Renewable Energy Potentials in the Administrative Regions of Hungary

Bálint Hartmann, Ph.D., Attila Talamon, Ph.D., Viktória Sugár
Hungarian Academy of Sciences, Centre for Energy Research

ABSTRACT

The purpose of the national "Energy map (E-map)" project (KEOP 7.9.0/12-2013-0017) was to create an interactive energy map for Hungary to serve as the basis for financial resource use planning and implementation from 2014 to 2020. The map incorporated all available regional energy data in sectoral components, using statistical databases and graphical information system (GIS) methodologies.

This article introduces the methodology and selected results of the evaluation process. In the first part, definitions of theoretical, technological and economic potentials of renewable energy sources are created, using the National Renewable Action Plan of Hungary. The assessment considers hydropower, wind energy, solar, geothermal and biomass energy potentials. It discusses how the regional potential of each energy source was determined, using available databases. The second part of the article provides an overview of the results. Finally, we offer an update on recent renewable energy policy changes that have occurred in Hungary.

INTRODUCTION

Studies that evaluate the utilization possibilities of renewable energy sources often estimate the potential of each energy source. These studies typically offer estimations that cover a very broad range. This occurs due to the varying ecological approaches used, resulting in differing definitions of potential concepts and methodologies. For this reason, before estimating Hungary's renewable energy potential, the definitions used in this article are detailed.

The initial estimates of the potential of renewable energy sources are usually similar in terms of methodology, since they are based on measurable physical parameters (e.g., irradiation, wind speed, flow rate or geothermal gradient). The physically available volume of energy is usually considered to be the theoretical potential. Proper determination of the theoretical potential is essential since it provides input data for other quantities or subsets.

One of these subsets is the ecologically sustainable potential, whose definition is closely related to the purposes of the study. This potential volume is used to estimate existing and future project possibilities. The methodology for determining the ecologically sustainable potential can be created separately for each energy source. Literature shows wide variances in such cases. There are three general processes: bottom-up assessments, top-down assessments by creating regulatory and other boundary conditions, and estimates applying international best practices and analogies. The efficiency of these methods is largely dependent on the type of renewable energy source: bottom-up assessments are often used to examine biomass while top-down assessments are commonly used for wind farms.

Another widely used subset of theoretical potential is the economic potential, which assesses the volume of economically usable renewable energy sources. This estimation of potentials is complex; its volume is affected by available technologies, energy demand, existing infrastructure, regulatory aspects and possibly existing support schemes. For this reason, it is reasonable to examine the economic potential only for concrete projects, where locally or regionally available energy sources are well known.

The combination of the two subsets, economic and ecologically sustainable potentials, is also called the sustainable potential which requires long term social and environmental sustainability.

The definition of convertible potential refers to the volume of energy demand that can be supplied by currently existing technologies. For such estimates, knowledge is required of the main parameters of energy generation technologies which may include the conversion efficiencies and annual full load operating hours.

For our purposes, the National Renewable Energy Action Plan (NREAP) was used including its estimates of potentials, thus its definitions also had to be interpreted [1]. For this study, sustainable potential (i.e., the sustainable potential coordinated with technical, economic, social and ecological aspects) was calculated using either the long-term (until 2030) realizable volume or the medium-term (until 2020) realizable volume chosen as targets. We emphasize that such a refined distinction is necessary since the thematic order of long-term plans usually provides estimates for a distant horizon, while concrete targets and action plans are deduced from shorter time periods. Such methodologies are useful in case of Hungary, since the targets defined by the NREAP are below the mandatory European Union (EU) targets. Thus possible increases should be evaluated not only until 2020 but also beyond. The potential definitions, used in the background study of the NREAP are shown in Figure 1.

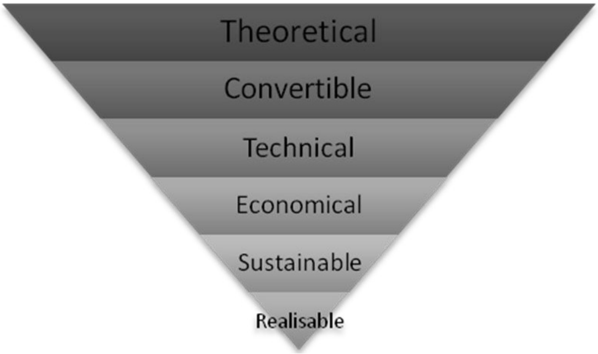

Figure 1. Hierarchical position of renewable energy potential concepts (NREAP).

- *Theoretical potential*—the physically modifiable energy source volume and structure, without accounting for constraints (elements: solar, hydropower, biomass, wind and geothermal energy).
- *Convertible potential*—the long-term total of usable volumes, taking into account constraints (mostly financial and regulatory).
- *Technical potential*—the volume of energy sources that can be utilized optimally by available, up-to-date technologies.
- *Economic potential*—the long-term (through 2030) volume of energy sources that can be utilized in an economically feasible manner under certain circumstances.
- *Sustainable potential*—the long-term (through 2030) volume of suggested energy source volume and structure, coordinated with

technical-economic-social-ecological aspects, consisting of optimal technologies.

In the background study, the sum of these potential concepts results in the quantities provided in Table 1.

The long-term technical potential of renewable energy sources can be estimated through 2030. Their combined volume is approximately 500 PJ/a. A slightly smaller number (425 PJ/a) represents the economic potential. The study, performed by the authors, was primarily based on these categories, noted in bold in Table 1. The long-term sustainable potential is estimated to be 350 PJ/a; it can be seen that this is the first column where sources other than biomass play a relevant role in future plans. The medium-term sustainable potential resulted as 237.5 PJ/a.

ASSESSMENT OF POTENTIALS

Hydropower Energy

The theoretical, technical and economic hydropower energy potential of Hungary is estimated by the literature as 100, 20 and 10 PJ/a, respectively.

Estimating hydropower energy potential is relatively simple compared to estimates for other sources since only a limited number of possible installation locations need to be examined. Furthermore, numerous measurements are available from hydropower sites. Approximately 90% of total Hungarian hydropower energy potential can be exploited from three rivers (Danube, Tisza and Dráva), while the remaining 10% is distributed among twelve others. Only the shares of Rába, Hernád and Sajó rivers exceed 1% each, and the majority of micro hydro plants are installed on the first two (see Table 2).

Long-term plans for hydropower in Hungary can be considered in four major groups: micro hydro plants, existing hydro plants and dams, small hydropower plants and plants on the Danube. Annual estimated GWh production quantities are provided for each site.

The first group are micro hydro plants, installed on small rivers, with installed capacities of a few MWs. According to the literature, twelve units can be constructed: five each on the Hernád (4.8 GWh total) and Sajó (5.2 GWh total) rivers with one on each on the Körös (10 GWh) and Maros (12 GWh) rivers.

Table 1. Theoretical, convertible, technical, economic, sustainable and realisable potential of renewable energy sources, as used in the NREAP.

Potential concept	Theoretical potential [PJ/a]	Convertible potential to 2050 [PJ/a]	Technical potential to 2030 [PJ/a]	Economic potential to 2030 [PJ/a]	Sustainable potential to 2030 [PJ/a]	Sustainable potential (existing and installable) to 2020 [PJ/a]
Solar heat	417,600	103	75	65	50	15
Solar electricity		1,749	50	25	15	7
Hydro electricity	100	27	20	15	5	2.3
Wind electricity	36,000	532	30	25	20	15.5
Wind combined head and electricity						
Biomass heat	420-500	203-328	150	180	180	150
Biomass electricity						
Biomass fermentation biogas			50	30	20	13.2
Other biomass (waste)			15	10	8	4.3
Geothermal electricity	102,180,000	343,000	20	15	12	6.1
Geothermal heat plant			30	25	20	13.2
Heat pump			35	30	15	10
Other combined		100	25	15	5	1
Total		**345 839**	**500**	**425**	**350**	**237.5**

Table 2. Theoretical hydropower energy potential of Hungarian rivers.

River	Duna	Tisza	Dráva, Mura	Rába	Hernád	Other
Average theoretical potential [GWh/a]	5,348	708	756	187	139	308
Share [%]	72	9.5	10	2.5	1.9	4.1

Another 85 GWh of production is expected from the development of existing hydro plants and dams. This group includes the power plants of Békésszentandrás (12.5 GWh), Nick (5 GWh), Tass (3.1 GWh), Dunakiliti (28.4 GWh), Kisköre (26 GWh) and Tiszalök (12 GWh).

Small hydro plants are planned for the Tisza river. According to hydrological assessments, three units should also be constructed in the areas of Dombrád (100 GWh), Vásárosnamény (90 GWh) and Csongrád (90 GWh).

Long-term plans for hydropower projects primarily focus on the Danube's potential. The smallest of these units is the hydropower plant in The Hague which has allocated another 1,000 GWh of the Gabcikovo hydropower plant for use by Hungary.

The present small utilization is reflected by the totals: realization of the previous plans would represent surplus electricity totaling 2,872 GWh compared to the present annual volume of 200 GWh.

These generation potentials can be assigned to administrative units (districts) since the plant locations are in most cases known. The exceptions are rivers Sajó and Hernád, where potentials are assigned to districts in proportion to river lengths. In formulas 1 and 2, E represents the potential, rkmj and rkmi are the river's distance from the first and last settlements in the examined district.

$$Ehydro,Saj\acute{o},i = (rkmj-rkmirkm)\ X\ E\ \ hydro,Saj\acute{o} \qquad (1)$$

$$Ehydro,Hern\acute{a}d,i = (rkmj-rkmirkm)\ X\ E\ \ hydro,Hern\acute{a}d \qquad (2)$$

In the case of the Gabcikovo power plan, the potentials cannot be assigned to local use, since most of the volume is generated in Slovakia rather than Hungary. Therefore, it was assigned to the nearest district, Mosonmagyaróvár.

In total, hydro energy potentials were assigned to 27 of 178 districts, but only the districts of Adony, Kalocsa and Mosonmagyaróvár represent a volumes greater than one PJ/a.

Wind Energy

The theoretical, technical and economic wind energy potentials for Hungary are estimated by the literature as 36,000, 30 and 25 PJ/a, respectively.

Wind characteristics play a key role when estimating a region's wind energy potential. A location's average wind speeds are internationally accepted parameters. Locations where wind speeds are less than 5 m/s are generally not considered to be feasible for development. Using international benchmarks, locations worthy of consideration are typically those with average wind speed levels reaching 5-7 m/s at 50 meters above ground level. In practice, investors usually have higher thresholds and choose the best available locations. In Hungary, some of these have already been developed. Investment thresholds and development locations are also affected by the local price of electricity and the availability of subsidies.

To assign energy potentials to districts, wind speed data for 50, 100 and 200 meters above ground level from the Global Wind Atlas (Technical University of Denmark) were used. Local wind speed values of distinct geographic locations are determined by microscale modeling, using WAsP (Wind Atlas Analysis and Application Program). WAsP considers the terrain of the ground which is needed to properly calculate the Hellmann Coefficients. The Atlas was created with 250 m spatial resolution, while available data uses one kilometer resolution which suited our purposes. From the available levels, data for 100 m above ground level was used as it is approximately equal to the hub height of many modern wind turbines.

To assess regional potentials, wind speeds of the district seats were recorded, while potential volumes were assigned in proportion to the geographic areas of the districts. In equation 3, E represents the potential, v the wind speed and A is the area of the examined district.

$$E_{wind,i} = \frac{v_i \ x \ A_i}{\sum^{175}{}_{j=1} v_j \ x \ \sum^{175}{}_{j=1} A_j} \ x \ E_{wind,country} \qquad (3)$$

The best wind speeds in Hungary are found in Győr-Moson-Sopron and Komárom-Esztergom counties. Wind characteristics are also favorable in Transdanubia. Detailed wind potential distributions are shown in Figure 2.

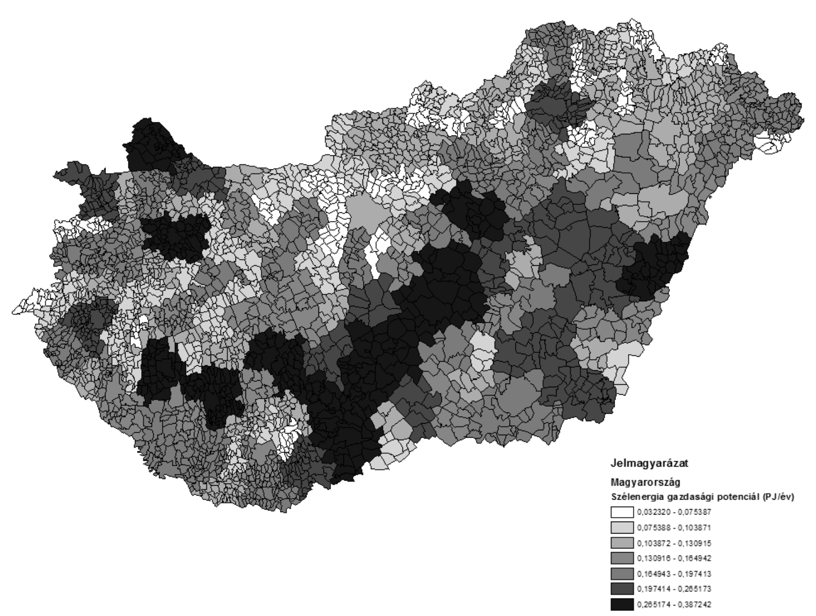

Figure 2. Economic wind energy potentials for electricity generation (darker areas represent better potentials, ranging from 0.0323 and 0.387 PJ/a).

Solar Energy

Theoretical, technical, and economic solar energy potentials for Hungary are estimated by the literature to be 417,600, 125 and 90 PJ/a, respectively. For technical potential, the proportion of heat energy to electricity is 75:50 PJ, while the ratio for economic potential is 65:25 PJ.

For regional assessment of potentials, the Global Solar Dataset of 3TIER was used. This provides annual average power (W/m^2) of global horizontal irradiation with a spatial resolution of three kilometers. This dataset provides a decade of data using analysis results from satellite images taken in 30-minute intervals. The satellites recorded the visible light spectrum and the images were processed by 3TIER.

When assigning potential volumes for solar energy we assumed that both the technical and economic potentials correlate with the geographic areas of districts. The reason for this assumption is that for both solar collectors and photovoltaic panels, residential use and small installed capacities are expected to dominate the market. Furthermore, the solar irradiation values of Hungarian regions vary only slightly and installations are not expected to be limited to only a few districts.

Each district's potential was calculated using the solar irradiation levels recorded at the district seats, while potential volumes were assigned in proportion to geographic areas of each district. In equations 4 and 5, E represents the potential, I the irradiation and A the total area of the examined district.

$$E_{solar,electricity,i} = \frac{I_i \, x \, A_i}{\sum^{175}_{j=1} I_j \ \ x \ \ \sum^{175}_{j=1} A_i} \ x \ E_{solar,elecrtricity,country} \tag{4}$$

$$E_{solar,heat,i} = \frac{I_i \, x \, A_i}{\sum^{175}_{j=1} I_j \ \ x \ \ \sum^{175}_{j=1} A_i} \ x \ E_{solar,heat,country} \tag{5}$$

The distribution of regional potentials is correlated with Hungary's solar irradiation map, thus significant utilization of solar energy is anticipated in districts located in the southern great plain region. The gap between national maximum and minimum is far less than for wind energy. Figure 3 shows the geographical distribution of economic potential for solar photovoltaics.

Geothermal Energy

Theoretical, technical and economic geothermal energy potential for Hungary is estimated by the literature as 102,180,000, 85 and 80 PJ/a, respectively. For technical and economic potential, the proportion of power plant, heating plant, and heat pump utilization is 20:30:35 and 15:25:30 PJ/a, respectively.

For geothermal energy, the higher temperature of the Earth's upper layers of the Earth is utilized, as the energy of steam or water is drawn to generate electricity and/or heat. The best utilization of temperature sources is given by the Lindal-diagram. For electricity generation, high-temperature sources (above 180°C) are best, since these can directly drive a power plant's turbine and provide base load generation. The low-temperature geothermal resources are only suitable for heat pumps, since large-scale heat energy and electricity production requires resources reaching 40°C and 120°C, respectively. The scale of utilization varies since heat pumps are predominantly used for residential and small commercial applications while heating plants and electrical power plants have large installed capacities.

To assign the potential volumes for each region, the GeoElec infor-

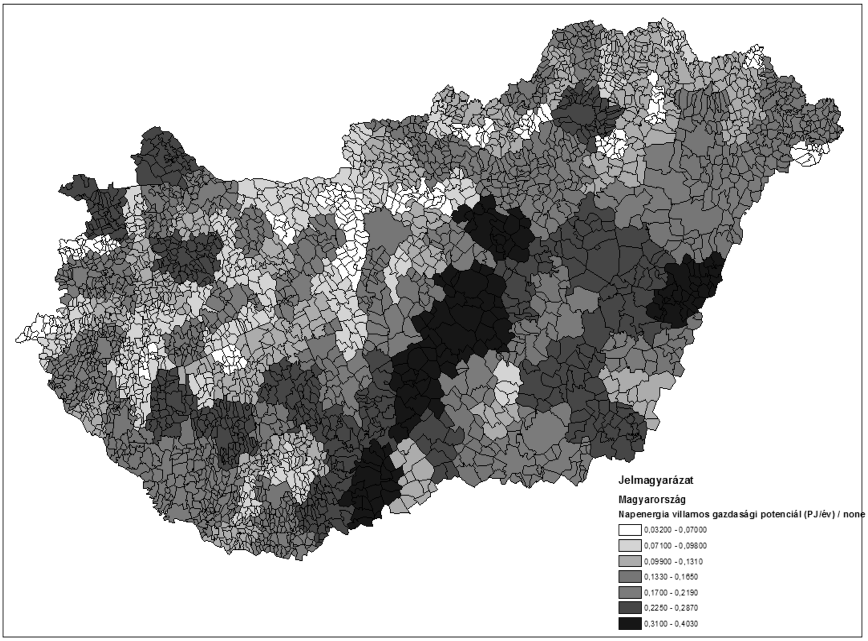

Figure 3. Economic solar energy potentials for electricity generation (darker areas represent better potentials, ranging from 0.0320 to 0.4030 PJ/a).

mation service of the European Geothermal Energy Council was used. The GeoElec project operated between 2011 and 2013 as a consortium of ten partners to support geothermal energy use in Europe. This project assessed the potential of geothermal energy within a 20 km spatial and 250 m vertical resolution (below ground). GeoElec's website provides theoretical potential volumes and technical potentials depending on certain economic boundary conditions and life cycle costs.

The distribution of regional potentials was performed using the potentials of district capitals, while potential volumes were assigned in proportion to the geographic areas of the districts. In equations 6 and 7, E represents the potential, Pg is the per area power of geothermal resources and A is the area of the examined district.

$$E_{geothermal,electricity,i} = \frac{Pg_i \ x \ A_i}{\sum^{175}{}_{j=1} \ Pg_{i\,j} \ x \ \sum^{175}{}_{j=1} A_i} \quad x \quad E_{geothermal,electricity,country} \tag{6}$$

$$E_{geothermal,heat,i} = \frac{Pg_i \ x \ A_i}{\sum^{175}{}_{j=1} \ Pg_{i\,j} \ x \ \sum^{175}{}_{j=1} A_i} \quad x \quad E_{geothermal,heat,country} \tag{7}$$

Based on the results, the best locations for geothermal energy in Hungary are in Hajdú-Bihar, Tolna and Bács-Kiskun counties and their neighboring districts. The distribution of economic potential for electricity generation is shown on Figure 4.

Bioenergy

Among all renewable energy resources, biomass assessments are the most complex. The reasons for this include the wide variation of possible combustible fuels, the large palette of energy generation technologies and the high levels of uncertainty using available data. We made several assumptions which are detailed below.

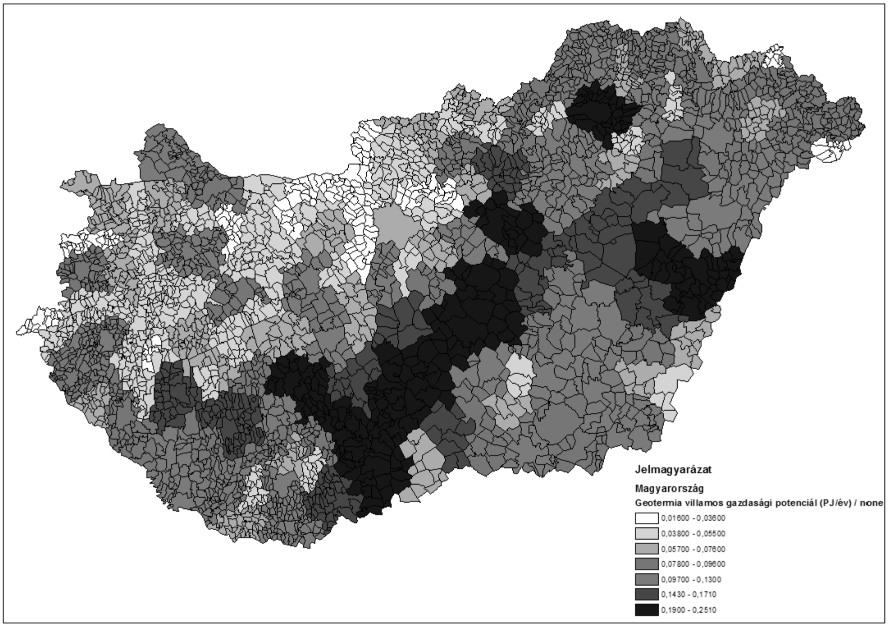

Figure 4. Economic geothermal energy potentials for electricity generation (darker areas represent better potentials, ranging between 0.0160 and 0.2510 PJ/a).

Studies estimating Hungary's biomass potential typically fail to separately identify biomass from biogas resources. However, technical and economic biomass potentials are separable while heat energy and electricity production can be allocated.

To assess regional biomass potentials, both top-down and bottom-up approaches were used. Since information was unavailable to allocate each fuel's proportion of generated heat and electricity production using the NREAP (and its background studies), we used our own assumptions. Our methodology was based on seven categories of potentially used biomass:

1. Wooden biomass
2. Energy crops
3. Agricultural by-products
4. Waste incineration
5. Biogas from organic material (manure)
6. Biogas from organic waste
7. Biogas from sewage

Since the NREAP handles category 4 separately, no further division was necessary. For waste incineration, combined heat and power (CHP) production was assumed. Typical efficiencies using CHP require 100 units of primary energy to generate 45 units of heat and 34 units of electricity (i.e., the ratio of latter secondary products is 57:43). All CHP producers were assumed to have the same efficiencies.

Biogas potentials were estimated for the gross volumes, without allocation between categories 5, 6 and 7. To assess the potentials of all sources, proportions found in the literature were used. Based on these, biogas generated from organic material (category 5) represents 69.7%, biogas from organic waste (category 6) represents 15.8%, and the remaining 14.5% is from sewage (category 7). For all three categories gas engines and CHP production were the assumed technologies. Considering the three remaining categories (1, 2 and 3), a literature review was performed based partly on the information of the NREAP.

After comparing these data sources, the respective proportions of wooden biomass, energy crops and agricultural by-products were 25%, 41% and 34%. Additional subgroups could have been created, based on the technologies used. As this would not have significantly affected the results, CHP generation was assumed for all fuels.

To summarize, three homogeneous groups were created (1-2-3, 4, 5-6-7). If 100% share is assumed, the technical and economic potentials for biomass and biogas can be divided based on fuel source. This division is shown in Table 3, highlighting the homogenous subgroups with different backgrounds.

Separate handling of the subgroups was important throughout the examinations, since the assignment of potential volumes to districts is performed based on the methodologies. These methodologies are discussed next.

Using the proportions of Table 3, exact potential volumes can be determined, as shown in Tables 4 and 5.

Wooden Biomass

To assess wooden biomass potentials, the volume of annual national forestry production was allocated in proportion to the geographic

Table 3. Fuels and secondary utilization based grouping of biomass potential.

	Electricity	Heat energy
Biomass		
1: Wooden biomass	10.76%	14.24%
2: Energy crops	17.65%	23.35%
3: Agricultural by-products	14.63%	19.37%
4: Waste incineration	57%	43%
Biogas		
5: Biogas from organic material (manure)	29.97%	39.73%
6: Biogas from organic waste	6.79%	9.01%
7: Biogas from sewage	6.28%	8.32%

Table 4. Fuels and secondary utilisation based grouping of technical biomass potential.

	Electricity	Heat energy
Biomass		
1: Wooden biomass	16.14 PJ/a	21.36 PJ/a
2: Energy crops	26.48 PJ/a	35.03 PJ/a
3: Agricultural by-products	21.95 PJ/a	29.06 PJ/a
4: Waste incineration	8.55 PJ/a	6.45 PJ/a
Biogas		
5: Biogas from organic material (manure)	14.99 PJ/a	19.87 PJ/a
6: Biogas from organic waste	3.40 PJ/a	4.51 PJ/a
7: Biogas from sewage	3.14 PJ/a	4.16 PJ/a

Table 5. Fuels and secondary utilization based grouping of economic biomass potential.

	Electricity	Heat energy
Biomass		
1: Wooden biomass	19.37 PJ/a	25.63 PJ/a
2: Energy crops	31.77 PJ/a	42.03 PJ/a
3: Agricultural by-products	26.33 PJ/a	34.87 PJ/a
Waste incineration	5.70 PJ/a	4.30 PJ/a
Biogas		
5: Biogas from organic material (manure)	8.99 PJ/a	11.92 PJ/a
6: Biogas from organic waste	2.04 PJ/a	2.70 PJ/a
7: Biogas from sewage	1.88 PJ/a	2.50 PJ/a

areas of the districts. The calorific value of wood was calculated using the produced volume of different species as 9.7 GJ/m^3, while industrial statistics publish the share of firewood as 52.6%. A district's share of can be calculated as:

$$E_{biomass1,share,i} = [(A_{forest,county} x A_i / A_{forest,county}) / A_{forest,country}\ x\ V_{wood,country}]\ x\ q_{production}\ x\ q_{firewood}\ x\ C_{wood}\ x\ (1/10^3) \qquad (8)$$

Annual potential volume of a district is calculated as:

$$E_{geothermal,electricity,i} = \frac{E_{biomass1,share,i}}{\sum^{175}_{j=1} E_{biomass1,share,j}}\ x\ 10.76\%\ x\ E_{biomass1\text{-}2\text{-}3,country} \qquad (9)$$

In equations 8 and 9, E is the potential, V is the volume of produced wood and A is the geographical area. The two coefficients ($q_{production}$ and $q_{firewood}$) represent the share of total production compared to growth volume and the share of firewood from production respectively. The magnitudes of these coefficients are 0.607 and 0.562 respectively, based on data of the Hungarian Central Statistical Office. C_{wood} is the estimated average calorific value of total produced wood. To determine this the following calorific values were used: 10.5 GJ/m^3 for oak, tern, beech, hornbeam, acacia and other hardwoods, 9.0 GJ/m^3 for pine species and other wood, 8.0 GJ/m^3 for poplar species and willow.

These values average 9.7 GJ/m^3. A 10.8% multiplier provides the assessed potential that can be used as the potential for the examined fuel subgroup to produce electricity (see Table 3). Heat energy potentials can be calculated in a similar manner.

Energy Crops

To assess the biomass potential from energy crops, the primary data needed is the area of unused land (withdrawn from cultivation) as such land can be used to grow energy crops. District potentials were determined in proportion to geographic areas. To estimate the yield potentials, an average was calculated from the per area yield of typical plants, resulting in 12.5 t/ha. The calorific value (16 MJ/kg) was determined according to the conditions of mixed flora. A district's potential share can be calculated as:

$$E_{biomass2,share,i} = [(A_{unused,county} x A_i / A_{county}) / A_{unused,county}] \; x \; q_{yield} \; x \; C_{energy} \; x \; (1/10^3) \qquad (10)$$

Annual potential volume of a district is calculated as:

$$E_{geothermal,electricity,i} = \frac{E_{biomass2,share,i}}{\sum^{175}_{j=1} E_{biomass2,share,j}} \; x \; 17.65\% \; x \; E_{biomass1\text{-}2\text{-}3,country} \qquad (11)$$

For equations 10 and 11, E is the potential, A is the land area, and q_{yield} is the estimated yield of energy crop plantations (approximately 12.5 t/ha for mixed woody and herbaceous tillage). $C_{energy\ crop}$ is the estimated average calorific value (16 MJ/kg) of produced biomass assuming both woody and herbaceous plants. The 17.65% multiplier indicates the proportion of known total potential that can be assessed as the potential for the specific fuel subgroup to produce electricity (see Table 3). Heat energy potentials can be calculated in a similar manner.

Agricultural By-products

Statistical data for several agricultural products were chosen to assess the volume of agricultural waste and by-products (i.e., wheat, maize, barley, oat and triticale). The size and the yield of arable land were determined for each county's crops. The first parameter was divided in proportion of the area of districts, while the second was handled as a homogeneous value for each county. The volume of utilizable by-products collected from the fields is assumed to reach 68% of the product volume; its calorific value was 14 MJ/kg. The potential share of a district can be calculated as:

$$E_{biomass3,share,i} = [\textstyle\sum^{n}{}_{i=1} (A_{cropi,county} x A_i / A_{county}) \; x \; q_{cropi,yield,county}] \; x \; q_{by\text{-}product} \; x \; C_{agr.by\text{-}product} \; x \; (1/10^6) \qquad (12)$$

Annual potential volume of a district is calculated as:

$$E_{biomass3,electricity,i} = \frac{E_{biomass3,share,i}}{\sum^{175}{}_{j=1} \; E_{biomass3,share,j}} \; x \; x \; 14.63\% \; x \; E_{biomass1\text{-}2\text{-}3,country} \qquad (13)$$

For equations 12 and 13, E is the potential, A is the land area, q_{yield} is the estimated yield of crops in the examined county, and $q_{by\text{-}product}$ is the volume of by-products compared to the product (68%). $C_{agr.by\text{-}product}$ is the estimated average calorific value (14 MJ/kg) of biomass. The 14.63% multiplier indicates the proportion of known assessable potential for the examined fuel subgroup to produce electricity (see Table 3). Heat energy potentials can be calculated in a similar manner.

Waste Incineration

Incineration potential of solid municipal waste can be assessed by the volume of combusted waste (which is the currently utilized part of the potential), available for all counties, and the volume of landfill waste (which sets an upper limit). Both volumes were divided among districts in proportion to their population, assuming that no significant difference can be observed among the waste production of the regions. The calorific value of municipal solid waste was calculated as 16 MJ/kg. A district's potential share can be calculated as:

$$E_{biomass4,share,i} = [(Q_{incinerated,county} x L_i / L_{county}) + (Q_{lerakott,county} x L_i / L_{county})] \; x \; C_{waste} \; x \; (1/10^6) \qquad (14)$$

Annual potential volume of a district is calculated as:

$$E_{biomass4,electricity,i} = \frac{E_{biomass4,share,i}}{\sum^{175}{}_{j=1}\ E_{biomass4,share,j}} \quad x$$
$$43\%\ x\ E_{biomass4,country} \qquad (15)$$

For equations 14 and 15, E is the potential, L is the population of the district, and m is the mass of the waste. C_{waste} is the estimated average calorific value (16 MJ/kg) of biomass. The 43% multiplier indicates the proportion of known potential that can be assessed as a potential for the examined fuel subgroup for electricity production (see Table 3). Heat energy potentials can be calculated in a similar manner.

Biogas from Organic Materials

Biogas raw material from organic materials is dominantly manure and small amounts of industrial organic waste. Our assessment emphasized wastes from the first group since there was limited information on the second. Among Hungarian livestock, cattle, swine and poultry were considered. Each county's waste volumes from these animals were divided among the districts in proportion to their geographical area. Manure of different species not only differs in volume but also in composition, affecting the quality of bedding. Using estimates from research, per unit biogas yield was set as 160, 26.7 and 0.3255 m^3 for cattle, swine and poultry, respectively. The calorific value of biogas was estimates to be 22 MJ/m^3. Potential share of a district can be calculated as:

$$E_{biomass5,share,i} = [(Q_{cattle,county}\ x\ A_i/A_{county}\ x$$
$$q_{cattle,yield}) + (Q_{swine,county}\ x\ A_i/\ {}_{Acoun}t\ x\ q_{swine,yield})$$
$$+ (Q_{poultry,county}\ x\ A_{i/}Acounty\ x\ q_{poultry,yield})]\ x$$
$$C_{biogas}\ x\ (1/10^6) \qquad (16)$$

Annual potential volume of a district is calculated as:

$$E_{biomass5,electricity,i} = \frac{E_{biomass5,share,i}}{\sum^{175}{}_{j=1}\ E_{biomass5,share,j}} \quad x$$
$$29.97\%\ x\ E_{biomass5\text{-}6\text{-}7,country} \qquad (17)$$

For equations 16 and 17, E is the potential, A is the area of the district, and Q is number of animals. The coefficient q_{yield} represents biogas yield per animal while C_{biogas} is the estimated average calorific value (22 MJ/m^3) of biogas. The 29.97% multiplier indicates the proportion of known potential that can be assessed as a potential for the examined fuel subgroup for electricity production (see Table 3). Heat energy potentials can be calculated in a similar manner.

Biogas from Organic Wastes

Biogas from organic waste can be handled similarly to municipal waste, since the raw material is the landfill waste in both cases. Biogas yield of municipal solid waste is approximately 100 m^3/t. The potential share of a district can be calculated as:

$$E_{biomass6,share,i} = \frac{m_{landfill,county}\ x\ L_i}{L_{county}}\ x\ q_{yield}\ x\ C_{biogas}\ \ x\ (1/10^9) \tag{18}$$

Annual potential volume of a district is calculated as:

$$E_{biomass6,electricity,} \quad \frac{E_{biomass6,share,i}}{\sum^{175}_{j=1}\ E_{biomass6,share,j}} \quad x$$

$$6.79\%\ x\ E_{biomass5\text{-}6\text{-}7,country} \tag{19}$$

For equations 18 and 19, E is the potential, L is the population of the examined district, and m is the mass of the waste. The 6.79% multiplier indicates the proportion of known potential that can be assessed as a potential for the examined fuel subgroup for electricity production (see Table 3). Heat energy potentials can be calculated in a similar way.

Biogas from Sewage

To assess the potential of biogas from sewage, each county's volume of treated sewage was divided among the districts in proportion to their populations. Biogas yield of sewage was estimated using the data of Budapest Sewage Works Private Limited as 0.2/m^3. The potential share of a district can be calculated as:

$$E_{biomass7,electricity,} \quad \frac{V_{sewage,county}}{L_{county}} \quad x$$

$$L_i \quad x \; q_{yield} \; x \; C_{biogas} \;\; x \; (1/10^9) \tag{20}$$

Annual potential volume of a district is calculated as:

$$E_{biomass7,electricity,} \quad \frac{E_{biomass7,share,i}}{\sum^{175}{}_{j=1} \; E_{biomass7,share,j}} \quad x$$

$$6.28\% \; x \; E_{biomass5\text{-}6\text{-}7,country} \tag{21}$$

For equations 20 and 21, E is the potential, L is the population of the examined district, and V is the volume of sewage. The 6.28% multiplier indicates the proportion of known potential that can be assessed as a potential for the examined fuel subgroup for electricity production (see Table 3). Heat energy potentials can be calculated in a similar way.

After assessing the technical and economic potential of all fuels, subgroups 1-4 and 5-7 were cumulated for both heat energy and electricity production. The results are shown in Figures 5-8. Cleary, traditional agricultural areas offer high potentials. County seats are also performing well and the large volumes of municipal waste and sewage could be used as fuel.

CONCLUSIONS

This article introduced a methodology to assess regional potentials of various renewable energy sources, and selected results of the evaluation process. If the potential of all renewable energy sources is cumulated, we obtain the distribution shown in Figure 9. This offers a theoretical cumulative potential, since in practice some renewable technologies directly compete. The three best performing districts are Mosonmagyaróvár, Kalocsa and Budapest. For the first two we conclude that they have performed relatively well in all aspects. For Budapest, the performance partly results from city size (approximately two million inhabitants) since waste materials and sewage utilization was emphasized in NREAP background studies for biomass.

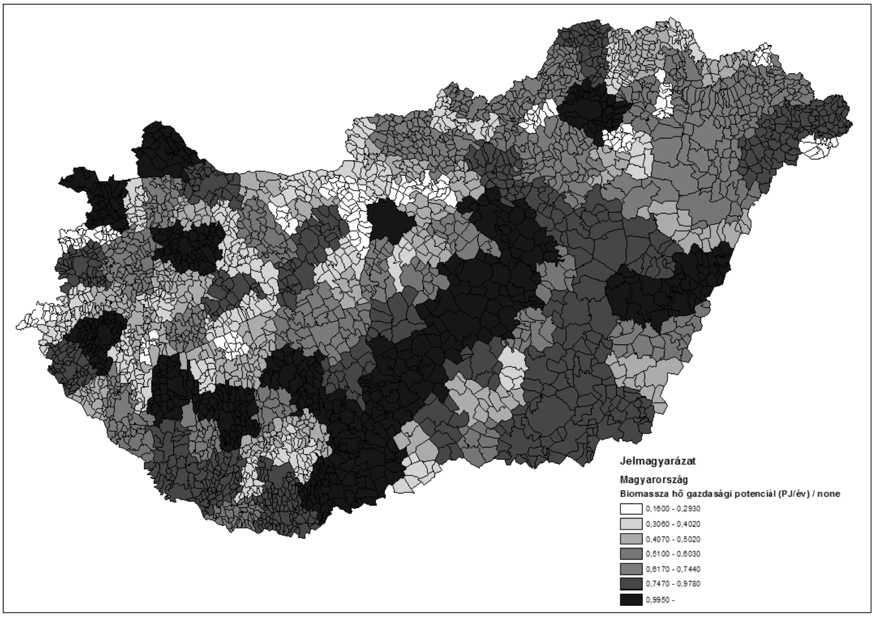

Figure 5. Economic biomass energy potentials for heat generation (darker areas represent better potentials, ranging between 0.160 and 0.995 PJ/a).

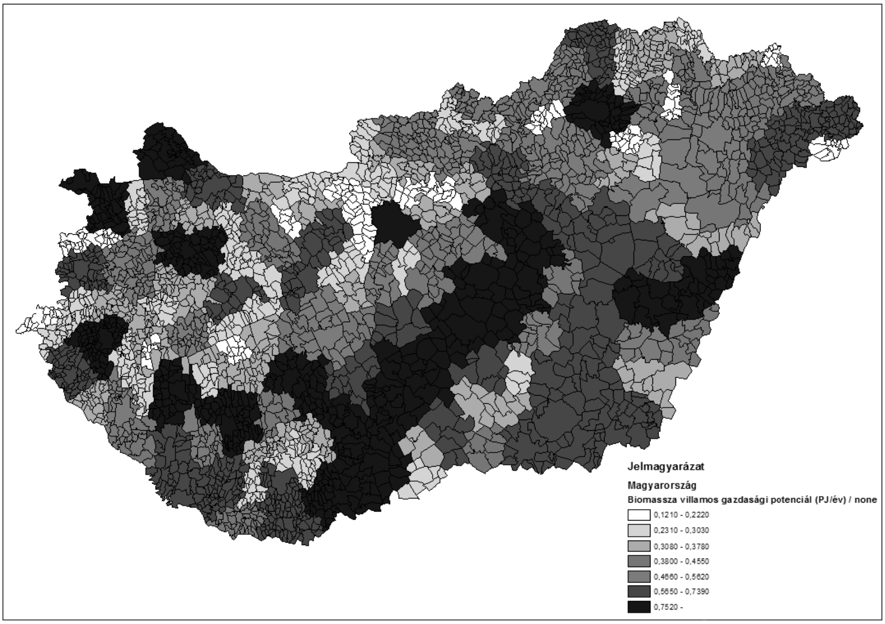

Figure 6. Economic biomass energy potentials for electricity generation (darker areas represent better potentials, ranging between 0.121 and 0.752 PJ/a).

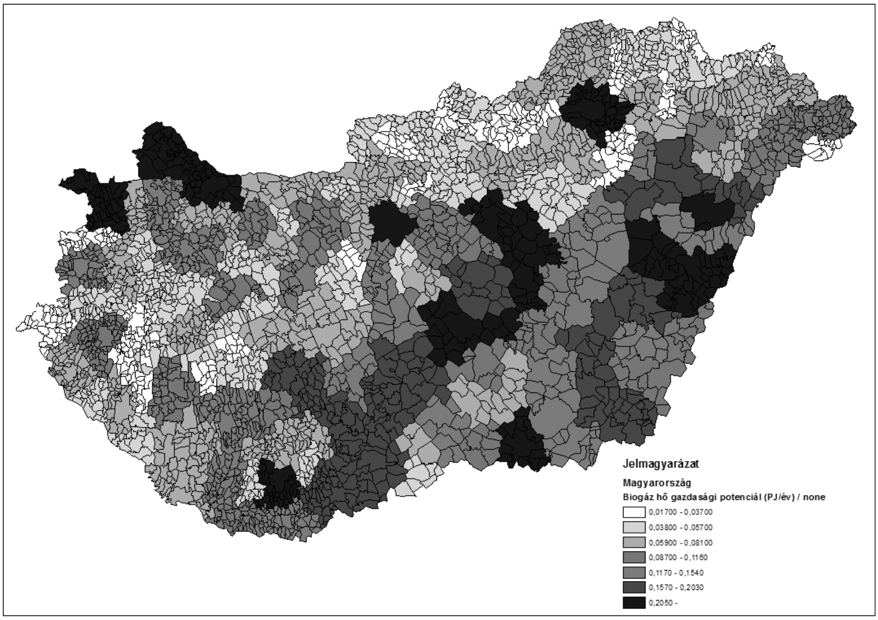

Figure 7. Economic biogas energy potentials for heat generation (darker areas represent better potentials, ranging between 0.017 and 0.205 PJ/a).

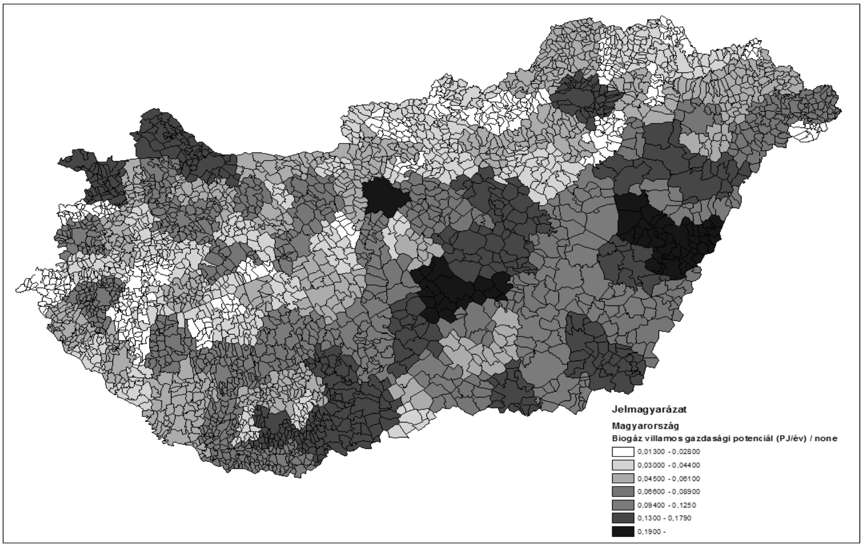

Figure 8. Economic biogas energy potentials for electricity generation (darker colours represent better potentials, ranges between 0.013 and 0.190 PJ/a).

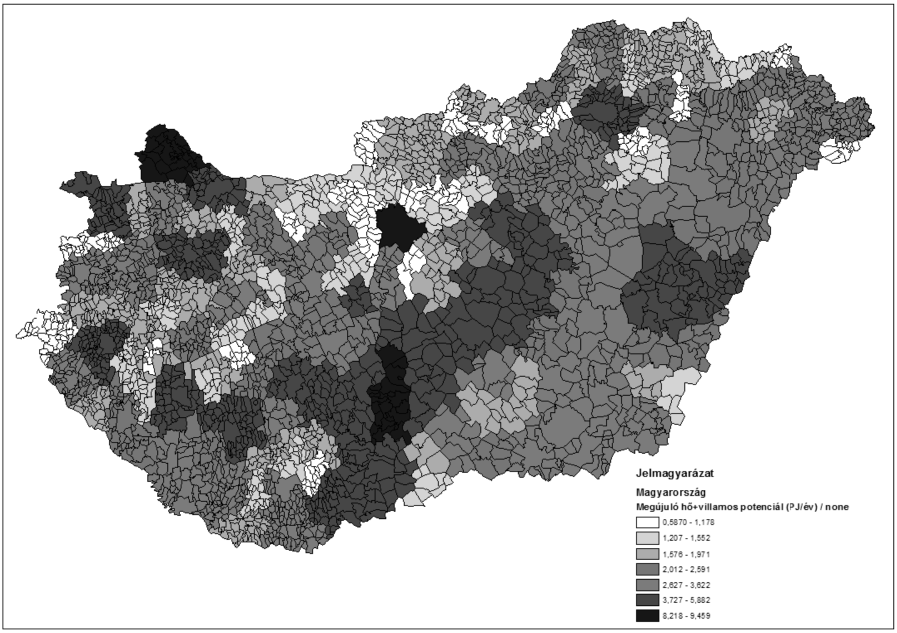

Figure 9. Economic renewable energy potentials for electricity generation (darker areas represent better potentials, ranging between 0.587 and 9.459 PJ/a).

Since the European Commission has published guidelines for state aid for environmental protection and energy 2014-2020 (2014/C 200/01) in 2014, all EU member states are working towards new support mechanisms for renewable energy sources. The main ideas of the guidelines were that future support for renewable energy producers should take the form of premiums rather than fixed support schemes and that mandatory tenders for new capacities should be developed beginning in 2017.

Several policy changes recently have been approved by the Hungarian government. It announced the Act CXXXVIII of 2016 which modified several climate policy and green industry development policies. Governmental Decree 393/2016 (XII. 5.) modified previous support schemes for renewable based electricity production.

Decrees 17/2016 (XII. 21.) and 5/2016 (XII. 21.) approved by the Hungarian Energy and Public Utility Regulatory Authority and the Ministry for National Development (MND), respectively quantified the new premiums and the technical requirements for power plants. Details of the tendering and settlement processes were announced in MND Decrees 62/2016 and 63/2016 (XII. 28.). Thus, newly introduced legislation has largely transformed the former support schemes for renewables.

The new policies redefine green and brown premiums. New electrical generation facilities with over 0.5 MW of installed capacity are eligible for green premiums. Plants with generation capacities below 1 MW do not require tender offerings (with the exception of wind power plants), and receives reference market prices and administrative premiums. The reference market price is the one-day average of prices on the Hungarian power exchange (HUPX), which is weighted by the actual production of wind and solar plants. The period and volume of subsidized electricity is determined by the regulator. If the capacity is above 1 MW, the premiums are determined in a tender offering.

The brown premium was designed for existing power plants (dominantly biomass and biogas units after pay-off), so that they can remain in operation after the expiration of previous subsidy periods. In case of the “normal” brown premium, the subsidized price is set to cover operation costs and is revised annually. For biomass co-firing plants, the premium is determined by the share of fuels. In some circumstances, power plants may sell electricity above the reference maker price and provide auxiliary services. The second case is called “alternative” for brown premium, which is designed to compensate for the competitive disadvantage of biomass co-firing. This premium is revised annually and calculated as the difference between the operation costs of fossil fuel and biomass firing. It also accounts for any additional costs (e.g., CO_2 prices). Brown premiums must be claimed and permissions are given for extendable five year periods.

Since the new legislation will begin in 2017, concerns have arisen among professionals regarding the tendering process. The annual tendered volume is determined by the minister for national development for five year periods which are revised annually. Other limitations include the limitations of annual support (supported price multiplied by annual volume), technologies (minimal and maximal allocable capacity), distribution utility areas and maximal offers. The intensity of competition will largely be determined by the premiums and quantities of cost-efficient renewable sources. Since we have aimed to highlight the best options for renewable energy utilization, we believe that the energy map tool will be able to support future investors and decision makers in their efforts to reach Hungary’s renewable energy targets.

An important goal of our research is to find ways to maximize the use of locally available resources. This will be reflected in our future efforts, part of which focuses on the synchronization of the database with the National Building Energy Performance Strategy, and the definitions of the energy performance of buildings directive. The latter defines a nearly-zero building as, "…a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby." As more buildings are constructed in accordance with the new directive, greater use of locally available renewable energy sources is inevitable. The developed energy potential map will be a useful tool to this end. We aim to improve the database by performing a sensitivity analysis of the assessment, and developing decision support systems for municipalities and districts.

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ABOUT THE AUTHORS

Bálint Hartmann, has a M. of Science degree in electrical engineering and a Ph.D. from Budapest University of Technology and Economics (BUTE) in 2008 and 2013, respectively. He is senior lecturer with the Department of Electric Power Engineering, Budapest University of Technology and Economics. He is also a part-time research fellow with the Centre for Energy Research, Hungarian Academy of Sciences. He is a former officer of the AEE Hungary Student Chapter. He received the AEE Legend in Energy recognition in 2011. His interests include distributed generation, renewable energy sources, energy storage and smart grids. He is the corresponding author for this article. Email: hartmann.balint@energia.mta.hu.

Attila Talamon received his Ph.D. in 2015 with research focusing on the Hungarian possibilities of low energy buildings. He received a M. of Science degree in mechanical engineering from BUTE. He joined the Student Association of Energy in 2007; he is currently a senior member. He holds certifications as an energy auditor and building energy specialist. He was involved in several international scientific projects as leading expert. Since 2009 he has been lecturing on subjects related to renewable sources and building energy at BUTE and University of Debreceni Egyetem (DE). He is currently with the Szent István University. He is also a research fellow with the Centre for Energy Research, Hungarian Academy of Sciences. Email: talamon.attila@energia.mta.hu.

Viktória Sugár received her M. of Science degree in architectural engineering from Szent István University where she has been lecturing since 2011. Her main research topics are sustainable architecture and complex architectural rehabilitation of densely built urban fabrics. She is a Ph.D. student and an assistant researcher with the Centre for Energy Research, Hungarian Academy of Sciences. Email: sugar.viktoria@energia.mta.hu.