Applied Studies in Agribusiness and Commerce – APSTRACT
Agroinform Publishing House, Budapest

ARGUMENTS FOR THE OPTIMISATION OF USING BIOMASS FOR ENERGY PRODUCTION

Takács István[1*] **& Takács-György Katalin**[2]

[1]Károly Róbert College, Hungary, Institute of Business Sciences
e-mail: itakacs@karolyrobert.hu
[2]Károly Róbert College, Hungary, Institute of Economics, Methodology and Informatics
e-mail: tgyk@karolyrobert.hu
**corresponding author*

Abstract: Using biomass to produce energy is not a new idea. In the past, the by-products of energy(?) production processes or naturally grown materials were mainly used for energy production. At the same time, during the production of biomass the conventional sources of energy are used (fuels, the embodied energy of which is used in the production of the biomass and equipment, etc.) which must be taken into account when determining the net energy production. This research aims to examine how to optimise the production and use of biomass energy and its supply chain in the energetic and economic criteria system, as well as how to impact upon the managing models of the processes to the energetic and economic parameters of the supply chain; we ask what criteria characterise the natural (environmental), economic and social sustainability, and how they can be implemented e.g. within the framework of an innovation cluster. This article describes a test model, and analyses the results of the model examinations and the conditions for compliance with sustainability criteria. *Arguing the environmental, economic and social sustainability among the criteria of the model for evaluation is not possible at all times by means of direct indicators. The results of the research proved that only multi-criteria optimisation models serve a proper decision-making instrument for the evaluation of biomass utilisation for energy production.*

Key words: sustainability, logistics, heating energy, local society, cluster

Introduction

Research on utilising biomass for energy purposes can be traced back over many decades in Hungary, as well as internationally. Back in the 1980s, the research focused primarily on the by-products of crop production (see for example Lehoczki, Takács 1981 and Lehoczki, Takács 1983, where the economic evaluation of field trials with KTB-R straw bale combustion equipment is introduced). Later in the 1990s, the researchers' attention was mainly directed towards the different crops grown for energy purposes and the technologies suitable for their utilisation (bioethanol, biodiesel production, ligneous and non-ligneous fuels). Nowadays, quite a few papers examine the relations between the use of biomass for energy purposes at settlement level and sustainability under Hungarian conditions. (Szemmelweisz, n. a.; Eco Cortex, 2010; Bai, 2012)

The demand for sustainable development has been intensifying. The complex criteria of sustainability imply the necessity of multi-criteria argumentation regarding the problem, thus supporting the selection of optimal decision alternatives. Furthermore, the strategic planning of biomass energy production and utilisation in regional relations is important, too. Italian scientists have developed a GIS-based Environmental Decision Support System (EDSS) to define planning and management strategies for the optimal logistics for energy production from woody biomass, such as forest biomass, agricultural scraps, industrial and urban untreated wood residues. (Frombo et al., 2009) Other researchers have also focused on the sustainable utilisation of renewable energy sources and highlight the importance of common thinking among the stakeholders. (Georgescu-Roegen; 1979; Erős and Bíró, 2010; Popp and Potori, 2011; Dombi et al., 2012)

The regularly examined criteria may actually include the fulfilment of criteria of environmental, economic and social sustainability, while a simultaneous examination is not made explicitly. The argumentation for natural sustainability can be made directly (for example energy balance (return) or aggregated CO^2 emission, or indirectly (e.g. by minimising the environmental burden (?) of transportation). The argumentation for social sustainability can be made, for example, by citing the impacts on employment, evaluating the performance of organisational structures and the analysis of impacts on instrument efficiency and capital investment needs (how many and what types of instruments are required to solve the task).

The examination of the questions includes the following aspects of sporadically emerging biomass which can be used for energy purposes:

- designating transportation areas,
- selecting the optimal site of the plant (power plant),

- evaluation of energy payback ratio and the impact on aggregated CO^2 emission, and
- analysing the economic impacts of organisational solutions required for efficient implementation.

The following indicators can be used for the evaluation of the above listed criteria:

- net transportation cost,
- energy balance,
- aggregated CO^2 emission,
- net returns on investment.

Main considerations concerning the components of the criteria set

Optimisation of logistics costs

The qualities of the growing site of biomass (or the site of production in case of by-products and waste) are known and include:

- geographical location of individual producers
- distance between production points and biomass utilising points
- quantity of biomass produced on the growing site
- energy-equivalent of biomass produced on the growing site
- the expected changes of quantity and energy-equivalence on the growing site during the project term
- average cost of transportation between production points and biomass utilising points

The proximity of raw materials, transportation infrastructure with the aim of minimising transportation costs, infrastructure supply, environmental aspects and marketing/utilisation aspects of the produced energy determines the placement of the energy-producing plant (power plant).

The most widely used methods to minimise logistical distance and transportation costs include the least square method and the weighted least square method. The question can be posed from a reverse standpoint, too, by asking where the geographical limits (in terms of transportation district) of an efficient supply would be for existing biomass power plants.

Borjesson [1996] examined not only biomass production and its energy balance, but also the energy use for biomass transportation by different vehicles in Sweden. He concluded that Salix chips can be transported by truck for about 250 km before the transportation energy is equal to the production energy.

Other authors examined the environmental impacts of biomass energy production and utilisation, and highlighted the complexity of the question. Among the environmental impacts, they mentioned the utilisation of nutrient stock: the biomass energy may be ‘carbon neutral’ but this does not mean that it is ‚nutrient neutral. (Abbasi and Abbasi, 2010). They also gave an important role to the question of limited land and water, soil erosion and water run-off, nutrient removal and losses, loss of natural biota, habitats and wildlife. Among the social and economic impacts, they mention shifts in employment and increases in occupational health and safety problems. It is expected that the total employment will increase, but on the other hand, the energy inherent in grain is of much higher benefit to humans when the grain is directly consumed as food instead of being used as a biofuel feedstock.

Returns on energy

Energy use and the returns on the utilised energy are calculated by applying the concept of material flow models. The concept of material flow models (Figure 1) is described by the balance equations of raw material mining/production-processing-utilisation-losses.

The energy flow or Sankey diagram offers some more possibilities to demonstrate energy flow. This demonstration model describes the distribution of the whole energy quantity. The analysis of the flow of available energy is made with energy flow or Grossmann diagram. (Wikipedia: Matthew Henry Phineas Riall Sankey, 2012)

This principle is also true for energy flow, but the quantity of energy utilised from the environment (in this study it is mostly solar energy) has a substantial share in the production of utilisable energy mass. At the same time, however, a considerable amount of energy is connected to the process of production, including both hidden energy (energy embodied in tools used for production taken in by materials used and energy utilised during production) and open energy (taken into process with fuels during the production). These tools transfer not only their economic value (see amortisation) to the products through multiple production cycles but also the energy required for their creation.

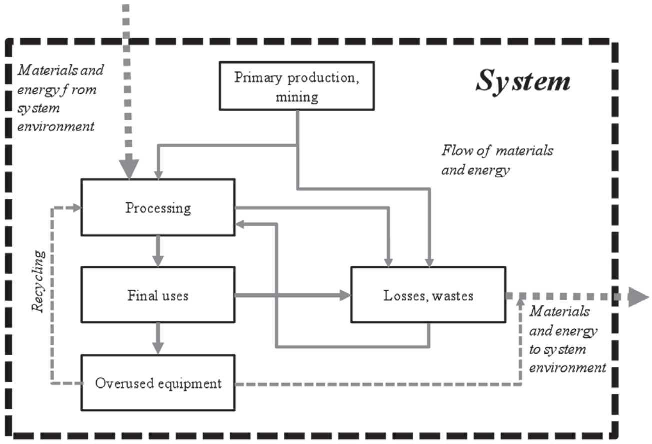

Figure 1. Model of material or energy flow
Source: own edition

Thus, from the aspect of energy payback we measure the extent to which the direct and indirect fossil-based energy input is paid off in the energy units produced by the system during its lifespan. In order to measure this, the so-called EPR Energy Payback Ratio was elaborated, which uses life cycle analysis to examine the relation between total net energy output and total energy input. (White and Kulcinski, 2000).

The estimation of the energy footprint, that is the embodied energy, is a modern approach to measuring energy efficiency with the help of which we can gain a real picture about the usefulness of different solutions aiming at energy savings. It is approached through the Leontief model called Input-Output Embodied Energy Analysis, an adaptation of the neoclassical general balance theory. (Leontief, 1966) (See furthermore Wikipedia: Embodied energy, 2012) As regards the practical implementation/applicability of the model those research projects and examinations have substantial role which try to determine the energy-equivalent of different materials and means. Table 1 presents the energy and CO^2 equivalent data of some typical materials and equipment.

The competitiveness of biomass is obvious primarily compared to oil- and coal-based energy production, and as such, their replacement with biomass is to be considered / can be considered.

Table 1. Embodied energy content of materials and equipment

Name of material	Energy	Coal	Density
	MJ/kg	kg CO_2/kg	kg/m^3
Brick (common)	3	0.24	1700
Concrete blocks (medium density)	0.67	0.073	1450
Cement mortar (1:3)	1.33	0.208	
Steel (standard, average recycled content)	20.1	1.37	7800
Wood (general, square-edged)	10	0.72	480–720
Aluminium (overall, 33% recycled ratio)	155	8.24	2700
Bitumen (general)	51	0.38–0.43	
Glass	15	0.85	2500
PVC (general)	77.2	28.1	1380

Source: Hammond, Jones 2008, Wikipedia: Embodied energy, 2012.

Material and methods

The examination model is a multifactor comparative method in which the logistic costs, energy payback, CO^2 load and economic returns are evaluated in parallel; the optimum is given by the version where the factors are most balanced.

Dimensions of the model:

1. Net transportation (logistic) cost
2. Energy balance (EPR)
3. Aggregated CO^2 emission
4. Net returns on investment (NPV)

Optimisation criteria: the area covered by the triangle or square made by the standardised values of criteria should be the maximum on the three- and four-dimension ray diagram.

Steps of optimisation:

1. Preparing the tables with the basic data
2. Preparing the parameters for the alternatives
3. Calculating the values of dimension variables per alternative
4. Standardising output values
5. Calculation of aggregated criterion value
6. Evaluation of results

Optimisation is made for the shortest transportation distance and the lowest transportation cost by using the least-squares method. Optimisation can be made on the basis of several considerations. If the biomass quantities produced are dispersed evenly, it is sufficient to optimise only on the basis of the transportation distance. If, however, the quantity of biomass is both spatially and temporally uneven and can be forecasted, and moreover the logistic costs also vary in the different transportation relationships, the optimum weighted transportation distance can be determined.

The basic data and the methods for estimating the processes were described in our former studies. (Takács-György and Takács, 2013) The optimum, on the basis of material quantities changing during the lifespan (without considering the costs), was set up on the basis of the least average distance weighted by the transportation quantity with the following equation. The determination of the optimum can also be made in those cases when biomass is collected in smaller local depots and is then shipped to the power plant.

The energy payback ratio (EPR) is determined by the analysis of project life cycle, by comparing the utilisable/utilised energy produced during the lifespan *(Y)* and the quantity of directly or indirectly utilised energy. It is calculated in the following way:

1. estimation of quantity of utilisable energy produced during the lifespan of the project
2. estimation of energy (size of energy footprint) utilised directly (fuels) or indirectly (embodied) during the whole duration of the project in the following cases:
    - 2.1. invested equipment which fully or partly serves the purposes of the project objectives and partly only
    - 2.2. estimation of energy value of fuels used during the lifespan of the project
    - 2.3. usage-based energy equivalent of infrastructure used in connection with project operation
    - 2.4. usage-based energy equivalent of ensuring subsistence needs of the labour force required for the operation of the project
    - 2.5. estimation of energy required for the liquidation of the project at the end of the lifespan.

The net energy that is produced during the lifespan of the project by operating the project can be estimated on the basis of the planned energy production (energy content of raw material input, energy footprint, energy equivalent of operation). Finally, the energy payback can be estimated.

Estimation of energy payback:

$$EPR=EiNEiE+EiO+EiR$$

where: *EPR is the* energy payback ratio for the lifespan of the project (–)

ENi is the estimated value of net (utilisable) energy in case of *i* project alternative during the lifespan of the project (J), depending on quantity of electric energy and quantity of heat energy that can be sold in case of *i* project alternative in *y* year; quantity of energy em-

bodied in materials that can be sold in case of *i* project alternative in *y* year
EEi is the estimated value of energy embodied in the equipment of *i* project alternative during the lifespan of the project (J)
EOi is the embodied energy equivalent of materials, energy, live labour subsistence used in the operation *i* project alternative during the lifespan of the project (J)
ERi is the estimated energy equivalent of restoring in case of *i* project alternative at the end of the lifespan (J)

Table 2. General characteristics of scenarios

Code of the scenario	Characteristics of the basic material supplying district	Characteristics of machinery	Organisational characteristics	Order	
				4D	3D
A	The sampling district covers the geographic area modelled, road networks density is balanced.	Modern machinery with average utilisation.	Occasional cooperation, not coordinated decision making	2	3
B	The sampling district goes beyond the geographic area modelled, road networks density is favourable.	Modern machinery with above-average utilisation.	Cooperating participants, coordinated decision making mechanisms	1	2
C	The sampling district is smaller than the geographic area modelled, road networks density is not balanced.	Machinery of low performance with above-average utilisation and significantly extra capacity.	Not cooperating participants, weak machinery performance, not coordinated decision making	5	5
D	The sampling district is smaller than the geographic area modelled, road networks density is not balanced.	Modern machinery of high performance with below the average utilisation and extra capacity.	Not cooperating participants, weak machinery performance, not coordinated decision making	4	4
E	The sampling district goes beyond the geographic area modelled, road networks density is favourable.	Old fashioned machinery of low performance with above-average utilisation and above-average environmental pollution.	Cooperating participants, coordinated decision making mechanisms	3	1

Source: own construction

It should be noted that the organisation model should be considered in the scheduling of technological equipment purchase and planning the amount of equipment required. The effect of consequent excess equipment need should be calculated in the embodied energy quantity. The adjustment factor – in case of usual conditions – can change between 1.5–3 (the nominal capacity is 90% compared to standard exploitation in case of 30–60% exploitation levels).

The estimation of present value created during the project‘s lifespan requires the planning of cash flow, based on the well-known NPV calculation. This calculation is made with well-known relations, as is therefore not described here.

The determination of aggregated CO^2 emission – similarly to the process used in the case of energy and economic payback – is made by the analysis of project lifecycle, by determining the CO^2 equivalent embodied in equipment and tools produced or directly used during the lifespan (*Y*). The optimum (?) is the maximum area covered by the standardised values of four evaluation criteria. In order to ensure comparability of results, the order of axes is fixed in a clockwise direction: (1) standardised logistic costs, (2) energy payback, (3) aggregated CO^2 emission, and (4) index of income during lifespan. (Figure 2)

It is at the optimum when the area bounded by the standardised values of the four criteria is maximal. The calculation of the area of the rectangle is made by the use of the areas of the right triangles forming it.

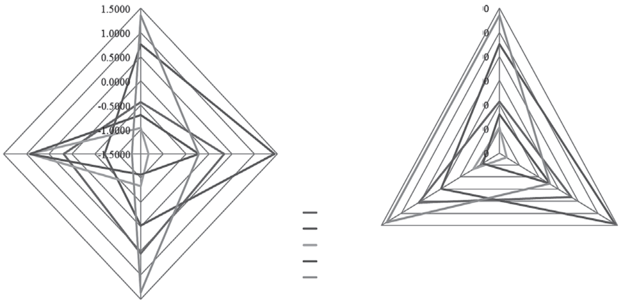

Figure 2. The polygon areas „stretched" by criteria variables on three- and four-dimension ray diagrams
Source: own edition

Results and discussion

5 possible scenarios (Table 2) were outlined for testing the model. These are evaluated with the help of input data based on expert estimations.

After the standardisation of criteria values of scenarios and, calculating the criteria, (Table 3, Figure 2) the received index values were suitable for sorting out the alternatives. Omitting the aggregated CO^2 emission from the criteria has rearranged the rank of scenarios.

It is clear, however, that the three-dimension analysis also provides enough information to drop the most unfavourable scenarios, the consequence of which is that the preparation works can be reduced by a two-stage examination consisting of a pre-screening and the values of the fourth dimension are developed only for a narrow group of alternatives.

Table 3. Comparing scenarios with the help of the model

Scenario	Standardised values of criteria variables	Area covered by the standardised values of indices	Order				
	SDÁT	-SDEPR	SDNPV	-SDCO2	4D	3D	4D	3D
A	-0.4310	0.3303	0.5521	0.1795	3.4030	1.9253	2	3
B	0.7543	1.4313	-0.0162	-0.7179	4.6567	4.1007	1	2
C	-0.9698	-1.3212	-0.8281	0.9273	0.2732	0.0000	5	5
D	-0.7004	-0.2202	-1.0717	0.9273	0.4505	0.1284	4	4
E	1.3469	-0.2202	1.3640	-1.3162	2.6161	4.7091	3	1

Note: 4D = average shipping distance, EPR, NPV, aggregated CO2; 3D = average shipping distance, EPR, NPV

Source: own edition

Conclusions

The complexity of economic and social processes requires a complex approach in the course of evaluation. Argumentation for environmental, economic and social sustainability among the criteria of evaluation models is not always possible with the help of direct indicators, and those indices should and must therefore be selected by considering the essential relations of process factors which are suitable for the numerical expression, description or estimation of observations.

This research focuses on the use of biomass for energy production purposes thus creating utilisable energy. On the other hand, however, the realisation of the process directly or indirectly absorbs energy (see embodied energy) as well as having some external environmental effects (heat emission, CO^2 emission) which are also unfavourable.

Obtaining the input is not only a question of logistics, but also affects the volume of the two factors outlined above (energy embodied in equipment and infrastructure used, CO^2 emission connected with shipping distance, etc.)

It should also be highlighted that the efficiency of production and the level of cooperation which also characterises the quality of social relations concerning the sustainability, affect the energy payback and the volume of externalities: a higher level of organisation and more efficient use of equipment can improve energy payback and decrease environmental loads.

Supplementing the traditional economic payback with criteria displaying the requirement of sustainability indicates a more long-sighted way of thinking and also supports well-founded decision-making.

Acknowledgement

The research was carried out with the support of TÁMOP-4.2.1.-09/1-2009-0001 research program, entitled „OPTILOG© organisational model for the optimum service of energy centres”.

References

Abbasi, T., Abbasi, S. A. (2010): Biomass energy and the environmental impacts associated with its production and utilisation. *Renewable and Sustainable Energy Reviews.* 14: 919–937

Bai A. (2012): A hazai biomassza-hasznosítás. *Agrárium.* 22. (7): 3–5

Dombi, M., Kuti, I., Balogh, P. (2012): Aspects of the sustainable utilisation of renewable energy sources. *APSTRACT.* 6. (5): 93–96

Eco Cortex (2012): Megújuló energiára alapozott komplex kistérségi energetikai modell. Tanulmány. Pécs. 102 p.

Erős V., Bíró T. (2010): Renewable energy resources in Hungary – solid biomass utilisation in terms of necessity and opportunity. *APSTRACT*. 4. (3-4): 75–78

Frombo, A., Minciardi, R., Robba, M., Rosso, F., Sacile, R.: (2009): Planning woody biomass logistics for energy production: A strategic decision model. *Biomass and Bioenergy*. 33: 372–383

Georgescu-Roegen, N. (1979): Energy Analysis and Economic Valuation. *Southern Economic Journal*. 45: 1023–1058

Hammond, G. P., Jones, C. I. (2008): Inventory of Carbon and Energy (ICE). University of Bath. 62 p. Online: http://perigordvacance.typepad.com/files/inventoryofcarbonandenergy.pdf. Download: 2012.06.16.

Lehoczky M., Takács I. (1981): A melléktermék felhasználás műszaki fejlesztésének lehetősége és gazdaságosságának összefüggése. Kutatási jelentés. Gödöllő, MÉMMI. 1981. 24 p.

Lehoczky M., Takács I. (1983): Növénytermesztési melléktermékek hasznosításának ökonómiai értékelése. In MTA AMB–MÉM. Kutatási Tanácskozás. Gödöllő, 1983. január 18-19.

Leontief, W. (1966): Input-Output Economics. Oxford University Press. New York. p. 134

Popp J., Potori N. (szerk.) (2011): A biomassza energetikai célú termelése Magyarországon. Budapest: Agrárgazdasági Kutató intézet. 173. p.

Szemmelweisz T-né, (n. a.): Biomassza. Stratégiai dokumentum. Fenntartható természeti Erőforrás Gazdálkodás Kiválósági Központ. Energiagazdálkodás Tudományos Műhely. Miskolc. Online: http://www.uni-miskolc.hu/1kk/downloads/biomassza.pdf. 5 p. Download: 2012.06.16.

Takács-György K., Takács I. (2013): Arguments of optimization of biomass utilisation for energy production. 3rd AGRIMBA-

AVA Congress: Agribusiness and Rural Development as a Global Challenge. Conference CD *pp. 1-20.*

White, S. W. – Kulcinski, G., L. (2000):Birth to death analysis of the energy payback ratio and CO2 gas emission rates from coal, fission, wind and DT-fusion electrical power plants. *Fusion engineering and design*. 48: 473-481

Wikipedia: Embodied energy (2012). Online: http://en.wikipedia.org/wiki/Embodied_energy. Download: 2012.06.16.

Wikipedia: Matthew Henry Phineas Riall Sankey (2012). Online: http://en.wikipedia.org/wiki/Matthew_Henry_Phineas_Riall_Sankey. Download: 2012.06.16.

Wikipedia: Sankey diagram (2012): In 1898, M.H.P.R. Sankey's published the first energy flow diagram (a visualisation to be christened 'Sankey diagram') Online: http://en.wikipedia.org/wiki/Sankey_diagram. Download: 2012.06.16.