Comparison of the energy and economic balance of crop production

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Abstract: The article deals with the connection between energy and economic indicators of crop production in the Czech Republic. Herein, a procedure for the determination of energy inputs and outputs from production based on soil-climatic conditions was outlined. For basic arable crops, other possibilities using the production in the energy sector as well as in relation to soil-climatic conditions were evaluated. The article reviews the production and economic parameters of crop production for potential energy use, such as natural production, energy production, electricity and operational profit. The maximum production parameters are achieved by sugar beet and, consequently, maize for silage. Other energy-efficient crops are alfalfa and clover, but with technological problems in processing of existing biogas technologies. The relationship of production results with production conditions shows that energy use of crops is more appropriate in marginal areas, as the margins for energy purposes are approximately constant, while for food purposes in marginal areas, it decreases. The different economic characteristics of crops for food purposes are mainly owe to higher quality production in lower areas, which is reflected in the price of production.

Keywords: energy, crops, operating margin, soil-climatic condition, maize, alfalfa

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1 Introduction

For political decision-making in the area of support for agricultural production, knowledge of the development of both economics and energy related to the production of crops in specific localities is of great importance when focusing on the potential for further development of energy crops. Previous developments in the promotion of renewable energy sources have expanded the area of energy crops with support for these types of energy sources. The question then arises as to how to further support the production of renewable energy sources, whether to maintain the existing range and/or reduce or increase production depending on the crops grown.

The need for further exploration of future energy consumption is recommended by the European Commission (EC) (Bertoldi et al., 2018). An increasing demand for primary energy in basic sectors was identified to 1.5% in 2015 and depended on the individual trend of national consumption. An overview of energy consumption in the production of agricultural products in Europe was supplied by the Slesser and Wallace (1981). The meaning and direction of energy in agricultural production is also processed within national states, e.g., in the Czech Republic. The main trend today is to reduce greenhouse gases (Koelemeijer, 2013), but building up energy flows is a necessary basis for a comprehensive assessment of

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agricultural production.

The main contribution of this work is the combination of the economic and energy assessment of agricultural production, which has more impetus and importance than the economic evaluation itself. The work herein concentrates on the assessment of the actual process of energy production and profitability of land, not on the competitive opportunities of obtaining energy using alternative energy sources, and reveals the main potential space for the use of agricultural production in the context of the options exercised for the production of renewable energy.

The energy obtained from agricultural production depends, in addition to the energy consumption of machinery in technological operations, to a great extent on the energy of fertilizers and pesticides, and there is a need to expand on the energy assessment of more crops (Slesser and Wallace, 1981). The analysis of energy efficiency is very important in different crops. According to Jacobs et al. (2016), the greatest energy efficiency is achieved with silage maize, but sugar beet yields have a similar efficiency under certain conditions. The goal of this paper is to evaluate the relationships of all major crops based on a detailed assessment of all crop inputs and outputs.

Comparison of economic and energy indicators is also important, and the corresponding principal comparisons, which rely on soil and climatic conditions, are important. Available literature states that energy efficiency also depends on soil-climatic conditions (Bertoldi et al., 2018; Jones, 1988), but the dependence on soil and climatic conditions has not been traced, e.g., Deike et al. (2008). However, the level of inputs should be in line with the yield conditions in place. Several indicators for monitoring energy consumption have been proposed in the literature (Hulsbergen et al., 2001).

A variety of sources are available for self-assessment of energy performance. In the Czech Republic, the energy requirements of Preininger were addressed in 1987, which described the complete assessment of inputs and outputs in agricultural production. Another source is the database obtained in the framework of the research of Institute of Agricultural Economics and Information (Jelinek et al., 2011) based on the methodology of the French database, Planete (2002). Under the production conditions of the corn-beet area, the relationship between energy inputs and production varies is that one unit of energy input can produce an average of five units of energy contained in grain and straw of winter wheat. The value differs, in particular, depending on the hectare yields of the year. Improved energy efficiency is expected to be achieved by businesses with better soil and environmental conditions and a larger area of wheat (characterized, in particular, by joint-stock companies or cooperatives). Higher efficiency is achieved in years with more favorable weather conditions (2007/08). Newer sources also offer work (Preininger, 1987) dealing with indirect energy input into the production process. In terms of soil quality, companies with more favorable soil-ecological conditions achieve higher yields and correspond to the amount of energy contained in wheat per hectare. In the case of the classification of enterprises by legal form, an average higher output per hectare of wheat is accomplished on larger farms.

Rajbhandari and Zhang (2018) admonished intensive energy efficiency policy as an important factor for economic growth, especially as an amendment of energy policy that provided economic growth over the long run, particularly in less developed economies.

Hrčková et al. (2016) demonstrated the highest energy crop output in corn silage and its energetic potential in terms of fuel energy requirements versus lower energy hay providers of grassland represented by 46.3% and approximately two-thirds of supplementary energy, respectively. Schahczenski (1985) presented in his energetic productivity analysis a growing trend in USA efficiency, maximising output energy unit per energy input since 1973 and 1982 in crop production for wheat 36%, soybean 26%, and corn 22%.

Ansari et al. (2017) quantitatively assessed the lowest energy-use efficiency in farmer´s practices with increased energy demand and yield, as well, in the range of 21,224.29 MJ ha^{-1} to 24,132.15 MJ ha^{-1} (27.94%), respectively, for irrigated wheat fields that, on the contrary, provided the highest efficiency.

Rossnera et al. (2014) demonstrated sugar beet as the highest energy input-output efficient crop, with inorganic nitrogen application (124 kg, N) as the second highest energy-yielding result (105.9 GJ ha^{-1}) compared to the optimum provider of N (128 kg ha^{-1}) that enhanced maximum yield up to 120.9 GJ $ha^{–1}$. Crop energy analysis led by Venturia and Venturi (2003) recognized sugar beet as the currently most efficient source of renewable energy, implementing a threshold of 20 GJ ha^{-1}, as a minimum gain, for European green policy. Tsatsarelis (1993) calculated that total winter wheat energy input varied between 16,000 MJ ha^{-1} and 26,000 MJ ha^{-1}, recognizing fertilizers and fuel as the major energy inputs, with 81% to 84% of energy requirements fulfilled. The energy output of the Greek farming system, produces 2500 kg $ha^{–1}$ to a maximum of 6000 kg $ha^{–1}$, corresponding to 38,000-91,000 MJ ha^{-1}. The additional energy gained from bailed straw was 4,500-6,000 kg ha^{-1}, representing 74,000 - 98,000 MJ ha^{-1}.

Unakıtan and Aydın (2018) identified wheat, with respect to energy output, as a more efficient crop (81,720 MJ $ha^{–1}$ and 38,250 MJ $ha^{–1}$), less energy demanding (23,231 MJ ·ha^{-1} and 10,139 MJ ha^{-1}), and conformable to output. Further, likewise, they defined wheat by means of economic indicators, such as benefit-cost ratio (1.2 for wheat and 1.02 for sunflower), as a more favorable crop versus sunflower. A comparative economic study led by Ziaei et al. (2015) determined that barley as more energy efficient and thus an economical crop for cultivation compared to wheat in the harsh Iranian climate on the basis of energy input (25,655.81, 32,492.97 MJ ha^{-1}), output (49,800.87, 48,517.24 MJ ha^{-1}), energy use efficiency (1.94, 1.49), and the amount of energy productivity in tested fields (0.066, 0.056), respectively.

Gemtos (2013) investigated possible energy use for rapeseed, sunflower and sweet sorghum and found the possibility of using all of these crops for transportation.

Asgharipour et al. (2012) stressed human labor (0.36) and machinery (0.22) energy, as the most vital indicators in sugar beet production in Iran, and were among others identifying direct energy (57%) as the main consumer of total energy inputs (42,231.9 MJ ha^{-1}), and the total sum of chemical fertilizers inputs (29%), as well. Sugar beet is not considered economical, at a total of 42,231.9 MJ ha^{-1}, which is poor energy performance. Hence, cost reduction in fertilizers, chemicals, and diesel consumption, along with the use of appropriate tillage management, may represent the right answer.

According to dynamic forage systems (DFS) (Tabacco et al., 2018) based on alfalfa for dairy farms render not only economical benefits but environmental ones, too, compared to Italian ryegrass with conventional systems. DFS in Italy, as the results show, exhibit increases in yield and qualitative parameters, such as dry matter (77% and 55%), crude protein and metabolizable energy (ME), with a likewise reduction in fertilizers converted in 1GJ of ME. Comparative corn silage and alfalfa production analysis led by Fathollahia et al. (2018) assessed the energy, economic, environmental, and the specific individual and general role of the production model, identifying silage corn as less efficient (2.4 GJ t^{-1} vs. 2.6 GJ t^{-1}) on account of a higher fertilizer-consumption ratio, energy use per ton of dry matter (8.0 GJ t^{-1} vs.15.8 GJ t^{-1}), and energy-use efficiency (6.1 vs. 3.3), whereas it scored a higher benefit-to-cost ratio (2.55 vs. 2.27) and indicated negative recognition of environmental depletion.

Kuesters and Lammel (1999) observed a linear relationship between increasing energy input into the total energy system of winter wheat and sugar beet in Europe and increasing N fertilizer application. Further findings revealed that low production intensity resulted in the highest energy output/input ratio. When N application was restricted, total energy input decreased to 7.5 GJ ha^{-1} for winter wheat and 8 GJ ha^{-1} for sugar beet, whereas 17.5 GJ ha^{-1} and 16 GJ ha^{-1} were the values, respectively, with conventional fertilization.

Modeling of production systems for biomass production was dealt with by Mishoe et al. (1984), which supported the development of models for the comprehensive assessment of commercially feasible production systems.

The existing methods of evaluation of production in the Czech Republic employing valued soil-ecological units (the official abbreviation in Czech is BPEJ, about 2200 units) and utilization of functional relationships in the assessment of yield dependence on inputs were used for energy quantification of the production process. Energy efficiency of production is compared with soil profitability. BPEJ can be simply described using the main soil-ecological units, in the Czech Republic standardly referred to as HPKJ

Based on the literature review, it can be stated that the determination of energy efficiency and production inputs dealt with a number of authors who have monitored energy efficiency in the production of various crops. The main crops that were the subject of monitoring were maize, winter wheat, oilseeds, and forage crops. The tracking object was usually the production technology. The purpose of this contribution was to establish a link between the economic and energy efficiency of crop production according to soil and climatic conditions and identify crops and areas where it may be beneficial to promote energy production.

The article also employs background materials that are part of the database system of soil and climatic conditions in the Czech Republic (Voltr et al., 2011, 2012a, 2012b). Individual crops, in accordance with the reality of the records of Land Parcel Identification System (LPIS), were evaluated by individual operations in technologies used in crop production. The system is not directly linked to animal production but use the appropriate crop structure and valuation.

2 Materials and methods

The individual operations in crop production and individual crops were assigned a working set by expert recommendations on appropriate technology, established on the basis of the monitoring operation. Each operation is individually evaluated by the energy source (tractor) and a working machine. Each material and labor cost are also allocated to each working unit, therefore providing the basis for an economic and energy assessment of the cost of growing the whole crop. The economic results are based on the published methodology (Voltr et al., 2012a, 2012b) and the updated data is based on the annual survey of economic indicators in agricultural operation, which, in turn, is based on the evaluation of approximately 200 enterprises (Poláčková et al., 2010).

Yield of crops, depending on soil and climatic conditions, are based on the observed long-term yields on valuated soil-climatic units (BPEJ) that are continually updated. The yield of the crops is subsequently valued in accordance with the field survey and also converted to energy.

As a foundation of this work, the method for determining the operating profit (difference of revenues and total energy costs) was applied at the level of individual crops, which was also transformed into the energy balance. Energy costs were determined on the basis of the technological description of work operations.

2.1 Determination of energy balance.

2.1.1 Energy costs of parameterized production

Energy cost estimation is based on optimized technological procedures for individual crops as a consequence of established procedures (Voltr et al., 2011) and in accordance with recognized principles. The energy costs of parameterized production (*ECP*, *MJ*) represents the amount of energy costs to be incurred to implement crop production while maintaining an ecological approach to production (Equation 1).

$$ECP_{i,p}=EIGT_{i,p}+ECT_{i,p}+ECM_{i,p}+FEC_{p,PA} \qquad (1)$$

Where, i represents specific soil and climatic conditions according to BPEJ, p represents a specific crop that is the subject of the calculation, PA represents production area, EIGT represents unit energy costs for the implementation of growing technologies for crops without transport energy energy costs (MJ ha^{-1}), ECT represents energy costs of transport, including the energy costs associated with the transport of crop production from land up to 5 km (MJ ha^{-1}), ECM represents energy unit cost of material, including the energy costs of fertilizers, chemical protection and auxiliary material (MJ ha^{-1}), and FEC represents fixed energy costs of crop production in a given production area (MJ ha^{-1}). Total ECP is expressed by MJ ha^{-1}. The energy costs of implementing cropping technologies for crops in crop rotation is carried out on the basis of energy costs normatives.

The calculation of the unit energy costs of the growing technologies for EIGT was determined according to Equation 2:

$$EIGT_{i,p}=\sum\nolimits_{r}EIGTO_{i,p} \tag{2}$$

Where, $EIGTO_{i,p}$ is unit energy costs for individual technological operations (MJ ha^{-1}).

EIGTO is given by the sum of the energy costs of workstation.

$$EIGTO_{i,p,r}=NTO_{i,p,r}(E_{i,p,r}+EWS_{i,p,r}+ELL_{i,p,r}) \tag{3}$$

Table 1 Used energy of machines per crops

Crops	All operations without chemical application and transport (MJ ha^{-1})	Chemical application (MJ ha^{-1})	Transport (MJ ha^{-1})
Potatoes	1 115	26	132
Sugar beet	595	36	185
Spring barley	462	36	248
Spring barley malting	410	48	248
Winter barley	415	48	248
Clover	363	0	55
Whole-grain silage maize 32%	473	12	76
Grain corn	475	18	76
Poppy	226	84	17
Oat	362	18	248
Winter wheat (non-food)	364	54	248
Winter wheat food	368	60	248
Winter rape	510	127	223
Winter triticale – rytus	344	36	223
Alfalfa	509	0	176
Winter rye	247	36	223

Note: Calculation for the conditions of the Czech Republic is based on normatives of Planete (2002) and Preininger (1987)

Where, NTO represents number of repetitions r-th technological operations within the proposed p-growing technology of crop during the year. With the calculation methodology, the chemical protection operation is based on the number of applications monitored in individual soil-climatic conditions, $E_{i,p,r}$ represents the standard energy of fuel consumption for the r-th technological operation (MJ ha^{-1}), $EWS_{i,p,r}$ represents unit cost of the working set used to perform the r-th technological operation (MJ ha^{-1}), $ELL_{i,p,r}$ represents the unit energy costs of live labor during the r-th technological operation (MJ ha^{-1}). The calculation of the fuel consumption normative set is calculated for each technological operation. For diesel, the energy consumption was 40.7 MJ L^{-1} (Planete, 2002).

Summary for each machine and crop used in the working set was, in addition to the economic evaluation, converted to energy consumption as in Table 1.

The energy costs of the fuel consumed (*jEF*) is differentiated on the basis of the normative attributes slope, production area, and type of soil on a plot (l ha^{-1}) by technological processes of production of crops.

$$EG_{i,p,r}= CE_{i,p,r}\times REC \tag{4}$$

Where, *EG* represents energy gain (MJ ha^{-1}), *CE* represents diesel consumption in liters (dm^3 ha^{-1}),, *REC* represents rated energy content,(MJ dm^{-3}) *r* represents technologial operation, *p* represents crop, and *i* represents BPEJ.

The calculation of the unit energy costs of the kit for the individual plant operations of each crop is determined separately for light and medium soils and heavy soils. The calculation accepts increased energy costs of mechanization in connection with the need for the equipment of the company to carry out the works within the narrow time span given by soil workability (MJ ha^{-1}).

The energy cost calculation of $uEM_{i,p,r}$ is based on energy for amortization as well as energy for repairs and storage.The energy to be repaired is in line with Czech procedures (Research Institute of Agricultural Engineering, p.r.i.,) applied as part of the cost proportional to fuel consumption. The cost of repairs and fuel costs range from 33% to 47% of the fuel price, and the cost level for the calculation was set at 40% of the fuel price. For the energy cost conversion, the ratio to fuel energy was used.

$$uEM_{i,p,r}= uEA_{i,p,r}+uER_{i,p,r}+uES_{i,p,r} \quad (5)$$

where, *uEA* is energy of amortization from the weight of machines (Table 2, MJ ha^{-1}),), *uER* is energy of repairs (MJ ha^{-1}),, *uES* is energy for storage of technology (MJ ha^{-1}) and $uEM_{i,p,r}$ *is expreesed in* MJ ha^{-1},

The unit energy costs of labor, *uDLEi,p,r*, is determined according to Equation 6:

$$uDLE_{i,p,r}=1.36\ hDLE_{i,p,r} \times kWO_{i,p,r}/hP_{08} \quad (6)$$

where, $hDLE_{i,\ p,\ r}$ is the hourly rate of direct labor energy costs during operation (MJ h^{-1}), hP_{08} is the hourly performance of a specific work set in total setup time (ha h^{-1}), and 1.36 is the constant for the conversion of the hourly rate of direct labor energy costs for the operation of the machine to the total energy costs of the enterprise for live work. The constant is given by offsetting the 34% rate for social and health insurance along with 2% for contributions to the fund of cultural and social needs of the enterprise.

For each technology operation for growing technologies of each crop, the normative power ($hDLE_{i,p,r}$) of the standard technologies is determined for each technological operation of the growing technology of each crop.

Selection coefficient of working operation (*kWO*) for a particular technological operation is performed in the calculation based on the attributes of slope, soil texture, and type of technological operations.

Transport energy costs, $uTEC_i$, includes energy costs associated with disposal crop production. These energy costs are set normative per hectare at a specified yield level. The final amount of these energy costs is derived from the yield of a given crop in the specified soil and climatic conditions.

Transport energy costs, $uTEC_i$, are derived in Equation 7:

$$uTEC_{i,p}=uTP_{i,p}/uYC_{i,p} \times YC_{i,p} \quad (7)$$

where, $uTP_{i,p}$ is normative energy costs of transporting production per one hectare of crop for a specified level of yield (MJ ha^{-1}), $uYC_{i,p}$ is yield level of crops for which the transport cost norms are used (t ha^{-1}), and $YC_{i,p}$ is yield of parametrized crop production per hectare in given soil and climatic conditions (t ha^{-1}).

The unit energy costs of the material, $uEM_{i,p}$, includes the energy costs of fertilizers, protective chemicals and auxiliary material (MJ ha^{-1}) and is determined as Equation 8:

$$uEM_{i,p}=uEBM_{i,p}+uEAM_{i,p} \quad (8)$$

where, $uEBM_{i,p}$ represents unit energy costs for basic material defined at BPEJ (MJ ha^{-1}) and $uEAM_{i,p}$ represents unit energy costs of the auxiliary material. The energy costs of the auxiliary material is part of the total energy costs of production of the crop within the framework of the Institute of akricutural economics and information (IAEI) survey (MJ ha^{-1}).

uEBM base material is determined by Equations 9 and 10. It consists of fertilizer energy costs by dose nitrogen and other elements (P, K, Mg, Ca, S) in proportion (Klír, 2008) to supplied manure, organic fertilizer, mineral fertilizers based on naturally determined doses derived from a statistical analysis of N dose, and unit prices based on crop yields. Doses of nutrient crops are set individually for each HPKJ. The energy costs of fertilizer for each element are determined based on the price analysis of fertilizers sold.

In addition, the energy costs of chemical protection of seeds and seedlings, in addition to nutrient intake, is included in the energy costs of basic material by crop at BPEJ *uEM* (Equation 9). The energy costs of chemical protection, seeds, and seedlings are compiled for each crop on the basis of the cost-saving survey of individual production areas.

$$uEM_{i,p}=uEBM_{i,p}+ES_{i,p} \quad (9)$$

where, *uEBM* represents unit energy costs for basic material defined for BPEJ (MJ ha^{-1}), $ES_{i,p}$ represents the energy costs of seed and seedlings on production area defined for cost investigations by IAEI (MJ ha^{-1}). Energy costs are given by the sum of seeds.

The energy costs of basic material by crop on BPEJ: *uEBM* is determined according to Equation 10:

$$uEBM_{i,p}=uEMOF_{i,p}+\sum_{z,i,p}uEMF_z+uECH_{i,p} \qquad (10)$$

where, *uEMOF* represents energy of manure and organic fertilizers resulting from statistical monitoring and normative N content in kilograms per tonne of manure (MJ ha^{-1}) (Klír, 2008), calculated from the manure dose for each of the crops at BPEJ, *uEMF* represents energy of mineral fertilizers (summing up energy costs of fertilizing elements, N, P, K, and Ca), *z* represents individual elements in MJ ha^{-1}, and *uECH* represents energy of chemicals on BPEJ (MJ ha^{-1}).

The actual consumption of mineral fertilizers is derived from the difference between the total nutrient demand for the crop and nutrient load in organic fertilizers (manure). The total energy costs of mineral fertilizers (*uEMF*) is derived from Equation 11:

$$uEMF_i=TSDN_i-Em_i \qquad (11)$$

where, $TSDN_i$ represents the total standard dose of nutrients (N, P, K, and Ca) in kg ha^{-1} which is to be supplied to the respective crops for securing the yield formation, *Em* represents nutrient doses (N, P, K, Ca)) in kg ha^{-1} delivered in manure and organic fertilizers.

Table 2 Conversion coefficients for calculating the energy contained in pure nutrients of mineral fertilizers

Type of Nutrient	Value	Reference
N (MJ kg^{-1})	82,5	Preininger (1987)
P_2O_5 (MJ kg^{-1})	17,7	Preininger (1987)
K_2O (MJ kg^{-1})	9,6	Preininger (1987)
CaO (MJ kg^{-1})	2,8	Planete (2002)

The energy of bread manure according to Planete (2002) is 463 MJ t^{-1}.Dosing of nutrients is derived from the crop yield of BPEJ and discharge of nutrients for yield formation in MJ kg^{-1} (Table 2).

Energy costs of chemical protection of crops on BPEJ are determined according to Equation 12:

$$uECH_{i,p}=EChA_{i,p}\ nCP_{i,p} \qquad (12)$$

where, *EChA* represents the energy of chemical applications derived from the technology of individual crops by production area, $nCP_{i,p}$ represents the number of chemical applications per BPEJ derived from the statistical survey (Voltr et al., 2012a).

For a complete estimate of all energy consumed in crop production and comparing the same conditions for operating profit, it was necessary to estimate the fixed costs of production. Their magnitude was estimated from the fixed cost share of the cost of production in monetary terms. The energy costs of fixed costs were then determined by the same ratio based on the average variable energy production costs. Operating profit of the crops was in the same proportion to fixed costs as for energy.

Energy equivalents for inputs of chemical application in crop production (summarized by Hulsbergen et al., 2001; according to different authors, modified): Herbicides 288 MJ kg^{-1}, Fungicides 196 MJ kg^{-1}, and Insecticides 237 MJ kg^{-1}. Other chemical protection agents: growth regulators and mordants were calculated with energy of 237 MJ kg^{-1} of active substance (Planete, 2002).

Active substance dosages (g ha^{-1}) in applied pesticide formulations per year in the total sum for the envisaged applications is to ensure standard average production technologies in the Czech Republic (Table 3).

Table 3 Quantity of chemical ingredients by crops (g ha^{-1})

Crop	Herbi-cides	Fungi-cides	Insecti-cides	Growth regula-tors	Mordants	Active substances - total
Winter rye	945	454.5	7.5	1080	16.8	2 503.8
Spring barley malting	183.125	434	7.5	460	14.4	1 099.0
Spring barley spring	153.125	334	7.5	100	14.4	609.0
Winter barley	945	490	7.5	1560	14.4	3 016.9
Oat	153.125	0	5	0	0	158.1
Triticale	195	454.5	0	0	21.6	671.1
Winter rape	2521.9	280	469.5	480	4.8	3 756.2
Poppy	441	1725	396	0	0	2 562.0
Potatoes for consumption	1850	11040	12	0	4320	17 222.0
Sugar beet	1482.5	334	7.5	0	109.2	1 933.2
Maize silage	1208.5	0	0	0	0.875	1 209.4
Alfalfa	960	0	0	0	0	960.0
Clover hay	487.5	0	0	0	0	487.5

2.1.2 Energetic and economic profit from the crop production

Revenues of production is calculated according to Table 4 with the yields of crops according to BPEJ.

Table 4 Energy of the main and by-product

Crop	Energy of main production (MJ kg^{-1})	Energy of the by-product (MJ kg^{-1})	Unit of production
Potatoes	3.45	3	Kg brutto
Sugar beet	3.89	1.76	Kg brutto
Spring barley	15.93	13.73	Kg brutto
Barley spring malt	15.93	13.73	Kg brutto
Winter barley	15.48	13.73	Kg brutto
Clover (hay)	13,06		Kg brutto
Corn for silage	5.984		Kg brutto
Corn for grain	16.21	13.50	Kg brutto
Poppy	15.48	13.69	Kg brutto
Oat	17.45	13.38	Kg brutto
Wheat	15.82	13.46	Kg brutto
Winter rape	25.22	13.64	Kg brutto
Triticale	16.22	13.46	Kg brutto
Lucerne (haylage)	6(25)		Kg brutto
Rye	15.48	13.46	Kg brutto

Note: Source: Planete (2002)

Several calculations have been selected to compare the energy and economic performance of the economy. Operating profit (OP_p) was determined as the difference between income and expenditure in cultivation in monetary terms in EUR ha^{-1} (Equation 13).

$$OP_p=\sum_i(SR-PC)A/\sum_i A \tag{13}$$

Where, sales revenue (*SR)* represents total production per hectare (EUR ha^{-1}) including by-product of straw, which is necessary for a complex comparison of production between forage crops and other crops grown for the main and by-products. Production costs (*PC)*, EUR ha^{-1}, are total cost of production, including overhead costs (EUR ha^{-1})., *A* is the area of each BPEJ (ha). The energy operating profit in EUR ha^{-1} (*EOP)*, is similarly calculated, including the straw (Equation 14).

$$EOP_p=\sum_i (EP-EC)A/\sum_i A \tag{14}$$

Where *EOP* is differencebetween Energy of production *EP* in MJ ha^{-1} and cost of production *EC* in MJ ha^{-1}.For a complete comparison, the margin of energy (*EM*) and food production (*FM*), both without dimension can also be assessed (Equation 15):

$$EM_p=EOP_p/EP_p;\ FM_p = OP_p/SR_p \tag{15}$$

3 Results and discussion

There is much to be learned from the point of view of the interaction between energy and economic benefits. The basis for assessing the suitability of crops for energy purposes is, of course, energy production and energy profits after deducting energy costs, but at the same time, the economic benefit of food production needs to be evaluated. For this purpose, energy and economic crop margins were determined to allow for the assessment of crop efficiency in both modes of application. The use of crops for energy purposes is particularly relevant given the large difference in energy and economic margins.

The results of the economic and energy balances for the current operating conditions of major crops are shown in Figure 1. The results showed that the largest energy production was from sugar beet, maize, and rapeseed. In the case of sugar beet, the total energy production was 330 GJ ha^{-1} and the total energy production cost was 24 GJ ha^{-1}. The award crowns in production was achieved in the amount of € 2,556, including price of tops. The energy margin was 92.8% and the economic margin was 17.3%. For a better comparison of food and energy production, the share of the energy and economic margin, which stands at 5.4, can be utilised to express the difference of margins - 0.775.

Potatoes, which had the highest operating profit, also reached the highest sales revenue, but the energy profit was very poor. For biogas stations, the most commonly used silage maize achieved the second greatest energy and operating profit. Owing to the high costs of growing sugar beet and challenging growing conditions, the maize silage is the first choice for biogas stations.

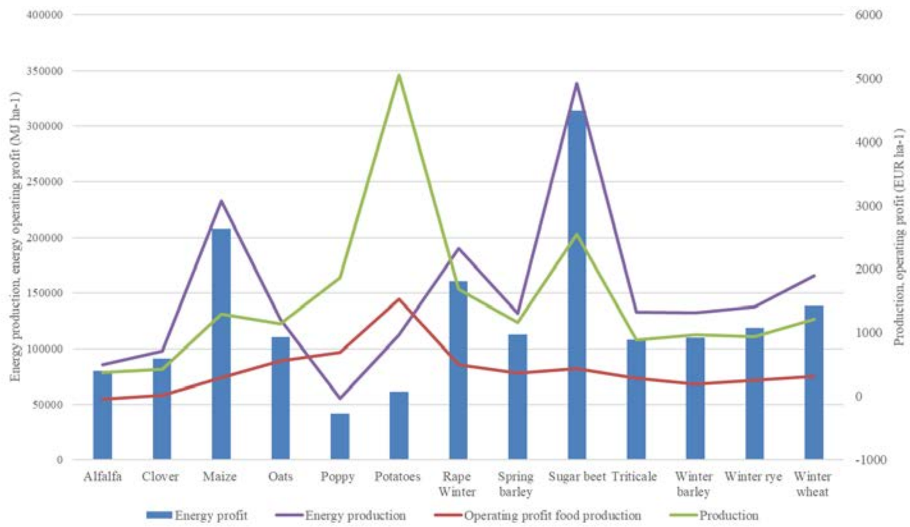


Figure 1 Profit, energy profit, and production of main crops in agriculture

Figure 2 depicts the high energy value of clover and alfalfa margins along with a very low margin of production for food purposes (for livestock production as feed). Silage maize and sugar beet also achieved a significant difference between the two margins. An indicator of share is most pronounced in clover, with other crops not significantly deviating. Potatoes have the greatest gain with this comparison depicting the achievement of a lower difference between energy and economic profit, therefore unsuitable for energy production.

The biggest difference between the margins from food and for energy production is reached for alfalfa and clover, in terms of costs incurred, and these crops are most energy-efficient.

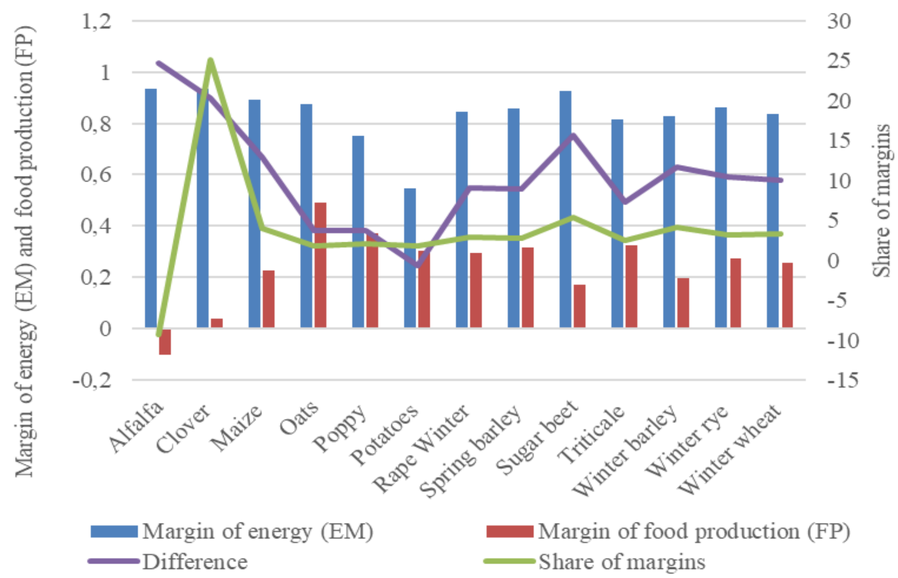


Figure 2 Values of crops in terms of margin of energy and food production, their difference, and their share.

When converting energy production to electricity production prices with the electricity price of 0.139 € kWh^{-1} (the purchase price in the Czech Republic from biogas stations) to the production of biogas, the price obtained from the production of electricity is compared with the operiting profit seen in Figure 3. The best profit (excluding the cost of electricity production technology) is reached by sugar beet with 2,500 € ha^{-1}, and the profit of silage maize is about 1,350 € ha^{-1}. Alfalfa and clover reached profit about 500-600 € ha^{-1}. In order to compare the profit of production of individual crops, it is also appropriate to take into account the production of the by-crop. The amount of profit generated by electricity generation is influenced by the secondary profit especially for sugar beet and energy in the shield is the main reason for high profit in electricity generation.

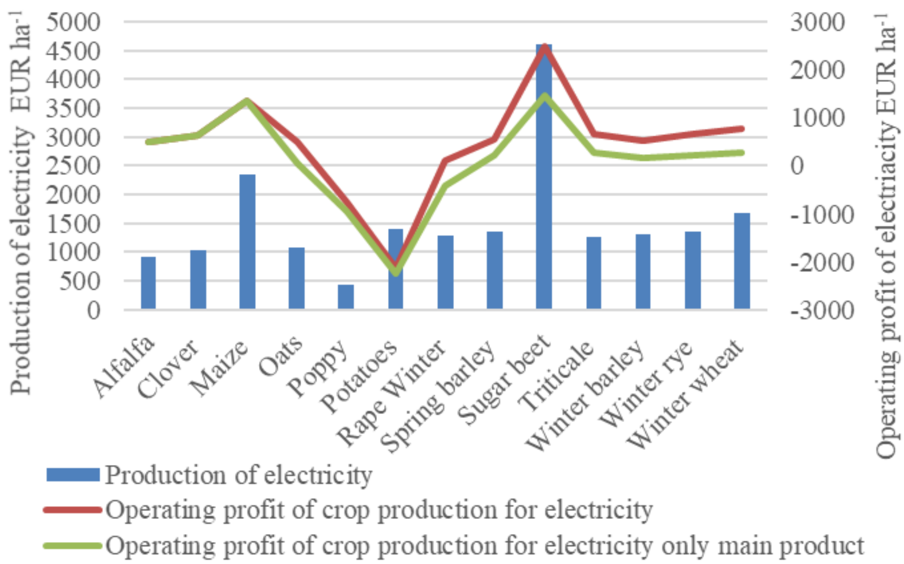
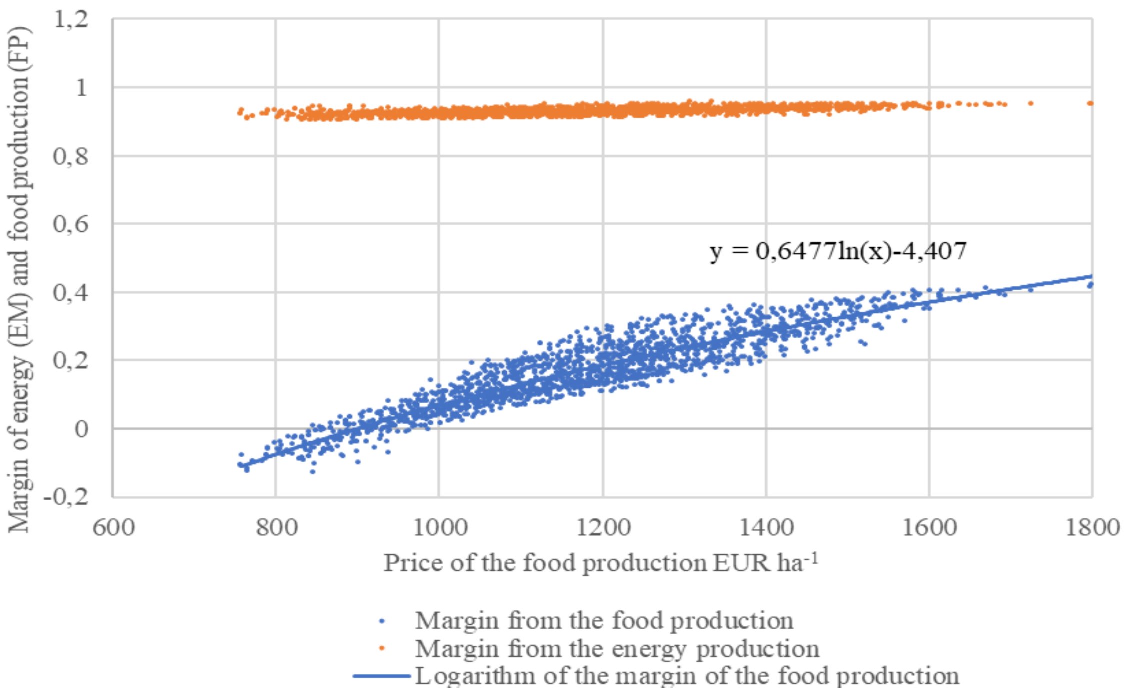


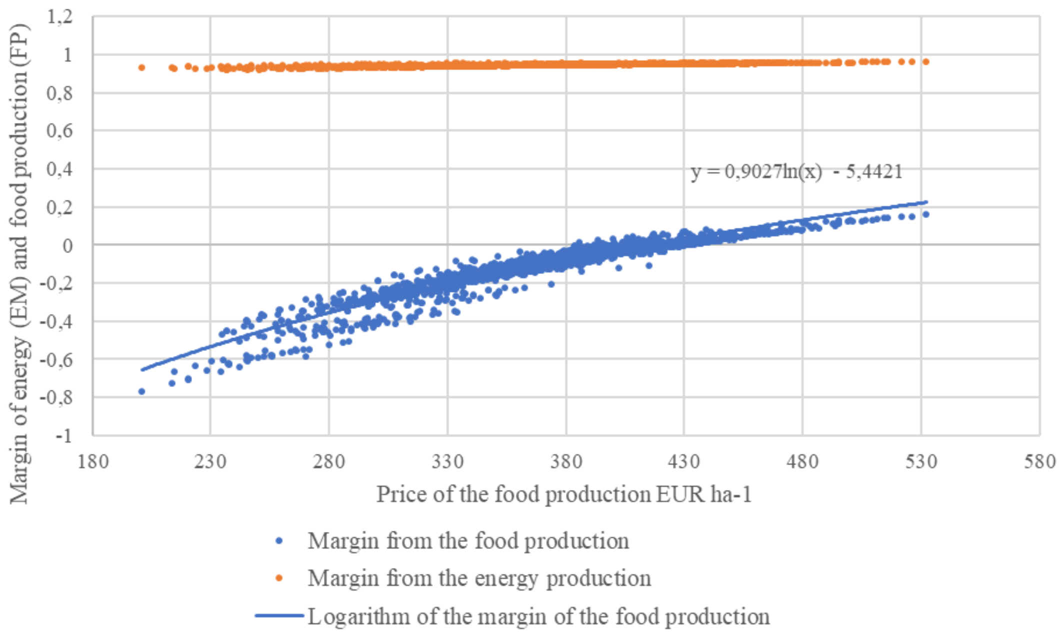
Figure 3 Production of electricity of main crops and operating profit of crop production

The cereals are in the energy rating at approximately the same level, but slightly exceeds the profit of winter wheat.

The margins relationship between food production and energy production is depicted in Figure 4 for maize silage (a) and alfalfa (b). It is seen that there is an increase in the food margin compared with the energy margin as production increases. From this dependence, it can be concluded that the use of energy production is particularly suitable for productive, albeit less favorable envelopes.



(a) Maize silage



(b) alfalfa

Figure 4 Food (feed) and energy margins

4 Conclusion

A comparison of agricultural crop production results showed that crops with the highest energy effect were sugar beet and maize silage, but other criteria such as the energy margin can also be assessed. It turned out that the production of perennial fodder was competitive despite the relatively low production of energy, but there were problems in the technological processing of biomass for biogas stations. However, it can be concluded that the margins of power production even with perennial forage is slightly higher than in corn silage. It is also possible to say that there are also the cultivation advantages of these crops, especially with the influence on soil structure, mainly alfalfa.

The impact of soil fertility on the economic parameters of crop margin has shown that food production margin increases with production size, unlike the margin for energy production that is almost independent of soil fertility.

For this reason, the possible development of support for the production of biomass for energy purposes is suitable for production, especially in marginal areas where the highest margins gap for energy and food purposes is reached. In any case, however, the production of biomass for energy purposes should not be based on significant reductions in food production and should serve primarily as a supplement. In particular, the use of alfalfa and clover can provide added value on hardened soils, where these crops can improve soil structure.

Knowing the behavior of crops in concrete soil-climatic conditions allows for the preparation of a proposal for optimal compliance of energy and food needs in place. The different economic characteristics of crops for food purposes are mainly based on higher quality production in less efficient areas, which is reflected in the price of production.

Further research will be devoted to combining the energy, economic and emission effects of energy production from biomass.

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References

Ansari, R., M. U. Liaqat, H. I. Khan, and S. Mushtaq. 2017. Energy efficiency analysis of wheat crop under different climate and soil-based irrigation schedules online. *Proceedings*, 2(5):184.

Asgharipour, M. R., F. Mondani, and S. Riahinia. 2012. Energy use efficiency and economic analysis of sugar beet production system in Iran: a case study in Khorasan Razavi province. *Energy*, 44(1): 1078-1084.

Bertoldi, P., F. Diluiso, L. Castellazzi, N. Labanca, and T. Serrenho. 2018. *Energy Consumption and Energy Efficiency Trends in the EU-28 2000-2015, Efficiency Trends of Energyrelated Products and Energy Consumption in the EU-28*. Publications Office of the European Union, JRC Science for Policy Report, Ispra (VA), Italy: 170.

Deike, S., B. Pallutt, B. Melander, J. Strassemeyer, and O. Christen. 2008. Long-term productivity and environmental effects of arable farming as affected by crop rotation, soil tillage intensity and strategy of pesticide use: A case-study of two long-term field experiments in Germany and Denmark. *European Journal of Agronomy*, 29(4): 191-199.

Fathollahia, H., S. H. Mousavi-Avval, A. Akram, and S. Rafiee. 2018. Comparative energy, economic and environmental analyses of forage production systems for dairy farming. *Journal of Cleaner Production*, 182: 852-862.

Gemtos, T. A., C. Cavalaris, C. Karamoutis, A. Tagarakis, and S. Fountas. 2013. Energy analysis of three energy crops in Greece. *CIGR Journal*, 15(4): 52-66.

Hrčková, K., Š. Pollák, N. Britaňák and R. Hašana. 2016. Energy balance of chosen crops and their potential to saturate energy consumption in Slovakia. *Journal of Central European Agriculture*, 17(2), 433-446.

Hulsbergen, K. J., B. Feil, S. Biermann, G. W. Rathke, W. D. Kalk, and W. Diepenbrock. 2001. A method of energy balancing in crop production and its application in a long term fertilizer trial. *Agric Ecosyst Environ*, 86:303-21.

Jacobs, A., W. Brauer-Siebrecht, O. Christen, P. Götze, H. J. Koch, J. Rücknagel, and B. Märländer. 2016. Silage maize and sugar beet for biogas production in crop rotations and continuous cultivation – energy efficiency and land demand. *Field Crops Research*, 196: 75-84.

Jelinek, L., T. Medonos, J. Curtiss, J. Humpál, D. Šmejkalová, J. Špička, and V. Vilhelm. 2011. *An economic system for assessing the performance of agricultural holdings, respecting the principles of sustainable management of natural resources. (Ekonomický systém hodnocení výkonnosti zemědělských podniků respektující principy trvalé udržitelnosti hospodaření s přírodními zdroji)*. Final Report of Research project MoA QH71016, Prague, Czech Republic: IAEI.

Jones, M. R. 1988. Analysis of the use of energy in agriculture-aproches and problems. *Agricultural Systems*, 29: 339-355.

Klír, J. 2008. *Framework methodology of plant nutrition and fertilization (Rámcová metodika výživy rostlin a hnojení)*. Prague, Czech Republic: CRI.

Koelemeijer, R., J. Ros, J. Notenboom, P. Boot, H. Groenenberg, and T. Winkel. 2013. EU policy options for climate and energy beyond 2020. Hague: PBL Publishers.

Kuesters, J., and J. Lammel. 1999. Investigations of the energy efficiency of the production of winter wheat and sugar beet in Europe. *European Journal of Agronomy*, 11(1): 35-43.

Mishoe, J. W., J. W. Jones, D. P. Swaney, and G. G. Wilkerson. 1984. Using crop and pest models for management applications. *Agriculture Systems*, 15(3): 153-170.

Planete. 2002. *Energy analysis of farms and global warming power. Method and results on 140 French farms. (Analyse énergétique d'exploitations agricoles et pouvoir de réchauffement global. Méthode et résultats sur 140 fermes françaises.)*. Database researcher results, Dijon, France: ENESAD.

Poláčková, J., J. Boudný, B. Janotová, and J. Novák. 2010. Methodology for calculation of energy costs and revenues in agriculture. Metodika kalkulací nákladů a výnosů v zemědělství. Prague: IAEI, 73.

Preininger, M. 1987. Energy assessment of production processes in crop production. Prague: ÚVTIZ.

Rajbhandari, A., and F. Zhang. 2018. Does energy efficiency promote economic growth? Evidence from a multicountry and multisectoral panel dataset. *Energy Economics*, 69: 128-139.

Rossnera, H., C. Ritz, and A. Astover. 2014. Optimisation of fertiliser rates in crop production against energy use indicators. *European Journal of Agronomy*, 55: 72-76.

Schahczenski, J. J.. 1985. Energetic analysis of Missouri crop farms online. *Energy in Agriculture*, 4: 253-269.

Slesser, M., and F. Wallace. Energy consumption per tonne of competing agricultural products available to the EC. 1981. *Information on Agriculture* 85: 96.

Tabacco, E., L. Comino, and G. Borreani. 2018. Production efficiency, costs and environmental impacts of conventional and dynamic forage systems for dairy farms in Italy [online]. *European Journal of Agronomy*, 99: 1-12.

Tsatsarelis, C. A.. 1993. Energy inputs and outputs for soft winter wheat production in Greece. *Agriculture, Ecosystems & Environment*, 43(2): 109-118.

Unakıtan, G., and B. Aydın. 2018. A comparison of energy use efficiency and economic analysis of wheat and sunflower production in Turkey: A case study in Thrace Region. *Energy*, 149(15): 279-285.

Venturia, P., and G. Venturi. 2003. Analysis of energy comparison for crops in European agricultural systems. *Biomass and Bioenergy*, 25(3): 235-255.

Voltr, V., J. Bartlová, M. Brtnický, O. Denešová, P. Froněk, J. Honz, T. Hlavsa, M. Hruška, T. Khel, M. Kohút, J. Křen, J. Kubát, J. Kučera, J. Lang, J. Leština, J. Lipavský, P. Míša, P. Novák, J. Podešvová, E. Pokorný, E. Rožnovský, M. Štolbová, O. Šařec, P. Šařec, M. Trantinová, J. Vigner, V. Vilhelm, and J. Vopravil. 2011. *Evaluation of land in environmental conditions. (Hodnocení půdy v podmínkách ochrany životního prostředí)*. Prague, Czech Republic: IAEI.

Voltr, V., M. Hruška, P. Šařec, J. Leština, and P. Froněk. 2012a. *Land Valuation Methodology for Bonitated Soil-Ecological Units (Metodika ocenění půdy pro bonitované půdně-ekologické jednotky (BPEJ))*. Prague, Czech Republic: IAEI.

Voltr, V. 2012b. Concept of soil fertility and soil productivity evaluation of agricultural sites in the Czech Republic. *Archives of Agronomy and Soil Science*, 58 (S1): 243-251.

Ziaei, . M., S. M. Mazloumzadeh, and M. Jabbaryk. 2007. A comparison of energy use and productivity of wheat and barley (case study). *Energy*, 32(1): 35-41.