

University doctoral (PhD) dissertation abstract

**SUSTAINABILITY ASSESSMENT OF RENEWABLE POWER
AND HEAT GENERATION TECHNOLOGIES**

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Debrecen, 2013

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1. RESEARCH OBJECTIVE AND BACKGROUND

It gives rise to concerns that regarding the ecological problems we have crossed or at least we have come close to that border where the space for the long-run survival of the human civilisation is doubtful. Social and economic processes need to be adjusted to the boundaries of the ecological systems towards long-run existence of human civilisation. This is the sustainable development principle.

1.1. Aims of the research

Amongst the ecological problems one of the most significant phenomena is the climate change which is mainly resulted by energetic processes. The current energetic system is unsustainable due to the increasing energy demand triggered by population expansion and economic growth, as well as short- and long-term uncertainty in connection with the availability of resources. Rationalisation of consumption, more efficient energy usage and a new energy structure are needed to be achieved in the same time. More intensive utilisation of renewable energy sources is an important aspect in order to shift the structure of energy system towards sustainability.

The aim of the study was to reveal the most beneficial technologies or utilisation of renewable energy sources with special respect to sustainable energy system. Primary results of the study, i.e the relative

ranking of the technologies as well as the secondary results are potentially useful in several environmental and development policies. From strategic planning viewpoint the estimation of the optimal Hungarian renewable energy mix regarding sustainability is a significant conclusion as well hence an ideal state can be modelled.

Numerous technologies of power and heat generation were compared in a sustainability assessment frame built up by seven attributes. Preferences of experts regarding these were evaluated by choice experiment (CE) survey. This group of attributes represents the three-dimensional definition of the sustainability.

1.2. Hypotheses

<p>H1 PRIORITIES OF HUNGARIAN EXPERTS ARE GIVEN FOR THE ECOLOGICAL AND SOCIAL ASPECTS OF THE UTILISATION OF RENEWABLE ENERGY SOURCES.</p>

It is assumed that the importance of ecological attributes (GHG emission, other harmful ecological impacts) and social attributes of the utilisation of renewable energy sources are equally evaluated by experts.

H2

BIOMASS UTILISATION TECHNOLOGIES ARE MORE BENEFICIAL WITH REGARD TO ASPECTS OF SUSTAINABILITY.

Bioenergy technologies are advantageous regarding social aspects of utilisation of renewable energy sources due to higher labour and local raw material demand in case of the social aspects are prioritised. However, the importance of positive social effects of biomass utilisation depends on the significance of land demand attribute in the assessment.

H3

SMALL-SCALED TECHNOLOGIES ARE RELATIVELY ADVANTAGEOUS REGARDING SUSTAINABILITY.

Generally, the higher is the amount of energy supplied the lower is the per-unit labour demand and costs, so large-scaled technologies are less beneficial regarding their social attributes. It is assumed that if social dimension has higher importance according to expert's survey, the small-scaled version of each technology will supposed to be favourable. Decentralised energy supply is probably preferred in this assessment.

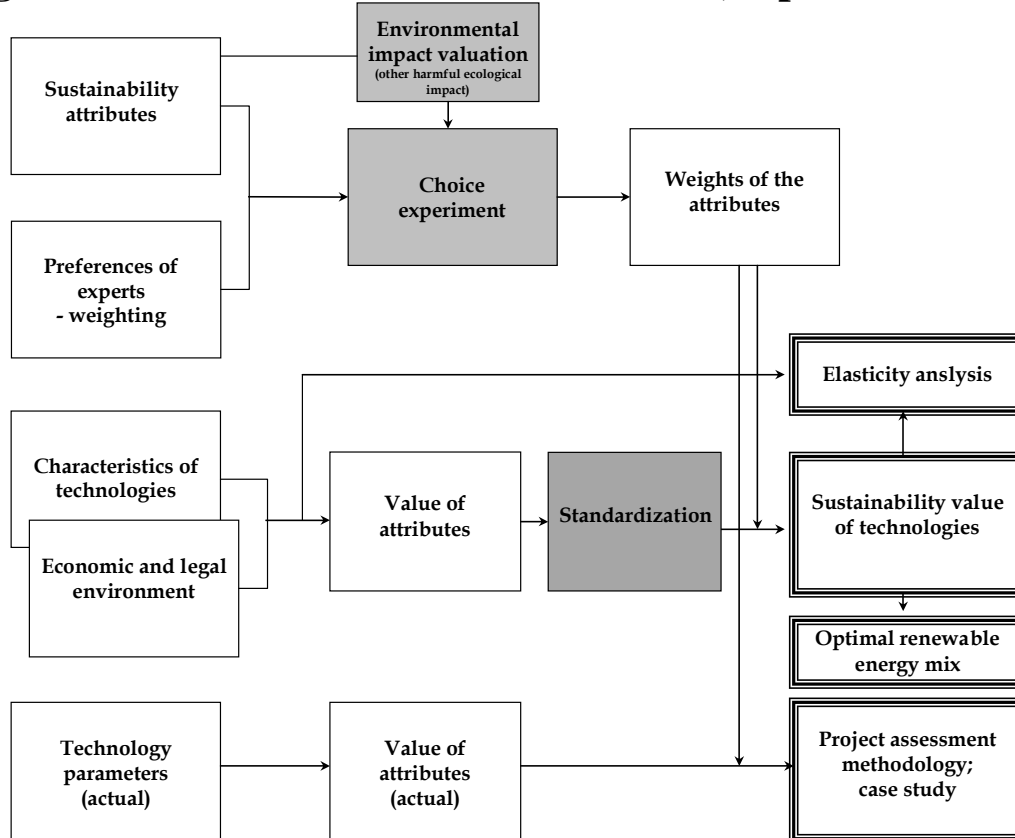
H4
THE OPTIMAL RENEWABLE ENERGY MIX OF HUNGARY IS BIOMASS-BASED.

The highest portion of current Hungarian sustainable renewable energy potential is based on biomass utilisation. Furthermore, bioenergy provides great amount of storable energy for all proposes. Additionally, bioenergy technologies are assumed to be placed in a position at the top of relative ranking, so bioenergy will play an important role in optimal energy mix as well.

2. DATABASE AND INTRODUCTION TO THE APPLIED METHODS

Method of the sustainable assessment is compensatory multi-criteria assessment with criteria weighting based on choice experiment (CE). The model of the assessment is presented in **Figure 1**. Input data is displayed on the left side, the applied methods are presented in the grey cells, while on the right side types of the main results are shown. The database of the research is built up by the preferences of the Hungarian experts (CE survey) as well as attributes values of each involved technology.

Figure 1. General model of the assessment, inputs and results



Source: own construction

The first step of the assessment was the definition of the most relevant descriptors of sustainable utilisation of RES. Seven sustainability attributes was established. The importance of each attribute was explored by a CE survey amongst Hungarian experts. Coefficients calculated by the survey were used as weights of the sustainability attributes in the technology assessment.

Attribute of ‘other harmful ecological impacts’ combines all negative ecological impacts beyond climate change. To evaluate all impacts as a unique environmental impact assessment frame were established.

Technical, ecological, social and economic parameters of technologies were collected from the literature. Each technology can be described on three levels, these are global, domestic (Hungary) and project (see **Figure 1**) levels. Comparison of renewable based projects of Miskolc was presented. Project assessment is able to adopt in optional environment.

The primary result of the sustainability assessment was the relative ranking of technologies on global and domestic level. During further analysis, impact of variation of technology parameters on the ranking was presented (elasticity assessment). The optimal renewable energy mix of Hungary was also estimated according to sustainability assessment’s results and individual project assessment was interpreted as well.

2.1. Sustainability attributes

During the sustainability assessment of utilization of renewable energy sources few relevant characteristics of the analysis has to be defined. These characteristics – attributes – are the basis of the comparison. Generally, in a CE survey respondents are asked to choose between few (2-4) hypothetic options regarding goods, investments or policies. Options are constructed by the combination of predefined attribute levels.

Table 1. Attributes and attribute levels

ATTRIBUTE	DESCRIPTION	LEVELS
GHG emission (relative to fossil fuels)	Decrease in GHG emission due to the different technology usage (LCA approach) compared to conventional technology – relative to fossil fuels (%).	5; 50; 80
Land demand	Amount of technological demand on land used for agricultural, forest or nature conservation purpose (ha/TJ).	2; 20
Energy efficiency	Ratio of used and produced energy (LCA approach, O/I) (%)	10, 30; 60
Other harmful ecological impacts (relative to fossil fuels)	Direct and indirect impacts of utilisation (e. g. landscape impact, noise pollution), relative to fossil fuels (%).	20; 60
Increase in costs	Investment and operation costs compared to conventional technology (%).	5; 30; 60
New jobs	New jobs due to utilization of RES by each technology (prs./100 TJ).	2; 10; 20
Local income	Income realized by local citizens, enterprises or local government due to RES utilisation (m HUF/TJ).	2; 5; 15








Source: own construction

The importance of the seven predefined attribute (**table 1.**) in the sustainable energy system was estimated by the CE methodology. These descriptors of the attributes were used as weights in the

assessment. Participants were asked to choose responsibly between the options and with special respect to sustainability of future energy system.

18 alternatives described by different level of every seven attribute were pared and organised into 9 choice sets. The sets contain three possible responses ('A', 'B' or neither). 'Neither' represents the continuous existence of the current energy system. Figure 1. shows an example for a choice set. Participants were asked to choose responsibly between the options and with special respect to sustainability of future energy system.

Figure 2. Example choice set

	Option „A”	Option „B	Neither
 GHG emission (relative to fossil fuels)	80%	80%	Further existing the current energy system
 Land demand	2 ha	20 ha	
 Energy efficiency	10%	30%	
 Other harmful ecological impacts (relative to fossil fuels)	20%	60%	
 Increase in costs	30%	30%	
 New jobs	10	2	
 Local income (excluding labour income)	15 M HUF	2 M HUF	
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Source: own construction

One hundred and seventy-two Hungarian professionals were invited to participate in the survey. All of them had previous publication in the

topic of RES, ecological economics or environmental policy and/or professionals with position in governmental units, universities or in NGOs are also considered as expert – even without publication activity. Thus, a database was set up which represents the whole community of the relevant Hungarian experts of this discipline. An on-line survey service was applied which was available between 11th October and 18th November 2011. Fifty-two valid questionnaires (30.2%) were received.

2.2. Technology assessment

Seventeen technologies of RES based electricity and heat generation technologies were involved into the sustainability assessment. Data regarding each attribute were collected for every technology based on wide review of scientific articles and professional reports of international organizations. More than 80 publications were used. Furthermore, the database contains the coefficients as weights of the attributes which represent the importance of each attributes according to the CE survey.

During the assessment the median of the given attribute was considered for each technology. Continuously, the attribute values were standardised amongst technologies. This step resulted in values from 0 to 1 with retained relative distance between the technologies. Standardisation also allows the aggregation of attributes characterised

by different dimensions. Hereafter, standardised values were corrected with the weights from the CE survey. Finally, the ‘sustainability values’ were calculated as a weighted sum of technology attribute values. Sustainability value is a value without dimension and is not informative in itself; it only makes sense used in definition of relative ranking. Relative ranking was also standardised for better understanding and visualisation.

Analysis of effect of different variables on the variance of the results – i.e. the sensitivity analysis – has a great importance regarding the interpretation of the results. Due to sensitivity analysis potential intervention possibilities can be identified which are more efficiently increasing the sustainability value of a technology by technical and other changes.

3. MAIN CONCLUSIONS OF THE DISSERTATION

3.1. Preferences of experts

The calculated results of our model are presented in Table 2. It shows that except of ‘energy efficiency’ all coefficients are at a 95% significance level. Signs of β coefficient are consistent with our expectations. Positive value implies that experts are more likely to choose a technology which is more efficient, creates new jobs and realises local incomes. The attributes with negative β coefficient are connected to harmful impacts.

Table 2. Estimation results of the choice experiment

Attribute	β	exp. β	SE	p
ASC	1.66407	5.281	0.29079	1.00E-08
GHG emission	-0.01156	0.989	0.00226	3.00E-07
Land demand	-0.03243	0.968	0.00865	1.80E-04
Energy efficiency	0.00444	1.004	0.00434	3.10E-01
Other harmful ecological impacts	-0.01178	0.988	0.00368	1.40E-03
Increase in costs	-0.01656	0.984	0.00374	9.70E-06
New jobs	0.02246	1.023	0.00959	1.90E-02
Local income	0.02835	1.029	0.01325	3.20E-02
<i>Pseudo-R²</i>	0.1229			

Likelihood ratio test=126, 8 df, p<0.001 n= 1404, N = 468

Exp. β coefficient = e^{β}

Source: own calculations

The β coefficient reports the role of each attribute in the choice as well as in utility function of the respondents. The highest β values is observed in the case of land demand (-0.03243) followed by local

income and jobs. High preferences connected to the low land demand are probably resulted by intensive debates about the land use conflict. The coefficient of costs shows mediate importance. Surprisingly, the β coefficients of GHG emissions and in other harmful impacts are lower. Since energy efficiency attribute was not characterised by statistically significant β coefficient, it was not built into the model hereafter. The necessity of the introduction of ‘other harmful ecological impacts’ attribute is proved, since its β coefficient is close to one of GHG emissions.

3.2. Global and domestic technology ranking

During the *global technology assessment* altogether 17 technologies were involved in the analysis. Ten of them are power generation, while seven are heat generation technologies. Technologies differ in utilised energy source, the method of energy conversation and the size (scale) of utilization.

Figure 4. contains the results of the sustainability assessment of RES utilisation technologies. The variance of sustainability value in the case of differently sized technologies is determined by the relation of labour intensity and costs. Small-scaled utilisation is characterised by higher labour demand and higher costs. Contrary, large-scaled technologies require less labour per produced energy and their production costs are lower due to economies of scale. Hence in this

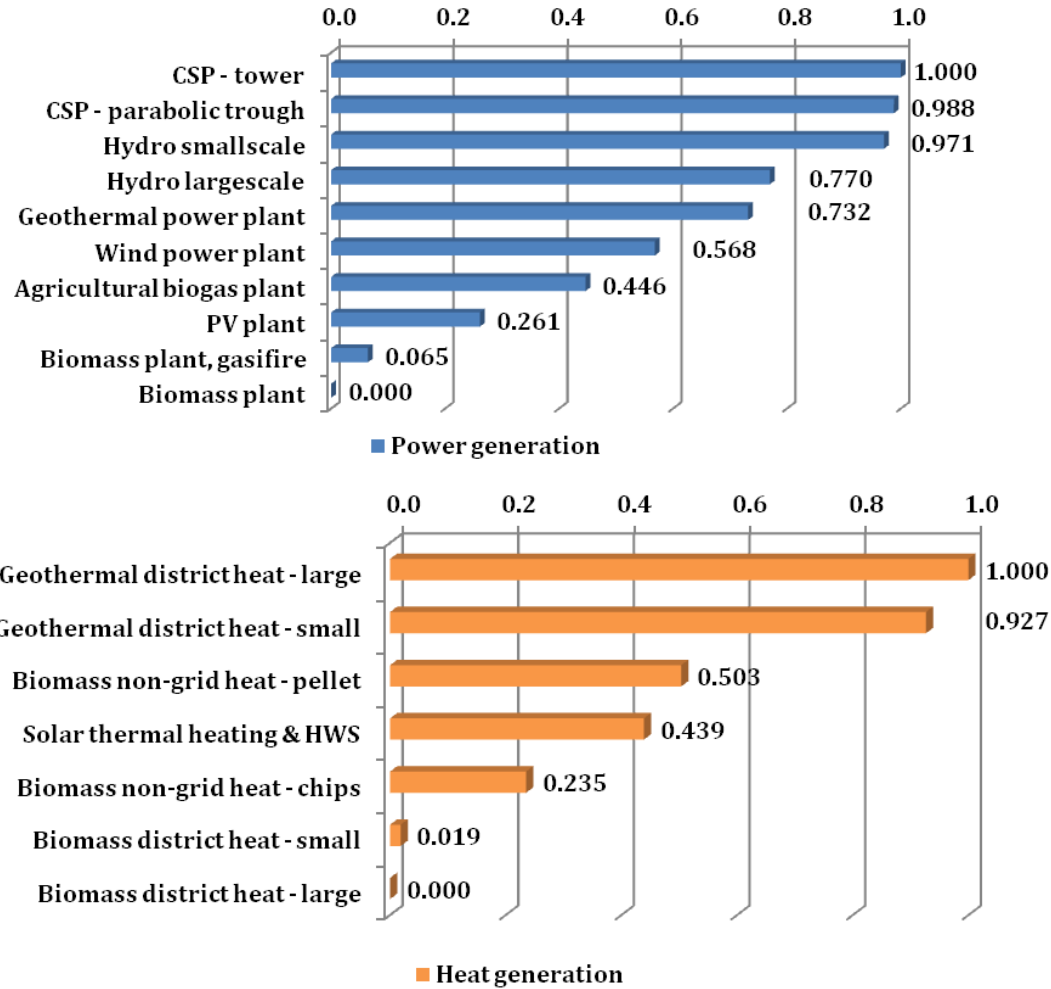
context employment effects are positive, however, increase in costs is a negative attribute; ranking is mainly influenced by the relative difference regarding these attributes in case of technologies using the same conversation method on different size. The difference between the two scales of utilisation according to employment is greater than in costs at hydropower installations, while the opposite is observed at geothermal district heating systems.

Analysing the lifecycle employment effects of the technologies, it turns out that options which are more technology-intensive require more labour force in phase of equipment production and installation. In case of the utilisation of energy of Sun and geothermics, these effects are significant. The labour demand is observed in those cases in some specific industry, so the support of the whole sector seems to be reasonable (e.g. PV panel production).

Analysing the LCOE, lower cost profile of wind, geothermal and hydropower utilisation technologies can be concluded. Operation cost advantage is caused by the lack of fuel costs. However, investment costs of solar energy conversation are still high. In turn, the fuel cost results in advantages regarding local income in case of bioenergetic conversation processes, hence the fire wood or agricultural by-products are probably supplied by producers of the region.

Analysing the results regarding relative ranking based on sustainability values of electricity generation technologies, concentrated solar power (CSP) seems to be the most favourable. The most advantageous attributes of CSP's are the high employment effects, low emissions and relatively high energy density that results in low land demand. CSP technologies are on the top of the ranking despite the worst performance in local income attribute.

Figure 4. Relative ranking and sustainability values of the electricity and heat generation technologies



Source: own calculations

Utilisation of the energy of water resources is also an advantageous possibility. Technologies (varied by size) were positioned at 3. and 4. place in the relative ranking. These conversation methods are the most favourable regarding ecological impacts and costs. Geothermal and wind power plants are found to be in the middle of the ranking. Cost and land demand are very low in these cases. Furthermore, geothermal power plants can be described by high employment effects and wind power with low emissions. However, emissions of geothermal energy and negligible positive social impacts of wind energy are compensating their positive features.

At the last four positions in the relative ranking three bioenergy conversation methods were positioned. Sustainability value of biogas production exceeds the sustainability value of biomass plants due to higher local income as well as much lower land demand as a result of utilisation of residues. PV is characterised by the highest costs and the lowest local income generation. Relatively high ecological damage was observed as well.

Geothermal district heating systems are the most favourable technologies due to minimal area requirement, costs and the highest employment effects. Small-scaled utilisation performs better regarding local income, but large-scale system is more advantageous due to much lower specific costs. Some fixed investment costs are

significantly increased (research, drilling and special equipments), therefore the lifecycle costs of a small system are relatively high.

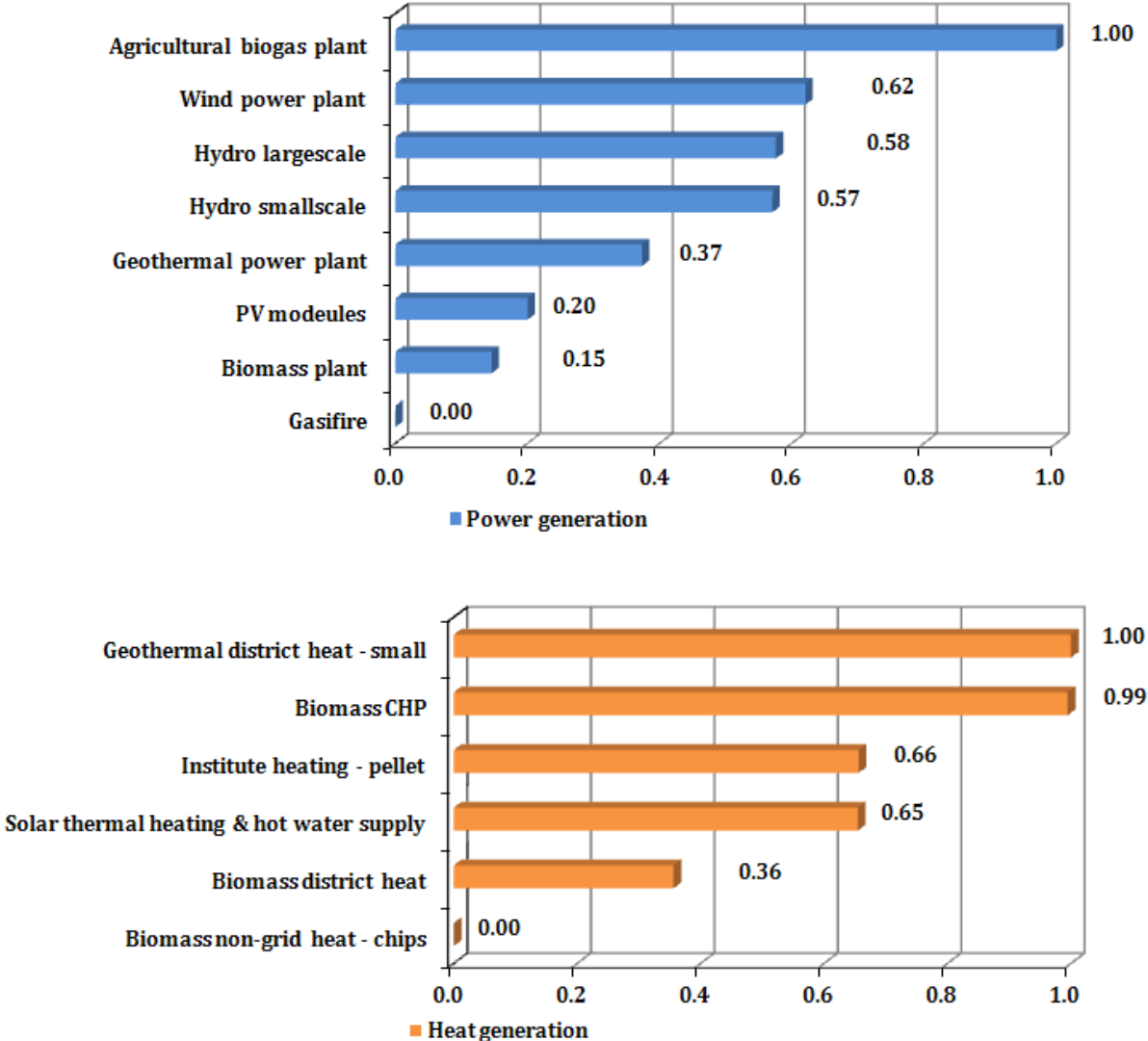
Solar thermal heating is a moderately favourable option. In this case the lowest GHG emission and land demand are noticed. Contrary, it generates minimal local incomes on a very high level of production costs. The only relative advantage of biomass based heating systems is their capability for local income generation. Environmental pressure, including also land demand, is very significant.

Figure 5. presents results of *domestic technology assessment*. In case of power generation, the biogas utilisation is on the top of the relative ranking, so it is the most advantageous technology regarding sustainability. Due to utilisation of residues the, land demand as well as ecological impacts of this conversation method are much lower than those of other bioenergy options. However, social impacts are positive: the highest per-unit employment and local income is observable. Despite wind power is characterised by the lowest positive social impacts amongst the involved technologies, it is positioned in the second place in the ranking due to low environmental pressure and the lowest lifecycle costs.

Hydropower generation is an efficient, clean, profitable technical option which requires also low area. Nonetheless, the decreased

employment-potential and local income generation are placed hydropower technologies on the 3th and 4th position.

Figure 5. Relative ranking and sustainability values of the electricity and heat generation technologies



Source: own calculations

In the assessment of heat generation options bioenergy technologies are differing significantly. Social impacts are similar, so the ranking is influenced rather by the land demand. In case of cogeneration the

lower land demand is resulted by the higher amount of produced energy, while pellet-based institute heating requires less land due to increased energy density. First position of the geothermal district heating is caused by high labour-intensity but low land demand. The solar thermal heating and HWS are the more land-effective techniques. However, immediate sustainability value is calculated because of low local income generation and high costs.

Since utilisation of energy of wind and hydropower are positioned at the top of the ranking, increment in portion of these sources in energy mix is at great importance in the energy mix with special regard to sustainability. Furthermore, the utilisation of wind energy is limited by its negative effect on regulation of the power system which is potentially decreasing if hydropower is intensively used.

The *sensitivity analysis* has a great importance for the interpretation of the results (**Table 3.**). Negative ε implies that negative connection is observable between the change in input variable and the sustainability value of a technology. Thus, the sustainability value will decrease in case of increment in value of a given attribute weight or technology parameter.

The local income has the highest influence on the results in both levels of analysis in case of *weight-elasticity*. One percent increment in weight of local income attribute results in 1.44 percent increase in

weighted average of sustainability values in the global technology assessment, while 1.65 percent increase is observable at the domestic level of assessment. Weight elasticity ratio of employment and land demand attributes is high as well.

Table 3. Effect of variance of input data on the results

	Weight-elasticity		Technology-elasticity			
	εW_i		εA_j			
	Global	Domestic	Power		Heat	
Global			Domestic	Global	Domestic	
GHG emission	-0.0032	-0.0031	-0.0021	-0.0023	-0.0057	-0.0066
Land demand	-0.0119	-0.0128	-0.0038	-0.0037	-0.0059	-0.0088
Other harmful ecological impacts	-0.0057	-0.0067	-0.0057	-0.0050	-0.0046	-0.0009
Increase in costs	-0.0040	-0.0068	-0.0053	-0.0081	-0.0080	-0.0126
New jobs	0.0104	0.0129	0.0051	0.0045	0.0042	0.0201
Local income	0.0144	0.0165	0.0084	0.0098	0.0127	0.0161

Source: own calculation

However, assay of *technology-elasticity* is even more important than influence of weights on results. The highest effect on sustainability value is the local income in case of power generation at global and domestic level of analysis as well, 1% increment leads to 0.84% and 0.98% higher average sustainability value, respectively. Cost-attribute’s technology-elasticity is also high (-0.53; and 0.81%). The change in GHG emissions has the lowest effect on the assessment. Local income and costs are also the strongest influential factors in heat generation. Additionally, at the domestic level of analysis the changes in employment and land demand attributes differs the values and the ranking.

In conclusion, the sustainability assessment of renewable based power and heat generation is intensively depended on costs and local income. It is important to support technologies with higher portion of local income generation – facing decreasing cost in line. Development toward lower cost requires first of all R + D + I expenditures, developments in management as well as high quality investments; while the increment of portion of locally expenditures needs administration changes and incentive regulation, e.g. awarded investments in operative programs.

3.3. Estimation of the optimal Hungarian renewable energy mix

Optimal renewable energy mix regarding sustainability can be described for Hungary on the basis of renewable energy potentials presented in the dissertation and on the results of the technology assessment. It is not useful for policy uses directly; however, it helps to recognise the expected status of each renewable energy source with respect to their current conditions.

During the estimation of the optimal energy portfolio the average value of sustainable potential of sources were considered. The primary consumption of renewable energy utilised in sustainable way is less than one-third of current requirement. It highlights repeatedly the necessity of the decrement in energy needs in line with the

remodelling of the energy structure. Present energy needs cannot be substituted by the actual renewable energy utilisation technologies.

Table 4. Primary and final energy consumption in the optimal energy mix

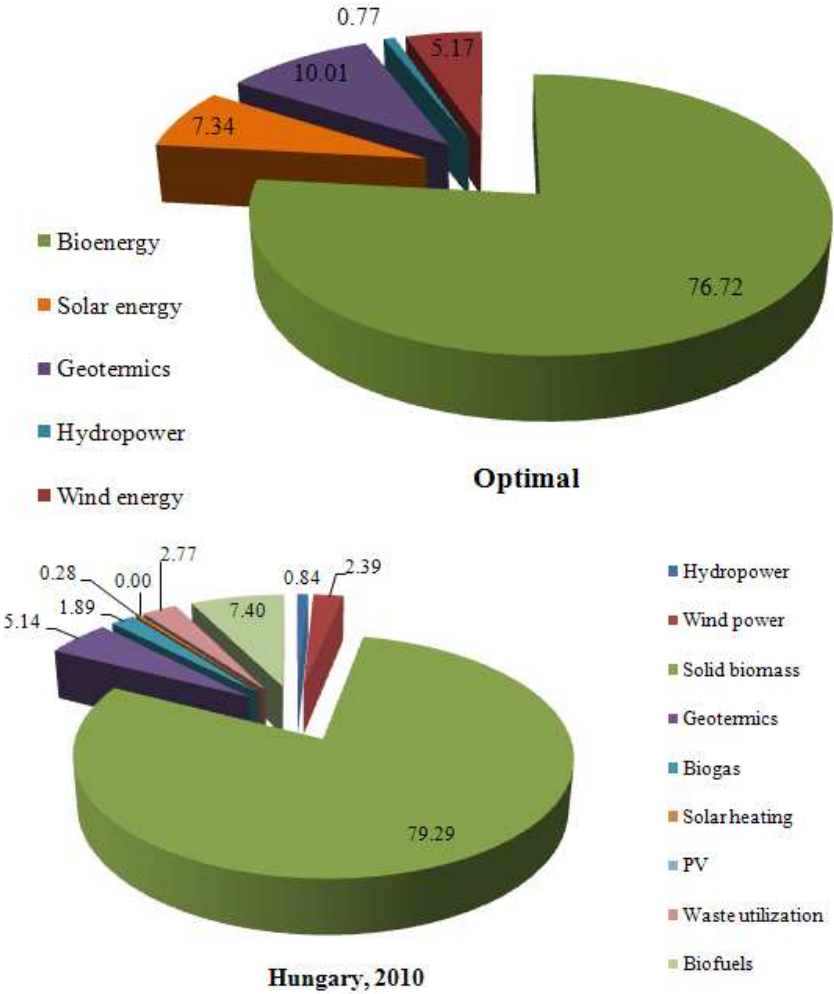
Technology	Primary energy consumption, PJ/a	Final energy consumption, PJ/a
POWER GENERATION		
Biogas plant	156.0	78.0
Wind power	15.5	3.1
Geothermal power plant	5.0	0.8
PV	5.0	0.8
Biomass plant	2.0	0.7
Biomass plant, gasifire	2.0	1.1
Hydropower, largescale	2.0	1.7
Hydropower, smallscale	0.3	0.2
Total	187.8	86.4
HEAT SUPPLY		
Biomass CHP	50.0	20.0
Geothermal district heating	25.0	21.3
Institute heating - pellet	18.0	14.4
Solar thermal heat and HWS	17.0	6.0
Biomass district heating	1.0	0.8
Biomass non-grid heating - chips	1.0	0.8
Total	112.0	63.3
TOTAL	299.8	149.7

Source: own calculations

The energy mix described above is able to supply the 48% of power consumption. The district heat is fully supplied; however, the needs of non-grid heating energy serving installations can be satisfied only at 8%. The largest deficiency is observable in case of the non-grid heating which implies also the demand for the increment in energy efficiency. Consequently, concentration of energy efficiency measures

in this sector is suitable. For instance, subvention aiming energetic modernisation is appropriate tool of supporting in this case.

Figure 6. Optimal Hungarian energy mix with regard to sustainability; %



Source: own calculations

Current portion and role in optimal energy mix of the renewable energy sources is presented in Figure 6. Comparing the ratio of biomass in energy mix in 2010 (81.2%¹) with the optimal level, the

¹ without biofuels

biomass ratio in optimal mix is lower (76.7%), however, it is still bioenergy-based. The solar energy plays significant role in the optimal mix. Additionally, the consumption of geothermal and wind energy is duplicated. Nevertheless, more intensive energetic utilisation of water resources is expected only if it will be politically accepted.

This mix is optimal from the sustainability viewpoint. The portfolio is far from the optimal with respect to costs or emissions into the atmosphere. For instance, in spite of utilisation of solar energy is one of the most expensive options both in power and heat generation, the solar energy content of the optimal energy mix regarding sustainability is 7.34%.

3.4. Verification of hypothesis

Results regarding H1 are influencing intensively the judgement on other hypotheses, because the weights as revealed preferences of the experts are determining the results of technology assessment. Hypotheses H2 and H3 has been rejected, while H1 and H4 has been verified. In this section, the background of these decisions is presented.

H1

PRIORITIES OF HUNGARIAN EXPERTS ARE GIVEN FOR THE ECOLOGICAL AND SOCIAL ASPECTS OF THE UTILISATION OF RENEWABLE ENERGY SOURCES.

The ecological impacts of utilisation of renewable energy sources are very importance according to experts, which result meets my assumptions. The preferences regarding GHG emission and ‘other harmful ecological impacts’ are rather low, while the attribute describing land demand has a prior significance in decisions (β coefficient = -0.03243). However, this attribute has also economic and social aspects; it is difficult to assign it into one dimension of sustainability.

The significance of specific social attributes is unequivocally: the β coefficients of local income and employment are high (0.028354 and 0.02246). These attributes are characterised with the second and the third strongest weights in the assessment based on the CE survey. Importance of the cost attribute as the only strict economic characteristic is moderate ($\beta = -0.01656$). The attribute with lowest importance is the energy efficiency according to experts, which was not involved into the assessment because of the lack of statistically significant connection with the expert’s choices. **This hypothesis has been verified.**

H2

BIOMASS UTILISATION TECHNOLOGIES ARE MORE BENEFICIAL WITH REGARD TO ASPECTS OF SUSTAINABILITY.

The importance of the land demand is very high according to revealed preferences of Hungarian experts. In spite of the fact that those social impacts are also high evaluated by them, the bioenergy conversion methods are less beneficial options according to global and domestic assessment as well. Bioenergy technologies are positioned on 7th, 9th and 10th place in the global assessment of power generation technologies, while they are at the end of the relative ranking in heat supply globally (positions 5-7th).

In the domestic assessment, some bioenergy technologies are more positively evaluated on the one hand: biogas plants are at the top of the ranking in power generation due to its higher labour demand in Hungarian literature. On the other hand, other bioenergy technologies (biomass plant and biomass gasifire power plant) are at the last positions. Biomass utilisation technologies were the best positioned in the domestic assessment of heat supply options. Biomass based cogeneration and pellet-based non-grid institute heating are the second and the third options. In fact, on the last two positions are also bioenergy technologies. **The hypothesis has been rejected.**

H3

SMALL-SCALED TECHNOLOGIES ARE RELATIVELY ADVANTAGEOUS REGARDING SUSTAINABILITY.

There is no strong correlation between size and sustainability value of a technology, so it is not possible to take a stand on the advantage of the decentralised or centralised energy supply regarding sustainability on the basis of the result of the dissertation. The relation of the small-scaled and large-scaled utilisation of a renewable energy source is mainly influenced by the per-unit costs and labour demand in the assessment. It is clearly shown in case of global assessment; the small-scaled technology of hydropower is characterised by higher sustainability value. Contrary, if two different scales of geothermal district heating are compared, the large-scale system is advantageous due to much lower per-unit costs which are compensating lower per-unit employment. The individual power generation (PV) and heat supply technologies are positioned rather at the end of the relative ranking. The pellet-based non-grid heating is the only exception. **The hypothesis has been rejected.**

H4

THE OPTIMAL RENEWABLE ENERGY MIX OF HUNGARY IS BIOMASS-BASED.

The optimal energy mix of Hungary regarding sustainability based on renewable energy utilisation technologies involved into the sustainability assessment is able to provide annually 299.8 PJ for

primary energy consumption, while 149.7 PJ for final energy uses. Priority of decrement in energy requirement can be concluded.

The optimal energy mix presented in the dissertation is only estimation. Nevertheless, the energetic biomass utilisation remains significant considering Hungarian technical and economic circumstances, with special respect to limits of sustainable utilisation of resources. According to the estimation, the biomass-based part of the primary renewable energy consumption is 76.72%, which is lower than the present portion (approximately 90%), but it is still the basis of renewable energy utilisation. Biomass in estimated mix is partly substituted by solar and geothermal energy (7.34% and 10.01%). **This hypothesis has been absolutely verified.**

Every hypothesis has been evaluated. Further important result of the research is the case study displayed in the Subsection 5.6 of the dissertation which proves the usefulness of the sustainability assessment frame on project level. One of the further aims of the research is to enlarge the assessed group of technologies. Furthermore, the periodic revision of the analysis is very important from scientific and policy point of view. The practical usage can be defined at different time scales; operative programmes framing energetic subsidies are takes seven years, while revision of domestic supporting systems is optimally repeated in every one or two years.

4. NEW AND INNOVATIVE RESULTS OF THE DISSERTATION

Sustainability assessment of renewable based power and heat generation technologies was aimed in the dissertation. My motivation was the contribution to the approaching of the sustainable energy management. In this context the main result of the research is the relative ranking of technologies at two levels. The following points contain major conclusions of the research as new and innovative results of the dissertation.

- 1) Three criteria of appropriate sustainability assessment model were revealed by the analysis of former sustainability assessment applications, i.e. complexity, ability for relative ranking and the weighting. An assessment method was established which contains advantageous features of the known methodologies. This is a non-compensatory multi-criteria assessment with criteria weighting based on choice experiment (CE).
- 2) Choice experiment (CE) was used for the revealing of preferences of experts regarding utilisation of renewable energy sources, which is a relatively complex problem. This methodology was rarely applied in Hungary on this research field.
- 3) According to these experts, the most important characteristics of renewable energy utilisation technologies are the land demand and social impacts, i.e. increase in employment and local income

generation. Priorities are given for these attributes during comparison of several renewable energy based technologies.

- 4) Concentrated solar power (CSP), hydropower as well as geothermal power plants are favourable power generation technologies at global scale, while biogas plants, wind power plants and hydropower are advantageous if national conditions are considered.
- 5) Globally, geothermal district heating and pellet-based non-grid heating are relatively advantageous in case of heat supply. At the domestic level of analysis, relative advantage of geothermal district heating and biomass CHP was revealed.
- 6) In contrast with the present conception, more intensive utilisation of energy of wind and water resources is advised, since these technologies are favourable with regard to sustainability.
- 7) More than two-third of the optimal Hungarian energy mix is based on biomass considering the primary energy consumption. Importance of the bioenergy utilisation will remain at high level.
- 8) The sustainability assessment is able to help in the establishment of macro-scaled supporting systems due to identification of the relatively advantageous technologies.
- 9) As it is proved by the case study in the dissertation, the introduced assessment frame is useful project assessment tool as well. It can be applied in the phase of decision making or even in project evaluation in supporting systems.

5. THEORETICAL AND PRACTICAL UTILITY OF THE RESULTS

Renewable energy technologies have their own well-known advantages and disadvantages; comparison of the available options is absolute necessary. Nevertheless, for the strategic planning on global, national and regional level, there is a great demand for the comparison of possible utilisation technologies of renewable energy sources.

Sustainability assessment is a potential tool for the ex ante evaluation of the EU supported national energy connected operative programmes. Ex ante evaluation is a preventive analysis of the expected effects of the actions. This process is required by the European Union in case of the operative programs and it can possibly manage the subsidies in the direction of more beneficial renewable energy utilisation technologies regarding sustainability.

Consideration of the sustainability in the operative programmes is solved; however, there is still space for more accurate evaluation of project plans. More aspects of sustainability, or a horizontal sustainability assay could be used if projects utilising renewable energy sources are analysed. In operative programmes, possibility of technology deifferented subsidies is expected. Ecological effects or efficiency aspects are the possible basis of the variation.

The reform of the Hungarian supporting system of renewable power generation (feed-in-tariffs) is planned to renew by the strong differentiation of possible technologies based on size and technical parameters. The differentiation would decrease the profit surplus caused by the subsidies towards lower consumer expenditures connected with the structural changes in energetic sector. Differentiation of technologies allows increment in efficiency of other supporting systems aiming more intensive utilisation of renewable energy sources (e.g. supported interest rates for the investors).

6. PUBLICATION RELATED TO THE SUBJECT OF THE DISSERTATION

Publications can be taken into consideration in compliance with the rules of the doctoral school:

- 1) **Dombi M. – Kuti I. – Balogh P. (2012):** *Aspects of the sustainable utilization of renewable energy sources.* Applied Studies in Agribusiness and Commerce – APSTRACT, 2012/5-6., pp. 91-95. ISSN: 1789-7874, IF: 0,04
- 2) **Dombi M. (2013):** *A megújuló energiaforrások technológiai és a vidékfejlesztés céljai.* A Falu, 2013/2., pp. 55-69. ISSN: 0237-4323
- 3) **Dombi M. – Kuti I. – Balogh P. (2011):** *Interpretation of sustainability in the case of utilization of renewable energy sources.* Agrártudományi Közlemények (Acta Agraria Debreceniensis), 2011/44., pp. 61-64. ISSN: 1588-8363
- 4) **Dombi M. – Kuti I. – Balogh P. (2012):** *Adalékok a megújuló energiaforrásokra alapozott projektek fenntarthatósági értékeléséhez.* Gazdálkodás, 2012/5., pp. 410-425. ISSN: 0046-5518
- 5) **Dombi M. (2012):** *Környezeti hatások értékelésének lehetősége ökoszisztéma-szolgáltatások alapján.* Tér és Társadalom, 2012/2., pp. 40-56. ISSN: 2062-9923.
- 6) **Dombi M. (2009):** *Fenntartható energiagazdálkodás – a megújuló energiaforrások hasznosításának jelentősége, korlátai és lehetőségei.* Agrártudományi Közlemények (Acta Agraria Debreceniensis), 2009/33., pp. 145-154. ISSN: 1587-1282

List of additional publications:

Articles published in Hungarian

Dombi M. (2010): *Egy fenntartható energiarendszer hatékonysági vizsgálata.* Energiagazdálkodás, 2010/4., pp. 3-9. ISSN: 0021-0757

Dombi M. – Balázs Á. (2010): *Magyarország maximális agro-erdészeti energia-potenciáljának számítása az agroökológiai lehetőségek figyelembevételével.* Gazdálkodástudományi Közlemények, 2. pp. 7-17. ISSN: 2061-2443

Conference abstract and poster presentations

Dombi M. – Kuti I. – Balogh P. (2013): *Sustainability assessment of renewable energy based power and heat generation technologies.* European Conference on Materials and Technologies for Sustainable Growth. 19-21 September 2013. Bled, Slovenia.

Dombi, M. – Kuti, I. – Balogh, P. (2012): *Sustainability assessment of certain renewable energy based projects in Hungary.* Technoport 2012 – Sharing possibilities, RERC – Renewable Energy Research Conference, Trondheim, 16-18 April 2012, poszter, Book of Abstracts, 267 p. (Poster abstract, p. 218)

http://2012.technoport.no/upload/Technoport_RERC_2012_abstract_book.pdf

Dombi M. (2009): *Analiza efektywności zrównoważonego i trwałego systemu energetycznego.* [A fenntartható energiagazdálkodás hatékonyságának kérdései]. XII. Konferencja Młodych Badaczy [XII. Fiatal Kutatók Konferenciája], Varsói Egyetem Regionális és Globális Tanulmányok Intézet, Varsó, 2009. december 7. (Előadás)

Lectures published in Hungarian

Dombi, M. – Kuti, I. – Balogh, P. (2012): *Megújuló energiaforrásokra alapozott technológiák fenntarthatósági értékelése.* III. Települési Környezet Konferencia, Debrecen, 2012. november 22-23. In: *A környezettudatos települések felé,* Meridián Alapítvány, Debrecen, 2012, pp. 13-20. ISBN: 978-963-08-5294-4

Dombi M. (2010): *Megújuló energiaforrások – fenntarthatók és „fenntarthatóbbak”.* In: A közép-európai terület-, település-, vidék- és környezetfejlesztéssel foglalkozó doktori iskolák találkozója, és „Félidőben”c. konferenciája. Pécs, Magyarország, 2010.10.08-09. PTE KTK Regionális Politika és Gazdaságtan Doktori Iskola, pp. 263-274. ISSN: 1588-5348.

Dombi M. – Karcagi-Kováts A. (2010): *A jövő gazdaságának anyagi alapjai.* Előadás „Hitel, Világ, Stádium”, Nyugat-Magyarországi Egyetem, Sopron, 2010. 11. 03. ISBN:978-963-9883-73-4

Lectures in foreign language

Dombi, M. (2012): *General Sustainability Assessment of Renewable Energy Technologies.* Scientific Conference of University of Debrecen Centre for Agricultural and Applied Economic Sciences and University of Oradea Faculty of Environmental Protection, Debrecen, 30th November 2012, (Conference presentation)

Conference abstract in Hungarian

Dombi M. (2009): *Fenntartható európai energiagazdálkodás.* TézEU sz 2011 – Tézisek az EU-elnökségi stratégiához (Második országos tanulmányi diákkonferencia és verseny – Az országos döntőbe jutott pályamunkák), Külügyminisztérium Kommunikációs és Közkapcsolati Főosztály, EU Tájékoztató Szolgálat, Budapest, 2009, pp. 18-25.

Dombi M. (2008): *Megújuló energiaforrások szerepe az energiagazdálkodásban.* Előadás „A fenntartható fejlődés és a megújuló természeti erőforrások környezetvédelmi összefüggései a Kárpát-medencében” Tudományos Konferencián, MTA Pécsi Területi Bizottság – MTA Regionális Kutatások Központja Dunántúli Tudományos Intézete, Pécs, 2008. november 10-11. (Előadás)