilobium*. pastoral (during summer) – hill and plain areas: forests with *Robinia* and *Tilia*, cultures of *Helianthus* and *Brassica*.
Transports type	Truck rented from third parties and personal vehicles
The number of bee colonies	18 - 221
Drug	Amitraz, Fluvalinate and Coumaphos
Extractor type	Electric and manual
Hive types	Wooden
Working temperature	-5 - 35°C
Distance between hives	10 - 70 centimetres
Time to replace the queen	June, in autumn or in case of disability
Food during winter	Honey, sugar syrup

Table 2. Minimum system of beekeeping operations in accordance with the Beekeepers Association of Romania (Barac et. al., 2007)

Name of the operation	***Month/decade***
Preparation for transport to the winter hearth	VIII-1
Actual transport to the winter hearth	VIII-2
Unpacking the hives	VIII-2
Autumn revision - the presence of the queen, the level of development of the hives	VIII-2
Strengthening of the bees families that are weakly developed with swarms developed during the season or with other weak hives	VIII-2
Formation of the wintering nest	VIII-2
Managing Completion Feeding	VIII-2
Apiculture inventory maintenance - cleaning, disinfecting, repair, painting	IX-2; I-3
Moving the bees into disinfected hives	IX-2
Treatment administration	IX-3; III-3; VI-2
Organizing the nest for winter	X-2
Hive control - auditory control	XI-2
Frame preparation - frame assembly, stitching	II-2
Remedies for abnormal situations - food, mice	III-1
Performing the spring control - reducing the nest, stimulation with syrup	III-2
Transfusing into the disinfected hives	IV-1
Enlargement of the nest and stimulation with sugar syrup	IV-2
Pastoral transport	V-1; V-3
Preparation of the hives for harvesting	V-1; VI-1
Extraction of honey, harvesting of honeycombs, transport, the extraction itself and insertion of frames into bee families	V-3; VI-2
Formation of artificial swarms	V-3
Orphanage of hives to replace the queens	VI-1; IX-1

To evaluate the results of this study, these energy indices were calculated for honey production by Eqs. (1-4):

$$Energy\ productivity\ (kg/MJ) = \\ = \text{product output (kg/hive)/energy input (MJ/hive)} \quad (1)$$

$$Energy\ use\ efficiency = \\ = \text{energy output (MJ/hive)/energy input (MJ/hive)} \quad (2)$$

$$Net\ energy\ (MJ/hive) = \\ = \text{energy output (MJ/hive) - energy input (MJ/hive)} \quad (3)$$

$$Specific\ energy\ (MJ/kg) = \\ = \text{energy input (MJ/hive)/product output (kg/hive)} \quad (4)$$

Energy productivity is an indicator of the amount of economic output that is derived from each unit of energy consumed. In this study, the energy productivity was determined by the ratio between physical output measured in physical terms (kg of honey) and energy inputs measured in terms of energy (MJ). Energy productivity is a partial measure and is intended explicitly not to be used as the sole criterion of efficiency in any general sense (Fluck and Baird, 1982; Schahczenski, 1985). Energy efficiency serves as an optimality measure for assessing the efficiency of agricultural production systems (Akbolat et al., 2006; Schahczenski, 1985) and has been evaluated by the ratio between the total energy value of the produced output (honey production) and the total amount of energy input to achieve this output. Specific energy provides quantitative data on how much energy was spent in the production of 1 kg of honey. Net energy represents the difference between the energy value of honey production and the amount of energy expended to obtain this production.

These indicators have been used during previous researches having the same objective (Demircan et al., 2006; Omidi-Arjenaki et al., 2016).

The energy inputs have been calculated by multiplying the consumed quantities with the specific energy input: diesel fuel - 56.31 MJ/l (Heidar and Omid, 2011; Omidi-Arjenaki et al., 2016), human labour - 1.96 MJ/h (Omidi-Arjenaki et al., 2016; Ozkan et al., 2004; Singh, 2002), drugs - 13.64 MJ/kg (Mortazavi, 2002; Omidi-Arjenaki et al., 2016), electricity - 11.93 MJ/kWh (Gundogmus, 2006; Omidi-Arjenaki et al., 2016), track - 10.15 MJ/t km (Davis et al., 2011; Omidi-Arjenaki et al., 2016), sugar - 15.4 MJ/kg (Coley et al., 1998; Omidi-Arjenaki et al., 2016). The energy outputs have been determined according to the honey production by multiplying the quantities with the specific energy input - 12.72 MJ/kg (Omidi-Arjenaki et al., 2016; Southwick, 1980).

The technological variants with potential impact on the energy efficiency of honey production have been also analysed: the number of treatments and the number of types of control treatments against *Varroa jacobsoni*; the percentage of beehives where the bee queens have been replaced with bee queens obtained in specialized breeding units; the percentage of hives moved in pastoral of the total apiary and the manner of placing the apiaries on soil / in beekeeping pavilions; multiplication by natural or artificial bee swarming and the moment of feeding the bee families with sugar syrup.

The data processing involved the use of t-test and Kolmogorov-Smirnov tests performed by MS Excel and SPSS, and to the field information has been added information obtained from the branches of the Romanian Beekeepers Association and the Directorate of Statistics from the counties belonging to the mountainous area.

3. Results and discussion

In 2017, the total energy output level for all the researched apiaries was 1037.8 GJ, value equivalent to a quantity of 88.4 tons of honey. This production was obtained based on a total energy consumption of 2343.0 GJ. The average value of the hive energy output recorded significant variations on apiary size categories (Fig. 1). Thus, the energy output provided by the apiaries with up to 50 hives was 49.4% smaller than the sample, while at the ones with more than 150 hives it exceeded this average by 40.1%

This situation is determined especially by the beekeepers' attitude in relation with their own apiary, starting with the beekeepers who obtain some apicultural products for their family to the farmers who wish to carry on an efficient apiculture. Beekeepers who only pursue the satisfaction of their own honey consumption usually have small apiaries, they sell small quantities of honey and consume few inputs. Some of them also hope to earn additional income in addition to the incomes from wages or pensions. However, all these beekeepers with small apiaries are not motivated enough to carry out an effective activity. Instead, beekeepers with apiaries with over 50 hives have as objective the maximisation of profits. However, only few of them understand the importance of conducting economically efficient and, above all, energy-efficient activities. Most of them are driven by the desire to get productions as big as possible, but they most often neglect the size of the costs. This fact influences not only the structure of the inputs, but also raises the issue of the efficiency of bee migration and the optimal distance between the apiaries and the beekeepers' residence. If the inputs determined by the mobility of the apiaries have a significant share in the apiaries, it is necessary to optimize their consumption in order to improve the energy performances.

The shares held in the total of the energy input were: 40.3% for fuel (5.4 l/hive), 32.7% for sugar (16.02 kg/hive), 21.6% for track (16.09 t km/hive), 4.7% for human labour (18.21 hours/hive), 0.62%

electricity (0.39 Kw h/hive) and 0.07% drugs (40 g/hive) (Table.3).

The direct inputs (labour, electricity, drugs and sugar) participate directly in the honey production process (Omidi-Arjenaki et al., 2016; Southwick, 1980), representing 38.1% of the total inputs (Fig. 2). In the stationary apiaries, direct and indirect energy consumption is almost equal, in contrast to the moving ones, where there is a difference ranging from 143.0 MJ/hive (101-150 hives) to 292.1 MJ/hive (51-100 hives). As indirect inputs that have been taken into account: the consumptions with track and diesel fuel. These are necessary for the transportation of raw materials, materials, apiaries and honey, but they are not used directly in the production process. The diesel fuel is used for the cars owned by the beekeepers. The average indirect inputs energy was about 467.3 MJ/hive (61.9% of total inputs).

This particular structure of the inputs suggests the predominance of the support activities in relation with the productive ones and leads to the idea that the vectors that increase the apiaries' energy performances might be: human labour, electricity, drugs and sugar. As consequence, the apiaries can be more energy efficient through the increase of the direct consumption and especially, through the increase of their productivity. The regression model between output energy (as dependent variable), direct inputs energy *DE* and indirect inputs energy *IDE* (Table 4) has been statistically ensured at the confidence level of 95.0%, $R^2 = 0.755$, and has the form determined by (Eq. 5):

$$y = 85.612 + 0.517\,DE + 0.149\,IDE \qquad (5)$$

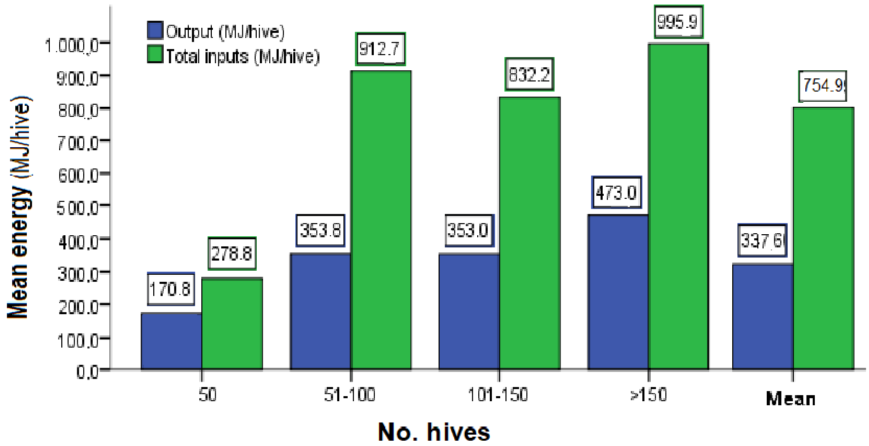

Fig. 1. The average of input and output energy

Table 3. Energy consumptions for honey production (MJ/hive)

Index	***0-50 hive***	***51-100 hive***	***101-150 hive***	***>150 hive***	***mean***
Labour	19.1	43.1	37.8	42.9	35.7
Fuel	120.8	411.8	322.8	360.4	303.9
Electricity	0.3	3.0	5.8	9.5	4.7
Track	21.5	190.6	164.8	276.4	163.3
Drugs	0.139	0.431	0.727	0.791	0.522
Sugar	117.0	263.7	300.3	305.9	246.7

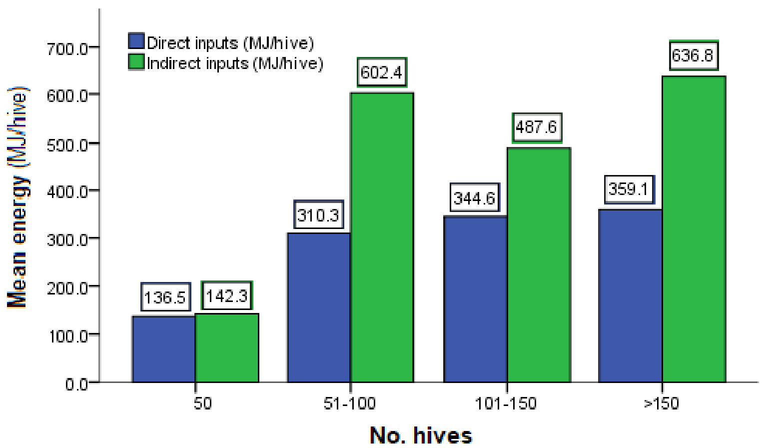

Fig. 2. Energy inputs for honey production in the form of direct and indirect energy

This model highlights the influence of direct consumption on output, compared to the indirect one. Direct consumption has a multiplication factor of 3.5 times higher than the indirect one. A unit of direct energy consumption determines the production of 0.517 output energy units, while an indirect energy consumption unit supplies only 0.149 output energy units. As renewable inputs there were taken into account the labour consumptions, while non-renewable energy inputs referred to: fuel, electricity, track, drugs and sugar. The structure of the inputs was dominated by non-renewable inputs, which accounted for 94.9% of the total, recording an average value of 719.2 MJ/hive (Fig. 3). Only 5.1% of total energy input was in the renewable form, the average value for this being 35.7 MJ/hive.

A positive sign is given by the regression model that indicates a multiplication factor of 6.43 for renewable inputs energy *RE* in comparison with 0.13 for non-renewable inputs energy *NRE* (Table 5).

The regression model was statistically ensured at the confidence level of 95.0% and R^2 = 0.771, having the form expressed according to (Eq. 6):

$$y = 9.184 + 0.130\,NRE + 6.428\,RE \quad (6)$$

The multiplication factor resulting from regression analysis for renewable inputs energy is 49.4 times higher than the multiplication factor of non-renewable inputs energy. Given that the mobility of hives leads to the neglect of certain apicultural works, it is necessary to reduce the consumption of fuel, electricity, track, drugs and sugar in favour of labour consumption. The function labour input has the shape as follows from (Eq. 7):

$$y = -82.21 + 14.33\,x - 0.07\,x^2 \quad (7)$$

This allows a maximum output of 651.2 MJ/hive (51.2 kg honey/hive) under the conditions of a maximum labour input of 102.4 MJ/hive (52.2 hours/hive), and a consumption of 182.3 MJ/hive under the conditions when the production is zero (Fig. 4). Hence, even if they do not get honey production, beekeepers have the obligation to carry out some of the activities such as: treatments, prevention of swarming, preparation for wintering. This situation has critical implications, as some apiaries are briefly maintained and hives become more vulnerable to diseases and pests and may become outbreaks of infection for the nearby apiaries.

Table 4. Results of the linear regression model between output energy[a] and direct and indirect inputs energy

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*Beta*		
(Constant)	85.621	8.269		10.354	.000
Direct inputs (MJ/hive)	.517	.043	.626	12.119	.000
Indirect inputs (MJ/hive)	.149	.022	.352	6.810	.000

a. Dependent Variable: Output (MJ/hive)

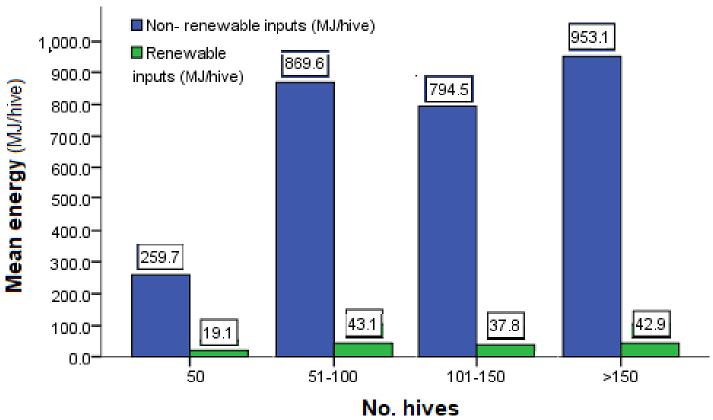

Fig. 3. Energy inputs for honey production in the form of renewable and non-renewable energy inputs

Table 5. Results of the linear regression model between output energy[a] and renewable and non-renewable inputs energy

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
	B	Std. Error	Beta		
(Constant)	9.184	13.365		.687	.493
Non-renewable inputs (MJ/hive)	.130	.020	.407	6.661	.000
Renewable inputs (MJ/hive)	6.428	.728	.540	8.835	.000

a. Dependent Variable: Output (MJ/hive)

This allows a maximum output of 651.2 MJ/hive (51.2 kg honey/hive) under the conditions of a maximum labour input of 102.4 MJ/hive (52.2 hours/hive), and a consumption of 182.3 MJ/hive under the conditions when the production is zero (Fig. 4). Hence, even if they do not get honey production, beekeepers have the obligation to carry out some of the activities such as: treatments, prevention of swarming, preparation for wintering. This situation has critical implications, as some apiaries are briefly maintained and hives become more vulnerable to diseases and pests and may become outbreaks of infection for the nearby apiaries.

If the labour consumption would increase with 46.3% (16.5 MJ/hive), the honey production would increase with 92.9% (313.5 MJ/hive), allowing also an increase of the energy efficiency up to 0.84. Labour proves to be a determining factor both for the survival of the hives, as well as for the growth of the apiaries' performances.

The polynomial regression for drug input (Fig. 5) indicates how important is to ensure the bees' health condition and the stimulators impact, by increasing the output to a maximum of 526.0 MJ/hive (41.3 kg honey/hive) with a maximum drug consumption of 1.4 MJ/hive (0.025 kg/hive).

The shape for this function is given by (Eq. 8):

$$y = 102.9 + 599.6\,x - 212.52\,x^2 \qquad (8)$$

The existence of some apiaries where there are no control treatments carried out against *Varroa jacobsoni* (the factor consumption is null) and still they obtain an output of 102.9 MJ/hive is very interesting. This situation is caused by the answers obtained from 4 beekeepers who reported not using drugs in their apiaries. On the contrary, if the labour consumption would increase with 270.3% (0.9 MJ/hive), the honey production would increase with 55.8% (88.3 MJ/hive), allowing also an increase of the energetic efficiency up to 0.70. Other studies might show a correlation between the infestation degree of the apiaries with this parasite, the altitude where the apiary is placed and the length of the inactive bee period. According to the polynomial regression for sugar input (Fig. 6), the maximum output of 430.7 MJ/hive (33.7 kg honey/hive) may be obtained when there is a maximum sugar input of 483.8 MJ/hive (31.4 kg/hive). The sugar input has the function presented in (Eq. 9):

$$y = 118.06 + 12e - 2x + 35e - 4x^2 - 5e - 6x^3 \qquad (9)$$

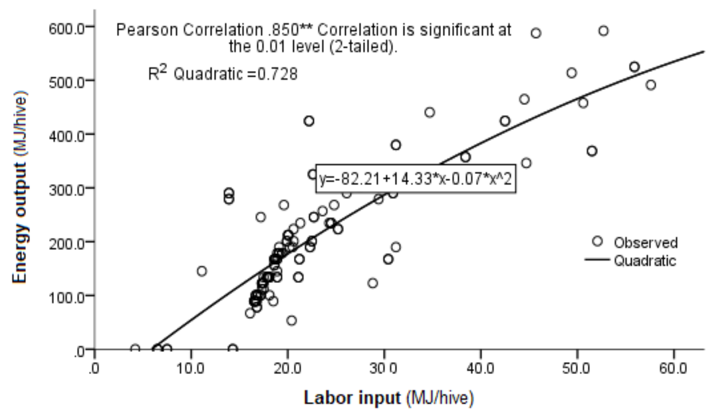

Fig. 4. Relationship between energy output and labour input

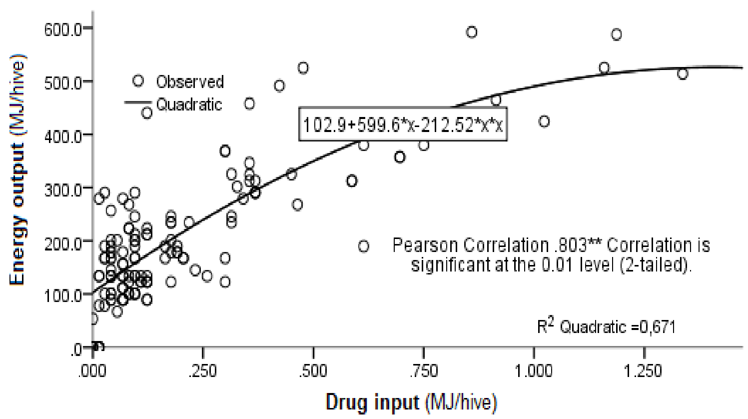

Fig. 5. Relationship between energy output and drug input

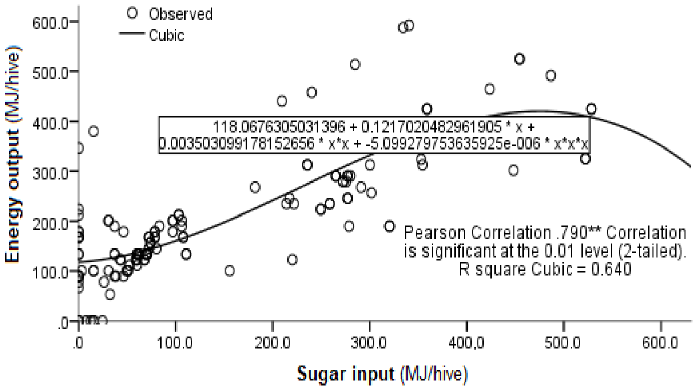

Fig. 6. Relationship between energy output and sugar input

An output of 118.8 MJ/hive for the null factor consumption (without using sugar syrup) is noticed. If the sugar quantity would increase with 96.1%, the honey production would increase with 23.6% (93.1 MJ/hive), allowing also an increase of the energetic efficiency up to 0.62. The increased necessity for sugar is justified by low temperatures, high humidity during winter and the length of the period of time with low or negative temperatures, which are inappropriate for the supply of bees with nectar. For this reason, beekeepers supplement the winter food reserves by feeding them with sugar syrup in significant amounts (10-15 kg/hive), administered in the months August - September.

The fuel, electricity and track inputs are not in correlation relationship with the energy output, because the Pearson Correlations were 0.576, 0.513 and 0.578, respectively.

The apiaries mobility or weight of the apiaries shifted to riched zones in nectar in relation to the total hives owned by beekeepers has the function expressed by (Eq. 10):

$$y = 227.61 - 17.20x + 0.43x^2 - 0.0023x^3 \quad (10)$$

The results of the polynomial regression revealed the possibility to achieve a maximum output of 525.7 MJ/hive (41.3 kg honey/hive) under the conditions when the beekeepers transport during pastoral 98.8% of the owned hives (Fig. 7). An average output of 170.8 MJ/hive (13.4 kg honey/hive) for the stationary apiaries is noticed.

At first sight, this situation shows that the majority of hives needs to be transported, because marginal output is superior to the marginal input. On the other hand, the energy efficiency associated with the mobility of hives must also be taken into account. In the energy efficiency analysis, it will be seen that apiaries with more than 50 hives (all or partially mobile) have significantly lower energy efficiency than the others. For the technological variants (number of treatment and number of types of control treatment against *Varroa jacobsoni*, manner of apiaries placement on soil / in beekeeping pavilions, multiplication by natural / artificial swarming and the moment of feeding the bee families with sugar syrup) the regression model is not statistically ensured at the confidence level 95.0%.

For labour *L*, drug *DG* and sugar *S*, the regression model (Table 6) is statistically ensured at a confidence level of 95.0% and $R^2 = 0.868$, having the form resulting from (Eq. 11):

$$y = 11.165 + 5.354\,L + 136.669\,DG + 0.287\,S \quad (11)$$

The maximization of the regression model results indicates that at a total factor consumption of 535.5 MJ/hive (52.2 MJ/hive labour, 1.4 MJ/hive drug and 483.8 MJ/hive sugar), the apiaries from the studied area can obtain an output of 623.8 MJ/hive and an energy use efficiency of 1.16. Also, this model might suggest the minimum level from which the factors drug and sugar, having a non-renewable character, were reduced to zero, level where the beekeepers obtain 290.6 MJ/hive with an exclusive consumption of renewable factors of 52.2 MJ/hive and an energy use efficiency of 5.57.

This model has an abstract character, but it can represent the basis of the development of energy preformat technologies, where one can use minimal quantities of non-renewable inputs associated with optimal quantities of renewable inputs. This means that the mountainous beekeeping can obtain remarkable results by using proper labour inputs, as well as the efficiency increase of using non-renewable inputs.

The regression model that correlates energy output with bee queen replacement has the function expressed by (Eq. 12), that allows to determine a maximum output of 504.2 MJ/hive (39.6 kg honey/hive) under the conditions when 56.7% of bee queens are replaced (Fig. 8).

$$y = 140.50 - 6.83x + 0.58x^2 - 0.0061x^3 \quad (12)$$

One can notice an average output of 138.9 MJ/hive (10.9 kg honey/hive) when the factor consumption is null, the bee queens have not been replaced, but they have been obtain by swarming or by natural replacement.

Among the technological factors, the bee queen's replacement determines the increase of energy output and energy efficiency, but the impact of this measure is limited at 56.7% bee queens replaced per year from the total of bee queens, probably due to the genotype and phenotype variability of the bee queens produced by the majority of the local bee queen keepers. Under these conditions, the beekeepers are encouraged to replace only the bee queens showing an obvious reduced potential, and this practice might determine significant loses, since they will apply this method after the intense harvesting periods. Also, beekeepers cannot identify the queens that have a poor quality or who are old until they have noticed that their hives have been a small number of sapling, which is inhomogeneous or with many drones. As a result, some of the production losses were already incurred at the time of the replacement. The results of analysing the mean of energy indices reveal a significant variation according to the apiary size (Table 7). For calculations, Eqs. (1-4) were used.

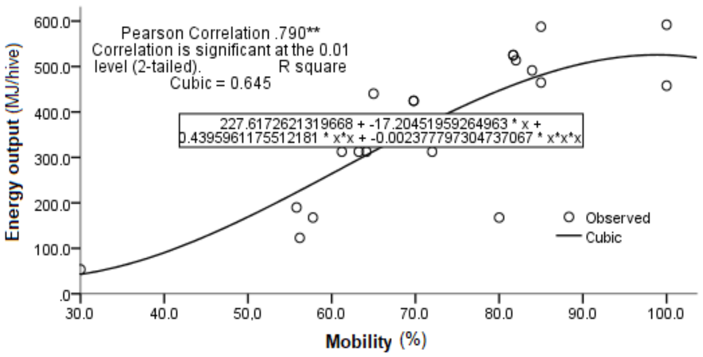

Fig. 7. Relationship between energy output and apiaries mobility

Table 6. Results of linear regression model between output energy[a] and labour, drug and sugar inputs energy

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*Beta*		
(Constant)	11.165	10.464		1.067	.004
Labour	5.354	.556	.450	9.634	.000
Drug	136.669	23.199	.280	5.891	.000
Sugar	.287	.038	.330	7.518	.000

[a.] *Dependent Variable: Output (MJ/hive)*

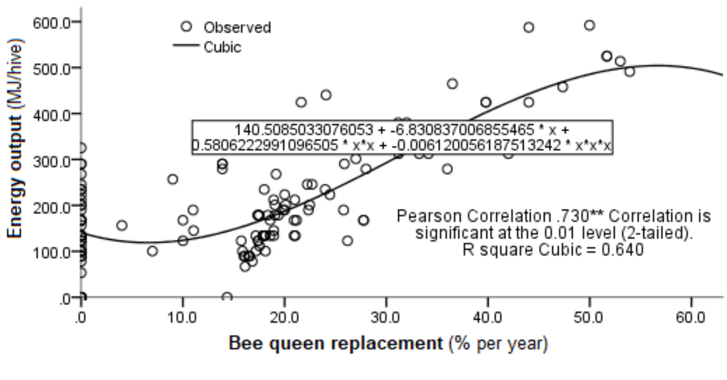

Fig. 8. Relationship between energy output and bee queen replacement

Table 7. The mean of energy indices

Index	*0-50 hive*	*51-100 hive*	*101-150 hive*	*>150 hive*	*mean*
Performance (kg/hive)	13.7	29.2	26.3	40.4	27.4
Net energy (MJ/hive)	-107.9	-558.9	-479.3	-522.9	-417.3
Energy productivity (kg/MJ)	0.05	0.03	0.03	0.04	0.04
Energy use efficiency (-)	0.61	0.39	0.42	0.47	0.47
Specific energy (MJ/kg)	20.4	31.3	31.6	24.7	27.0

The apiaries with more than 150 hives obtained an average production with 47.4% higher (+13.0 kg/hive) than the mean, while the apiaries smaller than 50 hives have obtained productions with 50.1% lower (-13.7 kg/hive) than the apiaries mean in the studied area.

The net energy is negative, having a value that is specific to apiculture, when only honey participates in the accomplishment of the output. It is important to mention that apiaries can also obtain other apicultural products such as wax, pollen, propolis and royal jelly, as well as the fact that apiculture ensures a significant amount of output by the pollination of cultivated and spontaneous plants. For this reason, the average energy efficiency was rather low, the value being close to the result obtained in similar research conducted by Omidi-Arjenaki et. al., 2016.

The superior energy efficiency has been obtained by the apiaries smaller than 50 hives, that have recorded an energy productivity and energy use efficiency higher with 28.1% and 29.1%, respectively, in comparison with the mean (with 0.01 kg/MJ and 0.14 kg/MJ, respectively), and the specific energy lower with -24.5% in comparison with the average (with 6.6 MJ/kg).

These results are justified by the fact that in the apiaries up to 50 hives some of the production factors (such as human labour and cars used for the transport of individuals) can be taken from their own household. That's why beekeepers do not rigorously quantify them. Instead, beekeepers of more than 50 hives need to acquire these factors from the market. Therefore, they must have management skills in order to optimize the consumption of inputs in order to obtain higher productivity.

Since apiaries larger than 50 hives are to be moved in the pastoral, we consider as significant the difference between their average energy efficiency (0.43) compared to the value recorded in the apiaries with less than 50 hives. Mobile apiaries are more productive than the fixed ones, but are less energy efficient and result in a higher net energy loss: 520.38 MJ/hive versus 107.93 MJ/hive. These results recommend the increase of the production capacity in fixed apiaries up to the level of the melliferous potential from the area and the improvement of the efficiency of the activities specific to mobile apiculture.

4. Conclusions

The average energy consumption recorded in Romania's apiaries from the mountain area was 754.9 MJ/hive, and the energy output of 337.6 MJ/hive, given the average honey production of 27.4 kg/hive. The highest energy output was obtained from apiaries with a size of over 150 hives (995.9 MJ/hive). In general, apiaries with more than 50 hives have requested larger quantities of inputs as they move in areas with a high melliferous potential, with the main goal of maximizing productions.

Consequently, fuel accounted for the largest share of the total inputs (40.26%). On the other hand, most beekeepers with apiaries of less than 50 hives make apiculture to satisfy their own honey consumption and to gain extra incomes. They use small quantities of inputs and do not believe they are performing an economic activity.

A secondary, but important place in the structure of the inputs is represented by sugar, with 32.7%. This result is justified by the climatic conditions with low temperatures and prolonged winters, the apiaries from the researched mountain area requiring more honey reserves than those in the plain and hill areas. Beekeepers need to feed substantial quantities of sugar syrup during the periods of time when bees do not have any activity and during fall, in order to provide food for wintering.

This situation adversely affects the level of obtained net energy. The net energy indicator had an average value of -417.3 MJ/hive, but other bee products (wax, pollen, propolis and royal jelly) were not taken into account, as well as pollination. The net energy value was clearly superior in the case of apiaries with less than 50 hives than in the other apiaries.

The structure of the inputs of the researched apiaries is dominated by the indirect inputs (61.9%) represented by fuel and transport, but these inputs do not determine directly the increase of the production. The regression analysis shows that the multiplication factor specific to the direct consumption is 3.5 times higher than the one of the indirect consumption. As a result of this fact, beekeepers could increase the energy performance of apiaries by increasing the share of direct inputs from the total inputs.

Regarding the renewable inputs, which are represented by labour in the apiaries, they had an average share of only 5.1% of the total inputs. The ratio between renewable and non-renewable inputs is a challenge for beekeepers. On the one hand, it is surprising that an activity that is so important for the environment through the effects of pollination has such a large share of non-renewable inputs. On the other hand, the multiplication factor resulting from the regression analysis for renewable inputs is 49.4 times higher than the multiplying factor of non-renewable inputs. Given that the mobility of the hives often leads to the neglect of certain apicultural works, it is necessary to reduce fuel consumption, electricity, track, drugs and sugar consumption in favour of labour consumption.

The efficiency of the used energy was on average 0.47, and the specific energy 27.0 MJ/kg of honey. These values are specific to the energy efficiency of apiculture, if only the honey output is taken into account. It is noted a higher energy efficiency in the case of apiaries of less than 50 hives, compared to other apiaries, which is justified because of the low level of inputs. The lower energy performance of other apiaries is determined by the additional consumption of indirect energy inputs required for the movement of the hives (fuel and track). Another cause is the fact that not always by moving the hives in areas with high melliferous potential guarantees large production, which would compensate in a satisfactory extent for this additional energy expenditure.

The regression models indicate the fact that optimization of labour force inputs, drugs and apiaries mobility, as well as the replacement of the queen can lead to the highest amounts of energy output (651.2 MJ/hive, 526.0 MJ/hive, 525.7 MJ/hive and 504.2 MJ/hive). Under these circumstances, apicultures must increase work productivity, improve the treatment system, reconsider the route, and optimize the distance for the pastoral and increase queen replacement rates. The frequency of queen replacement may be an important vector for increasing the energy efficiency of apiculture in the studied area by association with the use of queens with high genetic potential.

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