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Research Article

Determination of Energy Thresholds Based on Energy Equivalent in Crop Production for Economic Return on Biogas Production

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ABSTRACT

The article evaluates the economics of electricity generation in biogas plants based on the analysis of gross annual rental effect and energy yield of crops. The evaluation of the database of crops has shown that the crop most suitable as biogas plant substrate both in terms of economics and energy generation is the fodder sorrel. Ranking among other suitable crops is sugar beet, extensively grown grass, clovers, rye and silage maize. Because of the maximum energy yield, the most suitable is fodder sorrel and silage maize since they generate maximum yield per hectare. The economic analysis of the operation of biogas plants indicates that the guaranteed feed-in tariff for electricity is currently above the minimum 10% profit in biogas plants with the capacity above 200 kW. When sorrel is used as a substrate and its growing technology is well managed, the guaranteed price for 1 kWh may be reduced by almost 50% while maintaining the 10% profit. The technology of sorrel growing, however, has not been well managed in practice. The existing feed-in tariff of electricity is reflected in better economic results of farms with biogas plants, the net added value of which has increased by up to 200 EUR per hectare. Higher subsidies of electricity feed-in tariffs lead are accompanied also by higher price of inputs which is taken advantage of by non-agricultural suppliers and customers. Small biogas plants with the capacity below 200 kW are not competitive with regard to the use of substrates from agricultural crops, but it is assumed that they can better utilize the biological wastes from farming and thus achieve lower prices of inputs.

Keywords: Biogas plants; Feed-in tariffs of electricity; Fodder sorrel; Silage maize; Energy yield; Production price

INTRODUCTION

The plant biomass represents one of major energy sources in case the use of fossil fuels is limited or eliminated [1]. Even though the agricultural land is used primarily to ensure food self-sufficiency, it could perhaps also be used for energy purposes, due to the possibility to use the biogas or methane production infrastructure and local land that can reduce the transportation costs of harvest and ensure production also on less favorable soils [2,3].

One of the key factors regarding the future development of biomass use for energy purposes is the economics of biomass production. At present, with the current prices of fossil fuels, the energy generation from biomass is not competitive [4], but a question arises what economic conditions would make it possible to produce biomass for energy generation purposes in the future. The production technologies determine the costs of production and the return on production is largely determined by the current price of output, while the economic and energy related parameters are largely dependent on regional conditions for farming [5], namely whether there are any limiting factors such as areas at risk of erosion or limited doses of fertilizers in protected areas. A certain role is also played by climate conditions.

According to the EU IRENA [6] project estimate, biomass production shall have increased from the current 4% to 7% of available energy by 2030. The greatest development is anticipated in solar and wind energy which, however, represent time dependent energy generation.

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The conditions for better economics of biomass change rapidly due to changes in electricity prices. The World Economic Forum [7] assumes that the costs of electricity generated by solar panels have come down fast and in 2022 the production costs of panels for electricity generation per Wp from solar energy will decrease by approximately one fourth as against 2019. Similarly, also the production costs of electricity generated by wind farms are on a decrease.

The general development of electricity rates in the future can hardly be foreseen, but the available sources anticipate their further rise [8-12].

The use of biomass for energy generation purposes is currently explored by numerous analyses and statements [4,9]. Apart from scientific materials, the document reflects the applicable legislation relevant with respect to the support of biogas production. Primarily the Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2011, the European Parliament legislative resolution of 13 November 2018 on the proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast), according to which when developing support schemes for renewable sources of energy the Member States should consider the available sustainable supply of biomass and take due account of the principles of the circular economy and of the waste hierarchy established in Directive 2008/98/EC of the European Parliament and of the Council in order to avoid unnecessary distortions of raw materials markets.

The Directive 2009/28/EC and subsequently the Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC introduced a set of sustainability criteria including criteria for protection of soil of high biodiversity value and land with high carbon stock, which also deal with indirect land-use changes. Indirect land-use change occurs if growing crops for biofuels, bioliquids and fuels from biomass replaces the traditional growing of crops for food or feed. The aforementioned criteria limit the use of agricultural land for energy generation purposes.

Based on the energy support in line with the European Parliament requirements, support schemes for the development of bioenergy were launched in 2008. In the Czech Republic, a scheme for support of electricity generation in biogas plants was launched [7]. In consequence of high costs and criticism of excessive support of production a pressure has been exerted recently to reduce the support granted to biogas plants and the use of biowaste for biogas production. Currently, the support is channelled to the use of waste heat from biogas plants.

Also, the development in other countries has shown that a sustainable input for the environment can be the biogas upgrading and biomethane, especially when the main supported raw materials for biomass, i.e. manure and waste, are available [6]. Another alternative is the biogas upgrading (purification) to biomethane and its injection into the network.

Mészáros et al. [8] summed up the advantages of biogas plants which appropriately help diversify the energy sources and reduce the dependency on imported fossil fuels. They also help improve regional economies and increase employment. The biogas plants represent a decentralized source of energy and the advantage of the alternative for combined heat and power generation may consist in lower sensitivity to fluctuations in the feed-in tariff of electricity, guaranteed for a period shorter than the life of the production facilities.

The use of energy as an assigned value for biogas production economics is useful to cover the entire energy flow of production of the final product since the values are known across the whole spectrum of agricultural production and the energy balance is the basic precondition for comparisons of biogas generation options. The comprehensive energy balance of production of used products can thus be used for the analysis of biogas production balance [5].

The substrates as such and their selection can naturally also have a substantial effect on the economics of biogas production process and the information on biogas production efficiency shall complement the results of energy analysis.

This topic has been addressed by numerous authors. It shall be considered however whether the biogas production can be related to the energy content of the substrate which is essential in evaluating the power generation. Dohler et al. [13] published the results of biogas production from various substrates which, when compared with the energy content of substrates, indicate that the yield of individual substrates in m^3/GJ can differ by up to 25%. The biogas yield of cereals range around 20 m^3/GJ, whereas the specific yield of forage crops is substantially lower, namely around 17 m^3/GJ in maize, 16 m^3/GJ in grassland, while when considering the losses in biogas production technology this difference further increases and the yield of only 14 m^3/GJ is achieved by grassland. Also, Amon et al. (2007) studied various alternative substrates of diverse energy crops. The specific CH4 yield (norm litre per kg of volatile solids: lNkg-1VS) of standard maize (whole crop silage) was 390, in pressed beet pulp silage 430, intercrop 335. It means that the CH4 yield per kg of the product depends on the source substrate. Biogas production is dependent on crop management, for example Vasmara et al. [14] states that the yield of giant reed varies significantly according to the number of harvests.

Selection of crops for substrate is a complex process and the crops should meet multiple requirements. Cossel and Lewandowski [15] were evaluating the suitability of the mix of 27 crops in two wild plant mixtures (WPM) for biogas plants over the period of five years. They concluded that WPMs are a promising permanent cultivation system for biogas production with many benefits for the environment. They are, however, inadequate for the production as to the efficiency.

Mast et al. [16] explored the potential methane yield in new permanent crops for biogas plants. Of four crops, three (cup plant (Silphiumperfolatium), energy dock (Rumexschavnat), and Szarvasi (Elymuselongatus ssp. ponticus cv. Szarvasi-1) have proven suitable as a substrate for biogas plants. The research revealed that the suitability of investigated crops depends also on the harvest season and also the second harvest season should be determined. Havlíčková and Suchý [17] developed a model of the use of energy crops for power generation, which besides the use of woody plants reckons also with the use of energy crops on arable land such as sorrel, reed canary grass, triticale, whereas the sorrel achieved the best energy results from among the crops on arable land. The crops on arable land have the benefit of the use of agricultural machinery for the harvest. Also, sorrel can be successfully cloned, as described by Ślesak et al. [18] as an energy crop.

Another issue is the further technological processing of substrates, when in order to achieve optimal biogas production and considering the availability of sources the substrates are mixed in biogas production.

Excessive mixing can disrupt the microbial aggregates, reducing degradation efficiency and leading to digester instability [19]. But alternative mixed substrates with compare to the manure could leads to the increase of biogas production and its quality [20]. Nallathambi Gunaseelan [21] described, that harvesting frequency, plant age, clonal variations, particle size reduction and alkali treatment have a substantial effect on methane yield from grasses. The results of methane formation can therefore always be achieved under the specific conditions of the stand, as well as the digestate processing technology in the biogas plant. For a rough comparison of economic efficiency, however, we can start from the table assumptions of the previous experiments.

The ratios of mixtures are discussed by the research community, but the opinion prevails that for biogas production it is most appropriate to begin with silage maize. In practice, the share of up to approximately 30% of other substrates is reported as trouble-free.

There are multiple types of technological equipment which differ in both efficiency and suitability with respect to individual substrates. The purpose of this paper, however, was first and foremost to identify the main actions and principles leading to efficient and effective use of energy potential of biomass.

METHODOLOGY

The following has been done for the purpose of evaluation of the minimum price of energy from biomass.

- Determination of economic and energy parameters of crop production technologies
- Determination of the effect of subsidies on the price of used substrates
- Development of model solutions for the use of biomass for biogas production and electricity generation

Determination of economic and energy parameters of crop production technologies

Determination of economic parameters: Determination of economic and energy indicators for respective evaluated soil ecological conditions in the Czech Republic (evaluated soil ecological units - BPEJ) is based on the data stored in the BPEJ economic database at the Institute of Agricultural Economics and Information (IAEI) [22].

The calculations in economic background materials depend on the development of inputs and outputs in crop production over time [23]. That is why the outputs of basic 18 crops are evaluated over a period of five years that should reflect the current trends in farming technologies, composition of crops and climate factors. For subsequent purposes, the set of evaluated crops is extended into a total of 31 crops [5]. The original appraisal of yields over a ten-year period in 1970s on more than 5,000 land plots was updated by NAZV QH72257 project implemented in the period from 2007 to 2011 for the respective main soil climate units (HPKJ) on 500 land plots over a nine-year period, and the data has been continuously updated with the use of available sources, the costs survey of the Institute of Agricultural Economics and Information (IAEI), the Farm Accountancy Data Network (FADN), supporting documents provided by individual farms, the Central Institute for Supervising and Testing in Agriculture (CISTA) and the Czech Statistical Office (CZSO) at the respective regional level. The costs of crop growing are determined based on the database of material inputs of fertilizers, fuel consumption and frequency of chemical plant protection. The costs of technological operations are derived from the supporting documents of the Institute of Agricultural Economics and information (IAEI) [24] based on the proportional representation of BPEJ in production areas (PA) in the costs survey and FADN. The resulting standard costs are adjusted in percentage in individual items to reflect the results in real farms reported by the IAEI monitoring.

Crucial for the evaluation of economics of agricultural crops is the gross annual rental effect (GARE):

The gross annual rental effect expresses the difference between the income and the costs including the overhead costs. It is calculated using the following equation (1) [5]:

$$GARE_{i,p} = CPP_{i,p} - NPP_{i,p} \qquad (1)$$

where

CPPi,p price of parameterized output of p- crop per BPEJ (EUR/ha),

NPPi,p standardized cost of parameterized output of p- crop per BPEJ

Determination of energy indicators: In order to determine the energy indicators the supporting documents included in the database system of soil and climatic conditions in the Czech Republic are used [22,23]. The material and operating costs of crop production technologies together with the crop yield parameters were converted to energy indicators based on the available sources. The methodology uses the available database provided by Preininger [25], PLANETE [26] and others [27,28].

The background data for evaluation of energy of working sets is derived from direct and indirect energy of working sets and the energy depends on the weight of used materials in fertilizers, machinery, fuels and seeds, diesel consumption and labour in individual working operations.

When evaluating the mechanical means, 2-4 model sets were developed by the RIAE for each operation, to which parameters of sets were attributed, including their weight. This data was subsequently used in dependence on the set up technological procedures to calculate the energy costs.

The energy yield (EY) is basically calculated by the following equation (2) [5]

$$EY = Eout_p - Einp_p \qquad (2)$$

where Eoutp is the energy of the primary and secondary product of the crop and $Einp_p$ is the energy of material and working operations of individual crop growing technologies. In this article, conventional crop growing procedures were evaluated.

Determination of the effect of subsidies on the price of used substrates

Determination of the effect of subsidies on the price of used substrates is based on comparisons of economic results of groups of farms according to the FADN (Farm Accountancy Data Network) database. The comparison consisted in evaluating the results of 396 farms without biogas plants and 79 farms with biogas plants. In individual groups of farms, basic economic characteristics were described in line with the standard FADN output, the comparisons focused mainly on total operating subsidies, gross added value, net added value and family farm income. The referred to outputs served to identify the difference between individual indicators, which was later assessed in a statistical survey.

Since the operating subsidies were partly reflected in the total operating costs, also explored in the FADN database was the statistical dependence of the amount of inputs on the amount of subsidies and the size of output. Calculations were performed in IBM SPSS 17 software. The achieved results helped estimate the increase in the price of substrate caused by the volume of subsidies.

Development of model solutions of the use of biomass for biogas, methane and electricity production

In order to identify the threshold price of energy, economic data concerning biogas production and the price and energy content of production of agricultural crops usable for biogas production was analysed. The evaluation was based on the data on economics of production of biogas, which is at present the main technology for the use of biomass for energy generation purposes. The evaluation of biogas production follows from a detailed analysis of the material flow of biogas plants in basic parameters of their size. The models are based on the KTBL methodology [13], using background data for conditions in the Czech Republic, i.e, sorting biogas plants up to 200 kW, up to 550 kW and over 550 kW. All prices were used according to Czech conditions. The paper zeros in on biogas plants using substrates from farming, crop production in particular. The model proposal assumes the use of a mix of substrates for biogas production, for the purpose of a single conversion to substrate energy, however, the conversion was done for silage maize and fodder sorrel.

The results of economic and energy evaluation of crops by evaluated soil ecological unit (BPEJ) were obtained using the weighted average based on the area of BPEJ. In the Czech Republic. The main indicators are listed in Table 1 for potato production area, where biogas plants are mostly located. For the calculation of economic indicators, also the price of crop production including the ten percent profit added to the cost price of the product was determined. Figure 1 shows the relation of energy of the output, the costs and the energy yield by achieved result, for the sake of clarity the course of the function is provided instead of the actual data. The energy of outputs does not show a fully linear trend due to different energy content of the matter in silage maize in BPEJ. The costs have a more parabolic shape in consequence of bigger differences between production areas. Figure 2 comprises the comparison of the achieved energy yield and the cost price of the product including 10% profit. It is obvious from the result that evaluated as the best in terms of energy is the fodder sorrel with the second best energy yield after sugar beet, but with the most favorable ratio to the cost price of the output, which is why the energy is best achieved in a cheap product.

Figure 3 includes the results of the set of farms in the FADN database that illustrate the development of the price of outputs, subsidies and inputs. It is clear from the results that the value of inputs shows a similar development as the value of outputs and subsidies. This trend can partly be attributed to the general development of prices in the society. Nonetheless, Table 2 includes the evaluated statistical model of dependence of the costs on the value of outputs and subsidies, which gives a statistically very conclusive evidence of the correlation between the development of subsidies and the size of outputs. As a result, the costs are affected by sharing the profit by suppliers and processors (farmers). The lower the subsidies, the lesser the redistribution of subsidies. This result proves that the rate of support should be linked to the actual costs at the time with no support since the subsequent setting of the size of inputs impact economically also the downstream industries.

Table 1: Main economic and energy parameters of crop production in the Czech Republic.

Crop	Price of the crop total in EUR/ha	Production costs in EUR/ha	Costs including 10% profit in EUR/ha	GARE per hectare in EUR/ha	Crop energy in total MJ/ha	Energy for crop technology in MJ/ha	Energy yield in MJ/ha	Energy yield/ production price with 10% profit

Fodder sorrel	1,042	314	345	781	180,595	4,693	175,903	19,99
Sugar beet	2,691	1,596	1,756	1,095	285,135	28,245	256,890	5,74
Extensively grown grass	418	248	273	170	40,638	3,211	37,427	5,38
Clover-grass mixtures	1,008	603	663	405	98,337	9,140	89,197	5,28
Winter rye	1,066	801	881	266	138,104	23,383	114,721	5,11
Silage maize	1,816	1,149	1,264	667	192,520	28,109	164,411	5,10
Red clover for hay	1,008	619	681	389	88,954	9,484	79,470	4,57
Red clover as forage	1,171	654	719	517	98,334	18,212	80,122	4,37
Oat	869	732	805	137	109,050	20,065	88,985	4,33
Winter wheat	1,177	1,008	1,109	169	148,845	29,431	119,413	4,22
Spring barley	1,033	812	893	221	112,387	20,507	91,880	4,04
Triticale	894	892	981	3	122,472	26,437	96,035	3,84
Winter oilseed rape	1,706	1,131	1,244	574	150,700	29,688	121,013	3,81
Winter barley	934	930	1,023	4	122,366	25,395	96,970	3,72
Alfalfa	1,131	867	954	264	100,952	18,362	82,591	3,40
Intensively grown grass	561	520	572	42	54,544	12,138	42,407	2,91
Pea (Pisumsativum)	915	737	811	178	75,367	18,804	56,563	2,74
Opium poppy	1,352	708	778	645	38,074	18,272	19,802	1,00
Potatoes	4,971	2,453	2,698	2,519	103,657	47,824	55,834	0,81

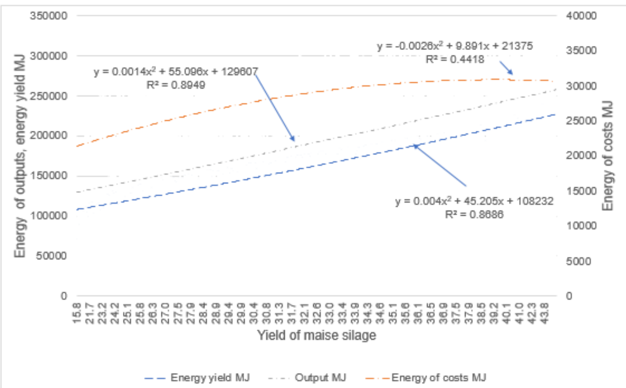

Figure 1: Energy of inputs, outputs and energy yield of maize silage.

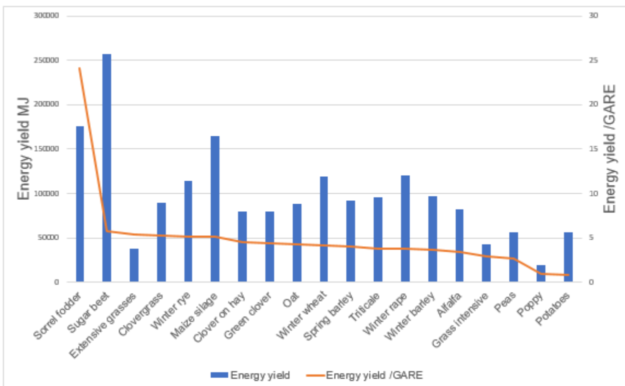

Figure 2: Comparison of the achieved energy yield and the cost price of the product including 10% profit.

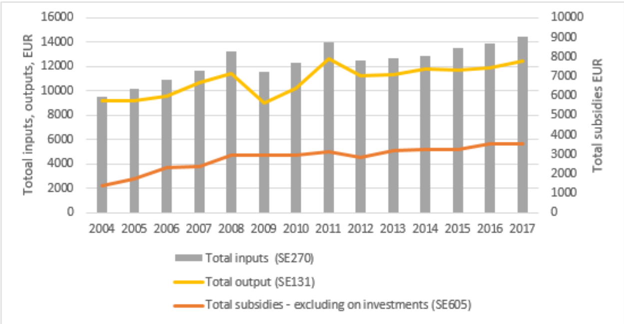

Figure 3: Inputs, outputs and subsidies on farms (FADN).

Table 2: Model of dependence of total inputs on subsidies and output of farms in the Czech Republic.

Variables	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	61,284,823	19,286,115		3,178	0,009
Total subsidies - excluding on investments (SE605)	1,268	0,189	0,549	6,697	0,000
Total output	0,594	0,098	0,499	6,082	0,000
Independent variable: total inputs					

Table 3 gives the main economic results of farms with and without biogas plants per hectare of agricultural land. The set with biogas plants comprises 79 farms, the set without biogas plants a total of 396 farms. Both the sets provide conclusive data. The farms with biogas plants have larger area and show generally higher costs and income. This trend may be associated with the size of farms, nevertheless the same results are achieved also when comparing the farms of the same size. The total net added value in farms with biogas plants is higher by 200 EUR/ha and the gross added value by 355 EUR/ha. The family farm income is higher by 56 EUR/ha.

Table 4 includes basic economic models of biogas plants. The models are classified as category below 200 kW, below 550 kW and above 550 kW, with substrate from mixed animal and crop production. Since the effect of energy parameters of crops in crop production was investigated, the referred to substrates were in the calculation replaced with the equivalent value of one investigated crop. The effect of silage maize and fodder sorrel on economic parameters of biogas plants was examined. The given models are based on the German Faustzahlen methodology [13].

Table 3: Comparison of economic results of farms with biogas plants.

	Number, EUR	Number, EUR
Biogas plant	Yes	No
Number of farms in the set	79	396
Utilized ag. area total per 1 farm in ha	1,847	1,004
Number of LU total in LU/100ha	44	35
Total output (CZK/ha)	1,975	1,537
Output crops	921	927
Output livestock	665	430
Other output	390	180
Total costs	2,636	1,812
Production consumption	1,676	1,152
Direct costs	1,133	713
Other material costs	543	438
Operating subsidies	828	386
Gross added value	1,117	762
Net added value	796	596
Family farm income	158	102
Net added value/Annual work unit (NAV/AWU)	26,428	24,170
Cash flow (2)	4,101	2,274

Table 4: Models of economic results of biogas plants.

	Unit	Small-scale on-farm biogas plant below 200 kW (manure, maize, GPS, grass)	Medium-scale on-farm biogas plant below 550 kW (manure, maize, GPS, grass)	Large-scale on-farm biogas plant above 550 kW (manure, maize, GPS, grass)
Installed capacity	kWe	200	500	1,000

Substrates				
Cattle manure	t/year	1,100	2,300	2,500
GPS	t/year	0	1,000	1,800
Grass silage	t/year	1,000	1,200	1,500
Maize silage	t/year	2,700	6,500	15,000
Recirculation liquid	t/year	400	800	2,200
Type of engine		Gas	Gas	Gas
Electrical efficiency	%	37	41	42
Thermal efficiency	%	44	43	43
Biogas production	m3/year	813,900	1,902,400	3,751,700
Methane content	%	53	52	52
Total investment	EUR	1,135,000	2,089,100	3,449,500
Specific investment costs [EUR/kWel]	EUR	5,675	4,178	3,450
Sale of electricity	EUR/year	250,240	628,722	1,272,497
Electricity sold	kWhel/year	1,579,200	3,967,700	8,030,400
Sale of heat	EUR/year	16,582	83,322	168,638
Heat sold	kWhth/year	473,760	2,380,620	4,818,240
Total	EUR/year	266,822	712,043	1,441,136
Substrate	EUR/year	125,500	288,400	594,200
Variable costs total	EUR/year	202,956	425,311	842,501
Gross margin (to cover the fixed costs)	EUR/year	63,866	286,733	598,635
Fixed costs total	EUR/year	127,590	228,621	374,703
Profit	EUR/year	63,724	58,112	223,932
Costs of electricity/gas production	ct/kWhel	19,88	14,38	13,06
Return on capital of EBITDA	%	3,03	11,30	15,09

In order to verify the effect of the selected substrate on the economics of the biogas plant, the minimum production costs of electricity generated by biogas plants were calculated based on the evaluation of productions costs in the selected model sizes of biogas plants, while including 10% profit. For the sake of simplicity, only two crops were compared, namely fodder sorrel and silage maize. Silage maize is currently the main substrate for biogas plants and sorrel has achieved the best energy yield per tonne of the product.

The selection of substrate is not only an economic and energy issue, but it is also important for the technological process as such due to the necessity to set the process of fermentation. The existing biogas plants are mostly designed to process silage maize [25]. As stated in the introduction, another substrate can be added in the amount of up to 30% of the filling. For this reason, in order to compare the economics of production also the alternative with 30% of sorrel and 70% of silage maize was considered.

The production costs of electricity are apart from the technological costs also affected by the size of the area under substrate. The production of silage maize is characterized by the highest energy production per hectare and when substituted the costs increase due to the need of a larger area under the alternative crop. This aspect has been dealt with by including the rent of the actual difference in the area necessary for growing other crops, sorrel in this particular case. The average rent in 2018 was EUR 116, which was related to the number of kWh generated based on the comparison of biogas production per hectare of individual crops. The methane production used in the calculations was 321 m^3/ha in silage maize, 300 m^3/t in sorrel.

The results of the calculation are included in Table 5 comprising the ascertained relevant feed-in tariffs of electricity in EUR/kW.

The comparison of the achieved production prices in percentage relative to the current electricity consumer prices is provided in Figure 4. The Figure 4 indicates that the best results are achieved by biogas plants with the highest output. In terms of substrate, the most cost effective is sorrel with minimum growing costs. With regard to technology, the question is the provision of 100% input material in the fermentation of another material than the tried and tested silage maize, in which the best onset of fermentation process is observed. For this reason, also the other option with 30% of sorrel and 70% of silage maize was chosen which according to experts does not cause any problems in setting the technological process.

Table 5: Current electricity price and electricity price calculated with 10% profit.

Substrate	Small up to 200 kW	Medium up to 550 kW	Large above 550 kW
Current price EUR/kWh	0,159	0,159	0,159
100% fodder sorrel EUR/kWh	0,158	0,105	0,089
100% fodder sorrel EUR/kWh including an extended area lease	0,164	0,111	0,094
30% fodder sorrel, 70% maize for silage EUR/kWh	0,200	0,133	0,115
30% of foddersorrel, 70% EUR/kWh including an extended area lease	0,201	0,134	0,117
100% maize for silage EUR/kWh	0,218	0,144	0,127

Figure 4: The percentage of the production price of electricity using different substrates to the current price.

DISCUSSION AND CONCLUSION

The paper aimed to provide an objective evaluation of alternative substrates for biogas production. The main crops were assessed in terms of energy and economic balance, concluding that the best crops in terms of energy yield are sugar beet, sorrel and silage maize. The paper offered also another perspective when characterizing the crops: the energy yield/cost of production ratio. The comparison shows that the best ratio is achieved by the energy crop, namely fodder sorrel. In this case the energy yield is achieved at the lowest costs per unit of energy that are primarily thanks to the growing of sorrel as a perennial, with no cover establishment operations except for the first year. The use of energy crops, represented by fodder sorrel in this paper, thus underlines their potential for economic utilization. The major challenge is to cope with all the technological problems associated with their growing and the traditional understanding of the function of agriculture. When observing all the agrotechnological procedures there are no problems associated with the technological process of sorrel growing as such, however, many recommendations are not observed in practice. This can result in its lower yield. It concerns primarily the need for treatment during vegetation, when weed control shall be achieved and the stand properly established. Another complication arises from the mistrust on the part of farming community of this product which is often viewed negatively as against the tried and tested agricultural products. At the same time, the growing of currently the main crop, silage maize, is restricted on slopes at risk of erosion, where strict anti-erosion measures have to be complied with, or its growing is explicitly prohibited in the Czech Republic. Certain problems may arise when using fodder sorrel in biogas plant technology since the beginning of the process of methanogenesis may be slow [29,30], but after 25 days biogas production equals the standard process.

The operators of biogas plants have concerns also due to the need of larger cultivation areas in order to ensure adequate biogas production. Based on the average rent of land it has been ascertained (Table 5) that the price of electricity increases due to a higher number of hectares when growing fodder sorrel in dependence on the size of biogas plant by 3-4%.

As became evident, the current higher rate of support of biogas plants resulted in conclusively better financial results of farms associated with the support of feed-in tariffs of electricity. At the launch of the biogas production support scheme, the electricity rates reached approximately 12 cents per kW. However, now the rates are much lower and the actual support of electricity generated from biogas thus increased. The increased effectiveness of biogas plant operation, however, is becoming ever more important from the economic point of view and a better use of energy from crops is an option to achieve good economics of biogas plants. The obtained results based on the used methodology in terms of economic and energy aspects are important to justify the use of fodder sorrel as a replacement for silage maize also with account taken of the environment.

The used models of biogas plants with the capacity below 200 kW, below 550 kW and above 550 kW indicate that under the existing economic conditions the profit is achieved by biogas plants above 200 kW, with the guaranteed electricity price which is composed of the green bonus in the amount of 2.948 CZK/kWh and the basic price of 1.172 CZK/kWh. The comparison with other substrates usable in biogas plants suggests that the existing production using mostly the silage maize as a source can be outperformed by fodder sorrel with comparable energy value achieved at considerably lower costs of crop production. The problem associated with this crop, however, is the caution on the part of farmers as well as non-compliance with the recommended technological procedures. Its weak spot is especially the weed control of the stand. A clear advantage of this crop is its multiannual growing on the same location without the necessity of annual soil tillage.

When evaluating the minimum electricity price with 10% profit based on the cost price of maize and sorrel production, it is obvious that in sorrel production cost effective can be even the half of the feed-in tariff of electricity. The existing price with the use of silage maize guaranteed for the farms a fairly high operating profit of 224 thousand EUR/year in the category above 550 kW. The survey of farm results suggests that the income of a farm with a biogas plant achieved the added value by almost 200 EUR/ha higher than a farm without a biogas plant. For the sake of sound spending of public funds with regard to business activities this situation shall be further investigated.

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