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A multi-criteria evaluation of energy crops with DEX methodology

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Abstract

The aim of the paper is to present the system for multi-criteria evaluation of energy crops for biogas production. Firstly, the deterministic simulation system consists of deterministic production simulation models was build. Simulation system enables different types of costs calculations for production of energy crops, electrical and heat energy in biogas production. Simulation model results were further evaluated using a qualitative multi-attribute modelling methodology (supported by the software tool DEX – i). The analysis showed that by using current model the most relevant alternative used for energy crop for biogas production is maize. The maize results in the best DEX – i multicriteria evaluation appropriate. The best alternative for maize is sorghum with multicriteria evaluation less appropriate.

Key words: DEX – i, simulation model, energy crops, biogas

Introduction

The 21st century faces the problem of growing energy consumption and diminishing supplies of fossile fuels, which has led to researches of the use of renewable energy sources and, consequently, the development of new technological processes of energy production. One of the most efficient energy sources is the biogas produced from green energy crops and organic waste matters. The biogas is formed during anaerobic fermentation of organic matters such as: farmyard manure, liquid manure, energy crops, organic waste materials, slaughter-house waste etc. (Navickas, 2007). Economic efficiency of anaerobic digestion depends on the investment costs, on the costs for operating the biogas plant and on the optimum methane production (Weiland, 2003).

From technological aspect the most suitable energy crops grown in the temperate conditions are the grasses, maize, sorghum and legumes such as white clover, vetches and lupine (Lehtomäki, 2006). Among the alternative energy crops the literature mentions the forage kale, Jerusalem artichoke, Miscanthus sp. and some weeds (Callaghan, 1985).

An important issue is evaluating the suitability of energy crops for biogas with respect to various criteria on the basis of different analyses (amount of produced biogas, biomass yield) and the association in a single multi-criteria estimate. In such cases, the multi-criteria analyses were used by different authors (Rozman et al., 2006; Pazek el. al., 2006). In the last few decades, the agricultural decision makers have gotten accustomed to the use of computers and consequently to the implementation of different complex computer models for solution of various planning problems. This includes decision problems and agricultural project solutions, which have long been predominated by different types of simulation models (Rozman et al., 2002) and cost benefit analysis (CBA) as presented by Pažek (2004).

The basic problem of the research is to develop a system to support decision making in the selection of appropriate energy crop, with the combination of the technological-economic simulation model (model calculations) and multi-criteria decision analysis. This paper presents the application of the simulation model for cost analysis of biogas, electricity and heat production from various energy crops in combination with multi criteria decision models. The simulation results are additionally evaluated with multi criteria decision models based on DEX-i expert system.

Material and methods

Using technological-economic simulation modelling one can obtain information about the system itself and its responses to different model input parameters. The relationships between system elements (in this case input material, human labor) are expressed with a series of technological equations that are used for calculation of input usage and outputs produced. For financial and technological analysis of energy crops for biogas production the computer simulation model was developed. There are three basic sub-models: the sub model of energy crop production by the farmer, the sub model of biogas production from energy crops and the sub model of electricity and heat production from biogas produced from energy crops. The developed model enables calculation of the most important economic parameters such as break-even price, coefficient of profitability and financial result. The simulation model output data represent some of the input parameter of analyzed energy crops in multi-criteria decision analysis. The structure of the assessment procedure is shown in Figure 1.

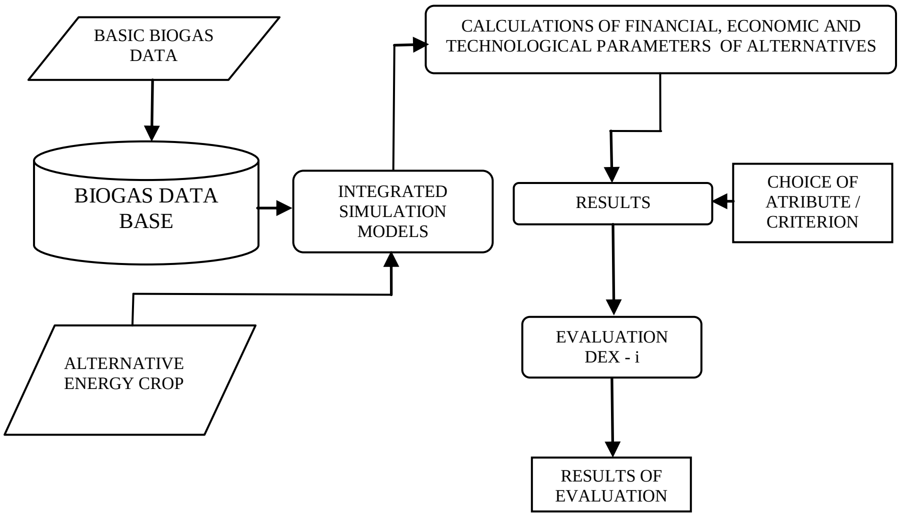

Figure 1. The structure of deterministic simulation model

The energy crops are further evaluated with multi criteria decision model. Hierarchical multi-criteria decision models are a general decision support methodology aimed at the classification or evaluation of options that occur in decision-making processes. Decision models are typically developed through the decomposition of complex decision problems into smaller and less complex sub-problems; the result of such decomposition is a hierarchical structure that consists of attributes and utility functions.

The variants are decomposed into specific parameters (criteria, attribute and objective) and evaluated separately for each single parameter. The final variant evolution is provided with the combined proceeding. The provided value presents the portfolio for selection of the most suitable variant (Bohanec and Rajkovic, 1995). For the assessment of simulated alternatives DEX-i methodology has been applied. DEX is a methodology for qualitative multi-criteria decision modelling and support (Bohanec and Rajkovic, 1990). DEX combines conventional multi-criteria decision-making with some elements of Expert Systems and Machine Learning. The distinguishing characteristic of DEX is its capability to deal with qualitative variables. Instead of numerical variables, which typically constitute traditional quantitative models, DEX uses qualitative variables whose values are usually represented by words rather than numbers, such as ‘‘low,’’ ‘‘appropriate,’’ and ‘‘unacceptable.’’ To represent and evaluate decision alternatives, DEX uses ‘if-then’ decision rules. The DEX method is implemented with the software program DEX-i.

The numerical attributes for the DEX – i analysis were obtained by simulation using the simulation model, while the non numerical attributes were estimated based on different data sources. The following qualitative scales were used for non numerical sub-attributes (Table 1).

Table 1. Categorization table for numerically measured attributes

The use of fertilizers (nitrogen)	
>195	high
131 - 194	medium
0-130	low
BEP farmer (Eu/kg)	
< 0,08	high
0,035 - 0,08	medium
> 0,035	low
BEP el. energy (Eu/kWh)	
< 0,4	high
0,2 – 0,4	medium
> 0,2	low
BEP heat energy (Eu/kWh)	
< 0,2	high
0,11 – 0,2	medium
> 0,1	low
C/N ratio	
15-30/1	optimum
>< 15-30/1	less appropriate

After each attribute has been assigned with qualitative value, the utility functions are defined. The utility function is conducted for each level in the hierarchy and the decision rules are presented in complex form. Table 2 shows qualitative scales for non-numerical attributes. Finally, attribute values for each alternative are put into DEX-i evaluation table and the analysis is ultimately conducted.

Table 2. Qualitative scales for non-numerical attributes

Hailstone risk	high; medium; low
Resistance to drought	resistant; partially resistant; un-resistant
Crop rotation	monoculture; two years; three years
The use of pesticides	high; medium; non
Insistence of the production	high; medium; low
suitability of plant for processing into biogas	appropriate; less appropriate; inappropriate
suitability of plant - digestor	appropriate; less appropriate; inappropriate

Results and discussion

In the first phase for every analyzed alternative the costs of energy crop production are calculated using the simulation model. In the second phase, the data from the experiment (produced biogas) were calculated into the electricity and heat yield.

The simulation results were further evaluated with multi criteria decision model DEX – i. Since the main results from the simulation model are numerical (break even prices, C/N ratio), the qualitative values must be assigned to each quantitative parameter in order to enable further analysis in DEX – i decision model. This is conducted with classification algorithm based on classification intervals. The DEX – i evaluation of alternatives (energy crops) with importance weights of aggregate attributes is shown in table 3.

Table 3. DEX –i project evaluation of alternatives with importance weights of aggregate attributes

Attribute	Sunflower	J. artichoke	Sorghum	Sugar beet	Amaranth	Maize
Assessment	less appropriate	inappropriate	less appropriate	less appropriate	inappropriate	appropriate
Economic criteria*W=55%	good	bad	good	good	bad	excellent
BEP farmer	high	medium	low	medium	high	low
BEP el. energy	medium	high	medium	medium	high	low
BEP heat energy	medium	high	medium	medium	high	low
Technological criteria *W=29%	bad	bad	good	bad	bad	good
Production technology - biogas	demanding	demanding	non demanding	demanding	non demanding	non demanding
Property of crop-biogas	less appropriate	less appropriate	appropriate	inappropriate	less appropriate	appropriate
Property of crop-digestor	less appropriate	inappropriate	appropriate	inappropriate	appropriate	appropriate
C/N ratio	less appropriate	less appropriate	optimum	less appropriate	optimum	optimum
Production technology-plants	demanding	middle demanding	middle demanding	demanding	middle demanding	middle demanding
Difficulty of production	medium	low	medium	high	low	medium
Crop rotation	three years	three years	two years	three years	two years	two years
Production risk	high	medium	medium	medium	medium	medium
Hailstone risk	high	medium	high	low	medium	high
Resistance to drought	un-resistant	partially resistant	resistant	un-resistant	partially resistant	partially resistant
Environment criteria*W=29%	good	good	bad	bad	bad	neutral
The use of fertilizers (nitrogen)	low	low	high	high	high	medium
The use of pesticides	medium	non	medium	high	medium	medium
Ranking	**2**	**3**	**2**	**2**	**3**	**1**

The DEX-i evaluation of alternatives result in the ranking of alternatives: maize, sorghum, sunflower, sugar beet, amaranth and Jerusalem artichoke. Using DEX-i expert system it can be defined which combination of attribute values is not acceptable for the decision maker. Thus, the DEX-i assessment can be used for exclusion of unacceptable alternatives, but the shortcoming of DEX – i is its inability to separate between alternatives with the same qualitative evaluation.

Conclusions

In this paper, an attempt is made to employ multi-criteria analysis to assess suitability of energy crops for processing into biogas. The integrated computer supported simulation model combined with multi criteria decision analysis presents a suitable methodology tool for decision support system on farms and biogas plants. The system takes into consideration different independent criteria and enables ranking of alternatives (energy crops for biogas production). The use of multi criteria decision approaches can bring additional information into the decision making framework (for instance the unacceptable alternatives can be excluded with the use of the DEX-i model). In the presented paper DEX-i method favoured the maize, which got the highest DEX-i evaluation. The maize is followed by sorghum and can be used as an alternative for maize (crop rotation, drought etc.). The next alternatives are sunflower, sugar beet, amaranth, while Jerusalem artichoke got the worst evaluation. The application of the proposed decision support system (combination of simulation model and DEX-i methodology) would increase the accuracy of information needed for developing farm and biogas plant plans and, in addition, it would help preventing many inappropriate decision being made on farms and biogas plants.

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