ISSN 2052-0018 (print) // ISSN 2053-3667 (online)
Geographical Locality Studies 2016 Volume 4, Number 1. pp. 820–853

Environmental Limits to Sustainable Energy Production in Hungary

Béla Munkácsy

PhD, Lecturer, Eötvös Loránd University, Faculty of Science, Institute of Geography and Earth Sciences, Department of Environmental and Landscape Geography
e-mail: munkacsy@elte.hu

Norbert Kohlheb

PhD, Senior Researcher, Helmholtz-Zentrum für Umweltforschung, Leipzig
e-mail: kohlheb.norbert@gmail.com

Ádám Harmat

MSc, Geographer, WWF Hungary
PhD Student, ELTE University, Faculty of Sciences, Doctoral School of Earth Science
e-mail: harmatadam@caesar.elte.hu

Fanni Sáfián

MSc, PhD Aspirant, Eötvös Loránd University, Budapest
Researcher, Energiaklub Climate Policy Institute and Applied Communications, Budapest
e-mail: safian@energiaklub.hu

Abstract

The aim of this paper is to calculate the sustainable portion of the renewable energy potential of Hungary, considering both ecological and technological limitations, in order to provide information for long term planning processes focusing on local energy solutions. In this research, the most important aspect is the multidisciplinary and spatial approach involving technical knowledge and branches of natural and social sciences. These novel aspects which have been mostly neglected in the management of centralised energy systems, emphasise the importance of locality as well as the necessity of involving new research areas, such as geography and new methodologies, for instance geographical information systems (GIS), which were used in this research to define wind, bio-mass and solar potentials. It was found that the sustainable potential (around

828.8 PJ/year after production losses) is very close to the recent energy consumption (963.4 PJ [KSH, 2016a]) of Hungary. This means that with increasing energy efficiency in renewable energy production Hungary's sustainable energy potential should be enough to sustain 100% energy autonomy from renewable energy resources in the future.

Key words

Sustainable energy; potential calculation; GIS; energy planning; multidisciplinary approach

1. Introduction

The progress towards sustainable energy transition is of utmost importance in the world since environmental consequences of the utilisation of fossil and nuclear energy resources have endangered the global ecosystem (LIOR, N. 2012; LI, F. G. N. *et al.* 2015). Conventional energy production and use determined by mainly technocratic and economic factors are the largest and still growing causes of massive local and global environmental problems. Greenhouse-gas emissions from the energy sector—representing roughly two-thirds of all anthropogenic greenhouse-gas emissions—have risen to the ever-highest level over the past century (IEA, 2015). Inside the sector another dominant problem area is nuclear energy, considering its unsolved waste management and the effects of nuclear accidents (SCHNEIDER, M. – FROGGATT, A. 2015). In the meantime, renewable energy technologies have been developed rapidly (OLABI, A. G. 2010; LIOR, N. 2012; OLABI, A. G. 2013) which represent a real alternative today.

Ecological footprint is, beside its simplifying factors, one of the most known aggregated sustainability indicators which can signal the environmental sustainability aspects of energy use in the societies. According to the *Living Planet Report* (LOH, J. 2002), the share of the energy footprint was 49.2% of the whole global ecological footprint in 1999. The global energy footprint increased from 2.5 billion to 6.7

billion hectares between 1961 and 1999, which means that it became the biggest and the fastest-growing component of the overall ecological footprint.

The latest *Living Planet Report* (MCLELLAN, R. *et al.* 2014) published similar figures: in the European countries, the ecological footprint (4.5 Gha/capita) is much higher than the global biological capacity (1.7 Gha/capita). This report calculates carbon footprint instead of energy footprint, with similar methodology and message. According to this analysis, the carbon footprint was 53% of the total ecological footprint on global level. As for the EU-25, its energy footprint was 57.1% of the total footprint in 2001 (WACKERNAGEL, M. 2005).

A detailed analysis was made for *Switzerland* by several governmental offices about the size and composition of the country's footprint (VON STOKAR, T. *et al.* 2006). According to this work, 67% of the Swiss ecological footprint was resulted by the energy sector—containing fossil fuels (35%), nuclear power (17%) and the embodied energy (15%). Moreover, the size of the whole ecological footprint is 3 times bigger (4.7 Gha/capita) than the country's biocapacity (1.6 Gha/capita)—mostly due to the significant size of energy footprint.

These developments hint at an unacceptably huge and wide environmental pressure originating from unsustainable energy production and consumption patterns. In the background, there is a defective energy planning and management practice that focuses firstly on economic, secondly on social aspects and underestimates or ignores the ecological consequences.

This situation necessarily draws the attention to alternative pathways that are analysed under the notion of energy transition and rapid decarbonisation. This new way of thinking firstly needs to be based on local solutions (JUROSZEK, Z. – KUDELKO, M. 2016; YANIK, S. *et al.* 2016). Dealing with energy transition, nonetheless, requires a transdisciplinary approach (PERSONAL, E. *et al.* 2014) which comprises environmental, social and economic aspects (LI, F. G. N. *et al.* 2015). That is the reason why this transition process is often understood as a co-evolution of socio-ecological (BERKES, F. *et al.* 2000), human-environment (SCHOLZ, R. W. 2011) or socio–technical systems (LI, F. G. N. *et al.* 2015). The facilitation of a proper energy transition pathway within these systems, especially from an environmental perspective, gained high priority. In this understanding, facilitation of energy transition should be started with a proper energy planning methodology—considering decisively the environmental dimension of sustainability. In this context, as a precursor of the planning process, the sustainably generated quantity, that is the sustainable energy potential of renewable energy sources needs to be assessed first. State-of-the-art energy strategies must consider these potentials, as limits of the system, in order to decrease the environmental impact of the energy sector.

In this understanding, sustainable energy sources are provided in the long run without irreversible environmental, social or economic consequences. According to this definition, waste incineration, nuclear and fossil energy generations are per se considered as not sustainable processes, because of the following reasons: *a)* waste incineration has a huge waste demand which is in contradiction to the principal of waste prevention; *b)* fossil fuel based technologies create huge greenhouse gas emissions while carbon capture and storage technologies are not proven to be reliable in the long-run; *c)* the final disposal of nuclear waste is unsolved in the entire world and may cause major accidents. However, the utilisation of renewable energy sources does not necessarily mean a sustainable energy production. In this field, it is also important to consider environmental consequences and add some ecological constraints concerning biodiversity, nitrogen and carbon budget and climate change (ROCKSTRÖM, J. *et al.* 2009).

This paper, as a case study, focuses on a Central European country, *Hungary*. In the first part, a methodology developed for assessing sustainable energy potentials will be introduced, using a relatively simple concept, in order to be able to use it in any other geographical areas. That will be followed by the calculation of the most relevant renewable energy potentials of *Hungary*, mentioning the methodological challenges too. Finally, the results are compared to similar outputs from the literature and conclusions are drawn.

2. Research concept: sustainable renewable energy potentials in the light of regulation

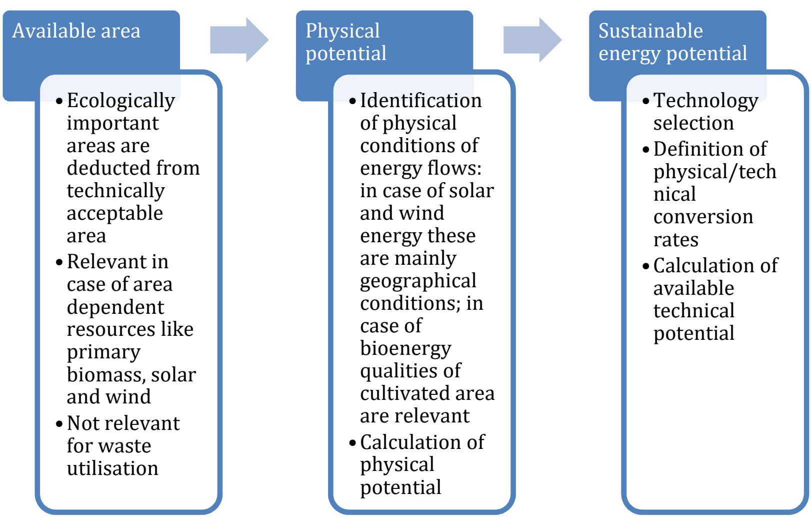
On the one hand, it was an important goal to use a relatively simple methodology assisting practical energy planning procedures. On the other hand, workable sustainability constraints had to be defined. For this purpose, the idea of embedded systems (CATO, M. S. 2009) and strong sustainability criteria were invoked (AYRES, R. U. *et al.* 1998; VAN DEN BERGH, J. C. J. M. 2014) that are common in environmental economics. The idea of embedded systems visualised by the three circles model articulates that both society and economy are dependent on and embedded in the overarching ecosystem highlighting biophysical constraints. This refers to the fact that limitless use of resources from the ecosystem is not possible and it destroys the carrying system which results in the ultimate collapse of the carried systems too. This emphasises the inequality of the three pillars: ecosystem, society, and economics (PEARCE, D. *et al.* 1989; CONSTANZA, R. – DALY, H. 1992) too.

Concerning renewable energy use in the context of the three circles model reveals the problem of scale which is a decisive factor of sustainability when using these resources. Practically, this means that area for harnessing renewable energy resources is limited and often excluded from the ecosystem. Thus, there exists a competition among society and the rest of the ecosystem for these resources. To resolve this problem while keeping in mind the ultimate role of the carrying ecosystem the use of the precautionary principle and the concept of strong sustainability should be considered. The conditions set by the precautionary principle and by the strong sustainability can be satisfied by setting the highest priorities to the ecological system and maintain its resilience in every way. Maintaining this criterion is one of the biggest challenges of humanity, since humanity must manage a transition from less area-dependent resources, for example fossil fuels, towards much more area-dependent renewable energy resources in a limited world.

Based on the ecological constraints, a methodology was developed for assessing sustainable energy potential intends to improve—or at least to conserve—the given ecological conditions, preventing any deteriorating long or short term processes. For defining sustainable energy potential to satisfy these requirements, the methodology used in this paper is a hierarchically structured set of barriers for each renewable energy technology. A strongly spatial approach was used, where in the first step the available area of renewable energy production must be defined in a way that it does not induce any environmental deterioration. This, of course, is not relevant for technologies using secondary and tertiary wastes. In the first instance the ecological requirement is guaranteed by the exclusion of any protected areas, including ecological corridors, from the area suitable for energy production purposes *(Figure 1)*.

Figure 1 – The general process of assessing sustainable energy potential

Edited by KOHLHEB, N. (2016)



If this is satisfied by the current regulation in force, it defines the available area. If not, it is defined by the ecological constraints. Based on the physical potential in the available area suitable for sustainable energy production, technical potentials are calculated using technological conversion rates. The area available for sustainable energy production can be fine-tuned by some important assumptions listed below:

1. Usage of already anthropogenic/industrialised areas are preferred, where the installed technology does not disturb human population;
2. To the usage of ecologically less valuable territories are given higher priority over the green/natural areas with high natural value.

Spatial calculations were made within the environment of ArcGIS 10.3 software. One of the biggest barriers of the work was the lack of accessibility of GIS data. In most of the cases data were provided by the given authority or research institute, since only few relevant spatial data are available for public.

When calculating the technical potential from the available area, besides the physical conditions of the area and the technical conversions rates, the following sustainability aspects are considered:

1. Exploitation of wastes and by-products always have priority over primary resources;
2. Energy efficiency improvement excluding unnecessary conversion steps and transport distances have priority.

In the following, the above described methodology for sustainable renewable energy potential assessment will be detailed in practice through the case of the Hungarian potential calculations. After the assessments, the results will be compared with Hungarian renewable energy potential calculations from the literature. Finally, based on this discussion, conclusions will be drawn related to the current renewable energy developments in the country.

3. Sustainable potential of solar energy

In *Hungary*, the legal regulation is not sufficient in the field of solar applications from an ecological point of view. On the one hand, regulations do not exclude green-field investments, even though this non-exclusion conflicts with the priority set above for maintaining biodiversity. In this approach, biological activity of the target area was important to protect resulting only brownfield areas and existing infrastructure (rooftops of buildings, parking lots, hypermarkets, etc.) to be acceptable for solar energy investments. On the other hand, some of the cities have strict regulation against solar applications in order to protect the historical urban landscape, which seems a contradiction, as equipment necessary for the traffic of modern vehicles are not excluded from the very same areas.

To calculate the sustainable solar energy potential, the first step is to determine the suitable area and the technology. The latter are the photovoltaic (PV) and the photovoltaic/thermal hybrid solar collector (PV/T) systems *(Figure 2)*.

Figure 2 – GIS-analysed orthophoto of Esztergom showing the south facing and flat rooftops to calculate solar potential

Source: MUNKÁCSY, B. et al. (2008)

As for the spatial aspect, firstly, in this research greenfield sites are not considered for solar applications, because existing technologies demand remarkable space and the result in a negative impact on biological activity and diversity.

Secondly, using GIS methodology in cases of settlements, it is necessary to calculate the surface areas offered by the existing building stock. A thorough GIS-based assessment of orthophotos of 17 settlements including 2 cities and 15 villages (MUNKÁCSY, B. *et al.* 2008) resulted in the following outcomes. Considering the area of flat roofs together with roofs facing to South (with a maximum 45° East or West deviation), the ratio of the proper building stock varies between 21 and 84%, as the average ratio for the whole area is 53%. The size of the suitable roofs varies between 36 and 115 m^2 per building, the average size per building is 53 m^2. Extrapolating the figures of the sample area at national level, the result is between 82 and 105.5 km^2 (94 km^2 in average) south-facing and flat roof area. This value needs to be corrected with the ratio of the urban fabric category represented in the *Corine Land Cover* database, as the urban fabric is 7.13% in the sample area of this research; meanwhile the same sort of area is 4.67% in *Hungary* in average, which is about the two-thirds of the value of the sample area. Using the correction factor, the final figure is 61.6 km^2, as suitable roof surface for solar applications in the whole country.

Thirdly, using the figures of some existing European PV-applications, like the solar train tunnel near *Antwerp* (width: 14.3 m) and several solar noise barriers along highways (width: 2 metres on one side of the road, 4 m on both sides), it is possible to refine the earlier published 11.11 km^2 figure (FARKAS, I. 2010). Considering the whole 8,000 km train network, and a 14.3 m tunnel width, it would be possible to cover 114.28 km^2 area with PV systems. As for the 1,400 km highway system, using a 2-m-width noise barrier on both sides of the road, 5.6 km^2 area would be utilisable by solar panels. Consequently, the existing traffic infrastructure could provide, as a potential, almost 120 km^2 surface for PV applications.

Fourthly, the shopping infrastructure including all their parking sites can also provide significant areas, as there are around 80 larger hypermarkets and 6,000 smaller local shops all over the country. Taking into consideration only half of their parking areas, as there are also underground parking areas and parking garages, another 4 km^2 can be added to the potential areas.

Fifthly, calculation of the planned elements of infrastructure by 2050 is also needed. According to the *National Development Policy Concept* (VARGA, M. 2013), there are 1,300 km highways and 800 km railways in need to be built. As for the planned highways, their south-facing noise barriers could provide 5.2 km^2 suitable area for solar applications (considering 2 m noise barrier height on both sides of the road). Regarding the planned railways, using the same methodology as the existing 50,000 m^2 PV tunnel system (3.92 MW) near *Antwerp*, it would be possible to utilise another 11.4 km^2 surface area.

Sixthly, the expanding 'average floor area per capita' also needs to be taken into account which means that growing building surfaces lead expanding roof areas suitable for solar applications. In *Hungary*, this increase was 5% between 2000 and 2010 (IEA, 2015). The recent 30.2 m^2/capita is much smaller than the EU-15 average (42.9 m^2/capita), so in this research there was assumed a (ENTRANZE, 2008.), therefore 25% expansion between 2000 and 2050. This factor results another 15 km^2 increase of the possible solar areas.

Table 1 – Potential areas for solar energy applications in Hungary and their sizes

Source: MUNKÁCSY, B. et al. (2016)

Type of surface area or other factors	**Size of surface (km^2)**
Roofs in settlements	61.6
Existing linear infrastructure	120.0
Parking areas in commercial zones	4.0
Expansion of the linear infrastructure by 2050	16.6
Increase of building area/capita by 2050	15.0
Total	**217.2**

In summary *(Table 1)*, using the different elements of the existing and planned infrastructure, almost 217.2 km^2 potential area can be considered as suitable for active solar applications in *Hungary*. Using a state-of-the-art PV technology (7 m^2/kW), it is possible to install 30,885 MW active solar capacity without any disturbance to green areas. The estimation of the average yearly power production was based on optimal (1,150 kWh/kW/year) and suboptimal (1,000 kWh/kW/year) predictions of the PV yield-estimation calculator developed by the *European Commission Joint Research Centre*. Using the suboptimal moderate value, 30.9 TWh/year (or 111.25 PJ) electricity can be predicted by 2050, a slightly more than the recent domestic power production (29.4 TWh or 105.7 PJ) in *Hungary* in 2014 (KSH, 2016c.). However, utilising the same area, this electricity production could be much higher using future technologies. Using the photovoltaic/thermal hybrid solar collector (PV/T) technology, it would be possible to increase the electricity production by 25%, moreover, these systems are also able to create heat (250 kWh/m^2/year), mainly hot water, which can be used in settlement areas. The available surface areas (buildings and parking areas) for solar applications in settlements cover 80.6 km^2. With this technological shift, it would be possible to produce another 3 TWh (10.8 PJ) electricity, as a surplus, by 2050. Additionally, utilising the same surface area, these PV/T systems could produce 20,150 GWh (72.5 PJ) heat.

4. Sustainable wind energy potential

The calculation of sustainable wind energy potential of this research also begins with defining the available area. In this case, the existing legal and technological regulations proved to be sufficient for a sustainable production. The *Environmental Ministry* (KvVM, 2005), published a list of excluded areas, creating strict environmental limits for wind energy investments. These are as follows:

a) protected natural areas (national, local, and international level)—including the ecological network, that prevents protected areas from fragmentation;

b) protected landscapes (national and county level);
c) Environmentally Sensitive Areas;
d) forests;
e) hydrographical elements;
f) roads, railways and airports;
g) transmission lines (it is a primary condition of these kind of projects; but in this context, the grid is a vulnerable element of the infrastructure).

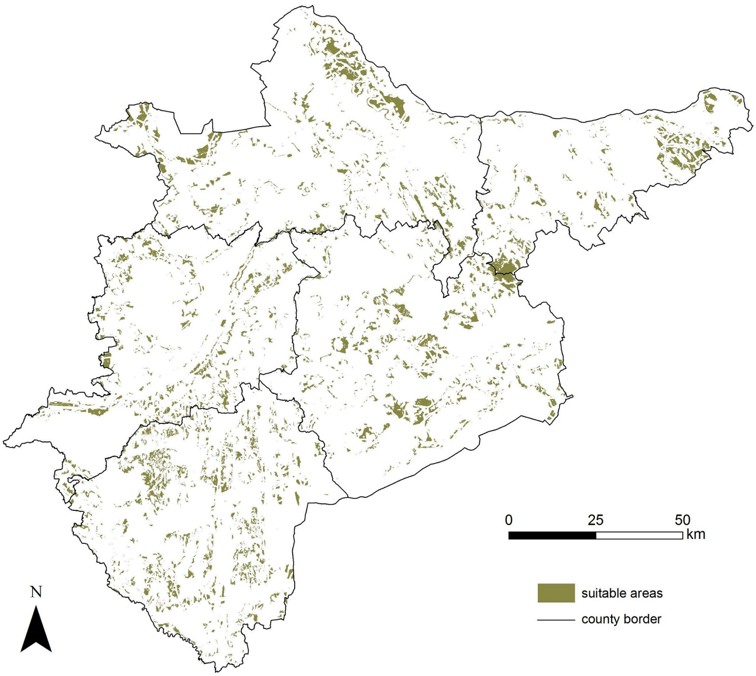


Figure 3 – Suitable areas for sustainable wind energy utilisation in north-western Hungary
Edited by HARMAT, Á. (2016)

Around the excluded areas there are buffer zones with distances which vary between 0 m and 1,000 m depending on the type of the areas. These restrictions are covering all the territories with the highest biodiversity and ecological values. Hence, it can be stated that, due to the regulation, aspects of sustainability are taken into consideration sufficiently *(Figure 3)*.

Using GIS application, all these limitations can be implemented and excluded from the technically suitable area in the country. The deduction of these areas restrains the potential areas to 5,396 km^2, which is only 5.8% of the total land area of *Hungary*—it also means that 94.2% of the land area is excluded, strictly considering the existing regulation.

The opportunities in *Sweden* were analysed by a GIS-based research. It was estimated that up to 69% of the total land area was excluded due to the constraints given by biodiversity and ecosystem services, in the form of areas of national interest for nature, culture and recreation values, as well as single houses with buffer zones (SIYAL, S. H. *et al.* 2015). According to a similar research of the *German Federal Environment Agency* (LÜTKEHUS, I. – SALECKER, H. 2013), using also a GIS methodology, this value is 86.2% in the case of *Germany*. In the case of *Austria*, due to the regulation, 93% of the land area are under restrictions and only 7% of the land area can be utilised for wind power production (GASS, V. *et al.* 2013). Comparing the above-mentioned values, 94.2% excluded area indicates a strict legal background in the case of *Hungary*.

In the next step, a proper technology was chosen. In the authors' analyses, the state-of-the-art horizontal axis wind turbine technology, developed especially for low wind sites, was used. These turbines have a moderate space demand and exceptionally high EROEI value. Involving ecology experts, it is possible to decrease their environmental pressure to a reasonable level (WANG, S. – WANG, S. 2015). For the analyses, the most important parameters are the capacity and the power curve. Because the Hungarian wind energy development has been blocked by political reasons (MVM, 2006; NFM, 2012), it is not possible to find proper local information, therefore it was necessary to use international data sets from regions with similar wind climate. According to the values of the *German Energy Agency* (DEUTSCHEN ENERGIE-

AGENTUR GMBH, 2010) the so-called land requirement value can be varied between 7 and 10 ha/MW, considering the state of the art turbine technology. Calculating with the less favourable 10 ha/MW land requirement value, 10 MW wind turbine capacity can be installed per 1 km^2. Adopting the GIS calculated 5,396 km^2, as the potential area, the Hungarian sustainable wind energy potential is around 54,000 MW. To calculate the electricity production of that huge capacity, it is possible to use the real-life capacity factor of the Hungarian wind energy sector. These values are between 20–25% in *Hungary* (MAVIR, 2010; MSZT, 2010). If the basis of the calculation the worst value, that means that 54,000 MW wind turbines could produce 94.6 TWh (340 PJ) electricity, which is three times higher than the recent domestic power production (29.4 TWh or 105.7 PJ) in the country.

5. Sustainable solid biomass potential

In case of solid bioenergy potential only forestry biomass and short rotation coppice (SRC) were taken into consideration.

5.1. Forestry biomass

In *Hungary*, 20.8% of the country area is covered by forest, namely 1929 thousand ha in 2014 (NÉBIH, 2015). In the period between 2004 and 2014, the average annual net growth of the forested area was 13 million m^3, the yearly logging was 7.3 million m^3 (NÉBIH, 2015). The amount of the natural mortality and the logging is less than the annual net growth, therefore the growing stock increases with 3% per year. That means that forestry is controlled by relatively strict technical regulation based on the annual and ten-year forestry operational plans, which in the authors' understanding, ensures sustainability, at least from a quantitative point of view. The potential calculated with the factors is presented in *Table 2*. The total gross logging data was determined as the average of the logging data from 2012 to 2014.The rate of the firewood from the total gross logging is available in the statistics only as aggregated data (54.5 %—average of 2012–2014); therefore, this rate was applied for the three timber-type group. Since the logging data are for fresh wood, the moisture content was determined in 50%, according to (Röder, M. *et al.* 2015), and the energy content was collected from Biomass Energy Centre (2016). In total, the gross calorific value is 30.7 PJ.

Table 2 – Factors determining solid bioenergy potential

Sources: [1](Nébih, 2015); [2](Biomass Energy Centre, 2016)

	Total gross logging[1] (thousands m^3/yr)	Firewood from the total logging[2] (thousands m^3/yr)	Energy content (with 50% moisture content)[2] (GJ/m^3)	Gross calorific value (PJ)
Hardwood	4,552.3	2,481.0	8.5	21.1
Softwood	1,580.5	861.4	6.0	5.2
Pine	1,162.7	633.7	7.0	4.4
Total	**7,295.5**	**3,976.1**	**21.5**	**30.7**

5.2. Short rotation coppice

The determination of energy potential from plantations was calculated using GIS database, too. The focus of the investigation was only arable land occupied by intensive cultures since using these areas for less intensive cropping like woody short rotation coppice (SRC) could improve their ecological services by conserving soils, enhance soil organic content balance and mitigate carbon emissions (Rowe, R. L. *et al.* 2009). The arable land was identified as the 211. Category—non-irrigated arable land in the national land cover database with the scale of 1:50,000.

Legal limitations exist only for the plantations of black locust *(Robinia)* on protected natural area and Natura 2000 sites (FVM, 2007). These limitations were considered as not sufficient for a sustainable SRC production. Thus, in the first step, arable land—where limitations of the current land-use are needed for protective purposes—were identified. The GIS database of the *National Agro-Environmental Program* was used for this purpose. This GIS database, with the integration of 28 parameters of agricultural production and environmental sensitivity, provides a value from 0 to 200 indicating an environmental sensitivity-agricultural suitability measure for each 1 ha grid cell of the whole country. In (ÁNGYÁN, J. *et al.* 1999) areas with a value less than 100 were ranked into the protection zone, between 100 and 125 as extensive agricultural zone, and with a value more than 125 as intensive agricultural area. The extensive agricultural zone was identified as suitable areas for the further steps. In the next step, suitable areas were identified for willow, *Robinia* and poplar (these are the approved SRC species by law (FVM, 2007) using soil parameters of GIS database like pH, lime condition of the soil, physical soil types, soil types and sub-types, water management parameter, and compaction of the productive soil *(Figure 4–5)*.

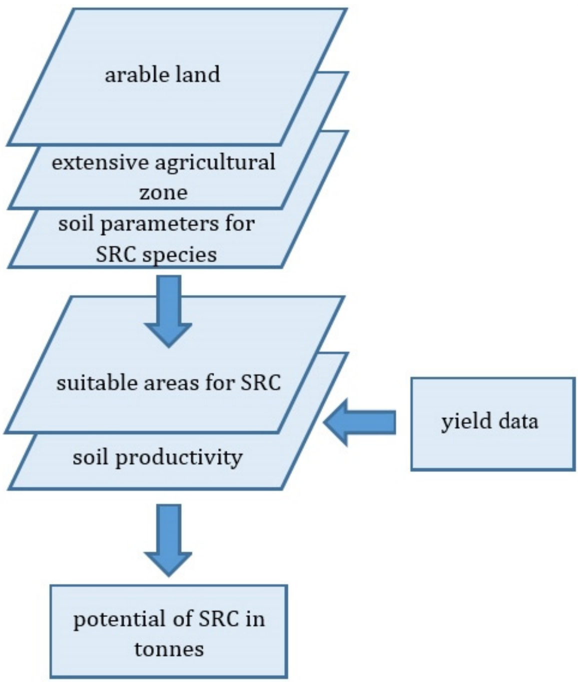


Figure 4 – Process of determining SRC potential

Edited by HARMAT, Á. (2016)

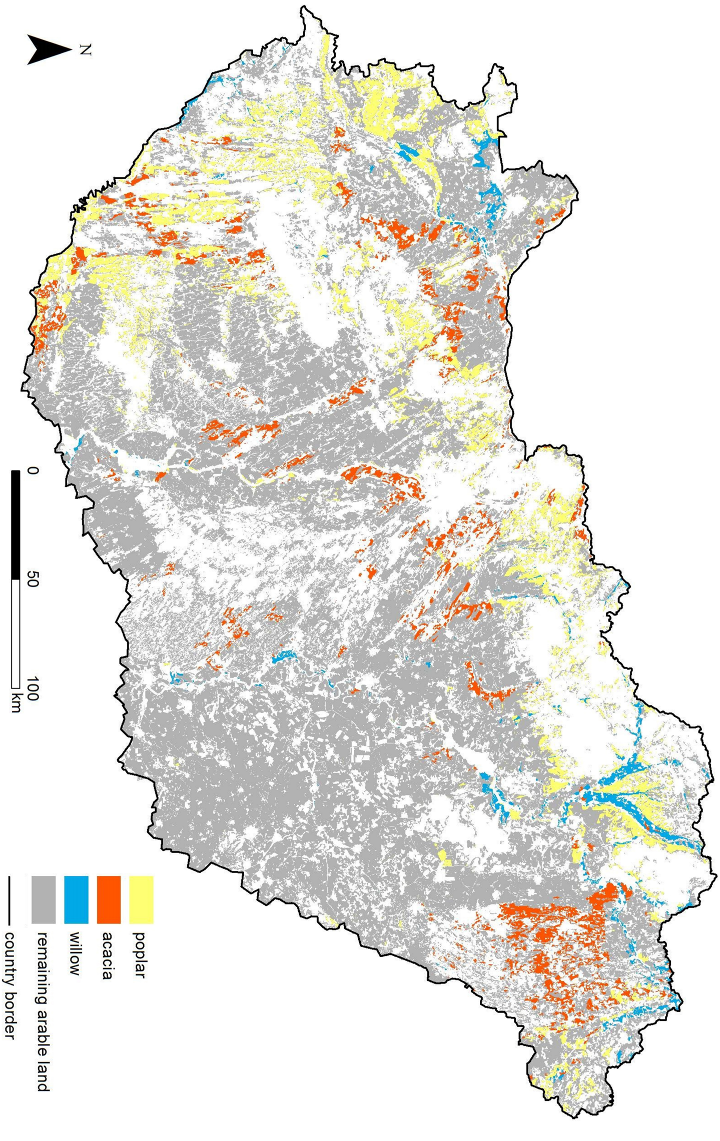


Figure 5 – Suitable areas for SRC plantations in agricultural areas
Edited by HARMAT, Á. (2016)

In the next step, the intersection of the suitable areas with the zone of extensive agriculture were selected yielding 0.96 million hectares for potential cultivation, which takes up 49.8% of the extensive agricultural zone. The exclusion of the area would not cause issues in the security of food-supply on national level, since only 1.5 million hectares of the total 4.3 million hectares of arable land are needed to secure the average current diet in *Hungary* (KOHLHEB, N. *et al.* 2009). In the final step the yield calculation was based on empirical yield values of the experimental plantations in *Hungary* (BARKÓCZY, ZS. – IVELICS, R. 2008). Here yield data—defined by the minimum and maximum measured yield for the three species—was differentiated by the soil productivity class for each 1 ha grid cell. According to the calculations, the average yield was 17 t/ha (fresh mass) and the total yield was 15.87 million tons on the whole designated area. With the heating value of 7 MJ/kg (IVELICS, R. 2006), the total energy content is 111.1 PJ. This, together with the forest based potential, amounts 141.8 PJ. This can be used in cogeneration units with 80% efficiency producing 34 PJ electricity and 79 PJ heat. Using high efficiency heating appliances working with 90% efficiency, 127.6 PJ heat can be produced. The exploitation of this resource only for power production would gain only 42.5 PJ with 0.3 efficiency ratio. So, this alternative does not satisfy the criteria for energy efficiency.

6. Potential of biofuels and biogas

Because of the well-known sustainability debate about biofuel, the calculation of this research has determined the biofuel potential as the minimum compulsory share of the total fuel (10%) (EUR-LEX, 2009), which is 12 PJ. According to (EUR-LEX, 2015), maximum 70% of the potential would be from crops grown on agricultural land.

6.1. Biogas potential

In the calculations following the ecological principles laid down above (favour wastes instead of primary resources), primary resources that consume valuable area either from the ecosystem or from food production were not considered. So, the Hungarian biogas potential was assessed considering only secondary and tertiary resources. In the first step, the available residues are accounted, for example manure, meat processing wastes and human residues as sewage, food wastes and landfill. Of course, the first step, namely calculating the available area was not relevant, when assessing biogas potential from residues. In the next step the utilisable share of these residues was assessed. In this step the usually collectable share was determined. This was made concerning usual size distribution of animal husbandry units and usual agricultural practices in bedding and in waste management.

To assess biogas potential from manure, the produced amount of feedstock was calculated first. In the approach of this research, the most important manure type (solid manure) was considered that also incorporates bedding materials, like straw and stover, that are crop residues. In case of grazing animals, like horses and sheep, smaller fraction of manure was collectable (approx. 50%), meanwhile for dairy cow and mast pig a higher share is possible (80% and 90% respectively). Only a fraction from the collectable amount of manure is utilised in biogas plants, since not every animal husbandry unit is able to build a biogas plant, mainly due to too small animal density. In the final step, according to the share of dry matter, organic matter and biogas yield ratios, the producible biogas and its energy content was calculated.

Table 3 – Biogas potential of manure

Sources: [1](KSH, 2016b); [2](FVM, 2008); [3](Institut für Energetik und Umwelt GGmbH, 2004)

	Number of animals[1]	***Specific manure production[2]***	***Dry material[3]***	***Organic dry matter[3]***	***Specific biogas yield[3]***	***Collectable share of manure***	***Share of manure treated in biogas plant***
	(pcs)	*(t/pcs/yr)*	*(%)*	*(% of DM)*	*(Nm3/t ODM)*	*(%)*	*(%)*
Cattle	821,000	9.923	0.25	0.72	255	80%	70%
Pig	3,124,000	2.184	0.25	0.78	360	90%	70%
Horse	62,200	4.888	0.25	0.72	255	50%	40%
Sheep	1,190,000	1.560	0.32	0.71	255	50%	40%
Poultry	37,895,900	0.021	0.32	0.71	350	80%	70%

Based on the calculation given in *Table 3*. 12.27 PJ manure based biogas energy can be produced in *Hungary*.

The tertiary wastes as slaughterhouse offal, DDGS from bioethanol production, food wastes, sewage and sewage mud were also considered. Here, also the utilisable share is assessed and then the special biogas yields are applied, since these gases often have different methane shares than those from manure *(Table 4)*.

Table 4 – Biogas potential of secondary residues and by-products

Sources: DDGS: Distiller's dried grains with solubles; [1]MUNKÁCSY, B. et al. (2016); [2] VADAS, T. 2012; [3]HANSEN, C. L. 2011; [4]MUNKÁCSY, B. et al. (2016) based on BAI, A. et al. (2002); [5]gross calorific value of biogas at 60% methane content (WELLINGER, A. 1991)

	Amount of wastes[1] (t/yr)	Biogas yield (Nm^3/t)	Energy content (MJ/Nm^3)	Utilisable share (%)
Slaughterhouse offal	**372,264**	900.00[2]	21.5[5]	50%
DDGS	**706,963**	106.50[3]	26.0[3]	50%
Food wastes	**4,506**	680.00[2]	21.5[5]	50%
Sewage mud	**1,059,832**	14.80[2]	21.5[5]	50%
Landfill	**20,087,407**	35.04[4]	15.74[4]	2%
Sewage, m^3	**600,571,382**	0.10[4]	21.5[5]	100%

According to *Table 4*, 6.29 PJ energy is embodied in the tertiary residues and by-products that could be used for biogas production. Altogether secondary and tertiary residues comprise 18.57 PJ renewable energy potential in *Hungary*. Currently the country produces only 3.2 PJ.

20% of the amount of 18.57 PJ biogas has to be used for heating the fermenters (BESGEN, S. – KEMPKENS, K. 2004). The rest, 14.85 PJ can be used with 80% efficiency in a cogeneration technology producing 5.9 PJ heat and 5.9 PJ electricity per year. Another way of utilisation would be upgrading and/or cleaning of biogas enabling a local direct heat production with approx. 90% efficiency. This gains 13.36 PJ heat energy.

7. Discussion

The preceding chapters of this paper focus on sustainable solar, wind and biomass energy solutions and contain new calculations for these potentials, since available sustainable energy has not been evaluated on a country level in *Hungary* ever before. In this part the goal is to compare the results with other calculations from the literature. As it appears, there were barely a few researches in this field except for biomass, which is broadly considered the most important renewable energy source in *Hungary*. In the case of hydropower and ambient heat potentials, data from literature was used, to get a complete picture of possibilities of sustainable energy in *Hungary*. Comparisons are made mostly on the level of technical and social-economic potential.

7.1. Solar potentials

Earlier calculations carried out by technology experts (PÁLFY, M. 2005; FARKAS, I. 2010) state that *Hungary* has theoretically more than 9,000 km^2 area where PV panels could be installed, and 4,000 km^2 area where PV installations should be favourably built. Approximately 90% of the latter value is agricultural area, 54.27 km^2 south-facing surfaces of the building stock (43.16 km^2) and suitable areas along railways and roads (11.11 km^2). Using the favourable surfaces, 400,000 MW PV capacity could be installed, which could produce 12 times more electricity than the electricity consumption in *Hungary* (PÁLFY, M. 2005). It is important to underline that these calculations mention almost 20 times bigger areas than the sustainably available (217.2 km^2) assessed in this study.

7.2. Wind energy potentials

The national level wind energy potential calculation, made by technology and meteorology experts and accepted by the relevant branch of the *Hungarian Academy of Science*, was published intensively during the last decade (HUNYÁR, M. 2004; BOHOCZKY, F. 2008; SZALAI, S. *et al.* 2010). These works were based on the same initial research that neglected several types of restricted areas, and contained overlapping. That can be explained by the facts that earlier research was conducted without environmental expertise such as nature conservationists and was accomplished without geographers and GIS methodology. The calculated 65.3% rate is a result of a simple addition which does not contain some types of restricted areas, as national and county level landscape protection zones or Nature 2000 areas. The incorrect methodology and the lack of knowledge in the field of landscape and nature protection produced an irrelevant and very high end-result (148 TWh or 533 PJ).

7.3. Bioenergy potentials

There have been a number of studies dealing with solid bioenergy potential. FISCHER, G. *et al.* (2005) concluded that in *Hungary*, SRC (mainly willow, poplar, and reed) could produce 327.6 PJ energy. Completed with the available forestry potential, altogether 1,777 PJ solid bioenergy potential is exploitable in the country. VAN DAM, J. *et al.* (2007) also calculated a physical potential of 400–1,200 PJ by the end of 2030. In this calculation, however, less suitable areas were excluded from potential areas. DE WIT, M.– FAAIJ, A. (2010) estimate 500 PJ bioenergy potential that can be achieved mainly by energy plantations by the end of 2030. The *European Environmental Agency* (EEA, 2006) in its model based approach, already considered environmental constraints like conserving extensively cultivated areas, excluding 3% set-a-side from cultivation, intensification of forest harvest on protected areas and the necessity of forest residues being kept on site. They conclude that by 2030 on arable land and in forest 146.6 PJ primary biomass theoretical potential can be produced, meanwhile the residue potential amounts 83.8 PJ.

Hungarian studies also estimate similar theoretical potential, for instance 203–328 PJ (IMRE, L. 2006), and 188 PJ (NFM, 2014). The study of (POPP, J. – POTORI, N. 2011) estimates theoretical potentials of 47.5 PJ for firewood and 39.8 PJ residue potential that can be used by firing processes, altogether 78.3 PJ. This potential was calculated by keeping the current land-use patterns, meanwhile the calculations of FISCHER, G. *et al.* (2005) assumed a massive change of land use favouring bioenergy production.

Compared to these results, the total 141.8 PJ theoretical potential represents a moderate value; however, it is slightly larger than the estimation made by POPP, J. – POTORI, N. (2011). This is due to their calculation which did not consider an increase in energy plantations, which, therefore, gained 111.1 PJ in the model. However, POPP, J. – POTORI, N. (2011) calculated with a slightly higher firewood potential than the model of this research, respectively with 47.5 PJ and 30.7 PJ. The study of POPP, J. – POTORI, N. (2011) also calculates technical potentials that are in case of cogeneration, 35.1 PJ for heat and 22.3 PJ for electricity. These are also smaller numbers than this research's results due to the above mentioned conservative approach of SRC production.

The residue potential degradable in anaerobic fermentation was estimated at 77.6 PJ by BAI, A. (2007) and 157 PJ by POPP, J. – POTORI, N. (2011) also estimated the biogas technical potential and calculated 118 PJ. This value is more than five times larger than the estimation of this research. This is due to two reasons. Firstly, in the calculation of POPP, J. – POTORI, N. (2011) the manure potential is 33.6 PJ while result calculated by the authors of this paper was only 12.27 PJ, because considerable fractions of manure due to less favourable animal density were excluded from the authors' calculation. Secondly, the calculation of POPP, J. – POTORI, N. (2011) takes into account a considerable amount of potential stemming from energy crops which were excluded for ecological reasons.

7.4. Hydropower potential

As *Hungary* has no favourable geographical settings (the rivers are either slow-flowing or in the mountains have low streamflow), significant hydropower potential was not taken into consideration. The theoretical potentials that are defined in the Hungarian literature (SZEREDI, I. *et al.* 2010; GŐŐZ, L. – KOVÁCS, T. 2011; TÓTH, P. *et al.* 2011) are approximately 1,400 MW, producing 7,446 GWh/year (14.22–27

PJ/year), and the technical potentials are 1,000–1,040 MW, 4,590 GWh/year. 80–90% of the potentials are connected to the two main rivers, *Danube* and *Tisza* (SZEREDI, I. *et al.* 2010), but utilising their potentials would cause large environmental consequences. Taking this into account, only a fraction of the above technical potential could be considered sustainable, consisting of small and micro hydropower plants of 10(–20) MW (IPCC, 2012); furthermore, rebuilding existing dams or installing, upgrading or fully reconstructing micro and pico hydroelectric stations can add further approx. 40 MW to the potential (SZEREDI, I. *et al.* 2010). Based on the assessments on these potentials, the sustainable hydropower potential was defined to be 2 PJ.

7.5. Potential of ambient heat

The ambient heat can be deep and shallow geothermal, as well as hydrothermal and aerothermal. The traditional and most well-known resource in *Hungary*, is the deep geothermal energy. Its potentials are influenced by geological conditions which results in outstanding heat resource in the *Carpathian Basin*. In the calculations, the approaches can be different, therefore the figures of the theoretical potential vary between 264 PJ and 102,000 EJ. The most respected figures of the technical potential are published by MÁDLNÉ SZŐNYI, J. *et al.* (2009), namely 65 PJ for deep and 35 PJ for shallow sources, respectively. With the reinjection of pumped groundwater, these last figures can be considered as sustainable potentials.

The potentials of hydrothermal and aerothermal heat pumping are more complicated to estimate, as the quantity of these ambient heat sources are practically inexhaustible. Their sustainability depends on the environmental characteristics of the used electricity. Namely, the ambient energy can be considered sustainable if the power production is based on sustainable renewable energy applications. According to a software based sustainable energy scenario (MUNKÁCSY, B. – KRASSOVÁN, K. 2011), in 25–35 years, as a surplus of the demand, 13–14 PJ sustainable electricity could be converted into 55 PJ heat in *Hungary*.

7.6. Sustainable energy potential in general

Table 5 summarises the sustainable energy potentials in *Hungary*. According to the calculations carried out by the authors of this paper, 828.8 PJ sustainable renewable energy potential could be made available in the country. This is a very promising number compared to the current primary energy use (963.4 PJ [KSH, 2016a]) is a very promising number, because the difference can be easily saved by energy efficiency and sufficiency measures.

Table 5 – Summary of sustainable energy potentials, concerning conversion losses in the production phase

Calculations by MUNKÁCSY, B. et al. (2016)

	Heat (PJ)	Power (PJ)	Transport (PJ)
Solar	122.5	72.5	0.0
Wind	0.0	340.0	0.0
Solid biomass	79.0	34.0	0.0
Liquid biofuel	0.0	0.0	12.0
Biogas	5.9	5.9	0.0
Hydro	0.0	2.0	0.0
Ambient heat	155.0	0.0	0.0
Total	**362.4**	**454.4**	**12.0**

8. Conclusions

In the last 10–15 years, there has been a lot of debate over the quantity of renewable energy sources in *Hungary*. The reason for this is that only a few good quality partial results were published, but the overall final outcomes have been missing so far. In this research's calculations, using strict sustainability and technological limitations, the country's overall sustainable technical potential resulted in 828.8 PJ, concerning conversion losses in the production phase. This number highlights that even under strict constraints renewable energy resources are significant in *Hungary*, since this number is very close to the recent primary energy supply (963.4 PJ in 2014), which was topped in 2005 (1,166 PJ) (KSH, 2016a).

In order to evaluate these figures correctly, it is important to consider the huge energy efficiency potential in particular and the immense resource efficiency potential in general, as it was introduced by some researchers in the 1990s (VON WEIZSÄCKER, E. U. *et al.* 1998). A less explored but at least as important area is the potential of sufficiency. Alternative energy strategies contain 40–60% decrease in energy consumption by 2030 (IDA, 2006; CAT, 2013). This means that using economic regulation as well as education, it would be possible to decrease the energy consumption significantly, in this country, and throughout *Europe*. Thus, a 100% energy autonomy could be covered by endemic renewables in *Hungary*, however, this seems to be a temporary solution only. The reason for is that there are other developments challenging renewable energy autonomy, for example the emerging industry of biorefinery which creates an additional market for biomass feedstock other than combustion.

Acknowledgements

The authors are grateful to *Betty Szilveszter* for the proofreading.

References

BAI, A. – LAKNER, Z. – MAROSVÖLGYI, B. – NÁBRÁDI, A. (2002): *A biomassza felhasználása.* Szaktudás Kiadó Ház, Budapest, 226 p.

BAI, A. (2007): *A biogáz.* Száz magyar falu könyvesháza. Budapest, 284 p.

BERKES, F. – FOLKE, C. – COLDING, J. (2000): *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience.* – Cambridge University Press, 480 p.

BOHOCZKY, F. (2008): *Megújuló energiaforrás hasznosítási elvárások*. Bioenergia, 3, pp. 14–18.

CATO, M. S. (2009): *Green economics, an introduction to theory, policy and practice.* – Earthscan, London, 240 p.

CONSTANZA, R. – DALY, H. (1992): *Natural Capital and Sustainable Development.* Conservation Biology, 6, pp. 37–46.

DE WIT, M. – FAAIJ, A. (2010): *European biomass resource potential and costs.* Biomass and Bioenergy, Volume 34, Issue 2, pp. 188–202.

FARKAS, I. (2010): *A napenergia hasznosításának hazai lehetőségei.* Magyar Tudomány, pp. 937–946.

FISCHER, G. – PRIELER, S. – VAN VELTHUIZEN, H. (2005): *Biomass potentials of miscanthus, willow and poplar: results and policy implications for Eastern Europe, Northern and Central Asia.* Biomass and Bioenergy, Volume 28, Issue 2, pp. 119–132.

GASS, V. – SCHMIDT, J. – STRAUSS, F. – SCHMID, E. (2013): Assessing the economic wind power potential in Austria. Energy Policy, 53, pp. 323–330.

HANSEN, C. L. (2011): *Using DDGS as a Feedstock for Bioenergy via Anaerobic Digestion*. In: ROSENTRATER, K. A. *Distillers Grains. Production, Properties, and Utilization.* – AOCS Publishing, pp. 465–474.

HUNYÁR, M. (2004): *A szélenergia potenciál hasznosítását korlátozó tényezők Magyarországon.* Magyar Energetika, pp. 3–7.

IMRE, L. (Ed.) (2006): *Magyarország Megújuló Energetikai Potenciálja*. Magyar Tudományos Akadémia, Energetikai Bizottság, Megújuló Energia Albizottság Szakmai Csoportja, Budapest

INSTITUT FÜR ENERGETIK UND UMWELT (2004): Handreichung Biogasgewinnung und -nutzung. Fachagentur für Nachwachsende Rohstoffe, 232 p.

IVELICS, R. (2006): *Minirotációs energetikai faültetvények termesztés-technológiájának és hasznosításának fejlesztése.* Nyugat-magyarországi Egyetem, Sopron, 117 p.

JUROSZEK, Z. – KUDELKO, M. (2016): *A model of optimization for local energy infrastructure development.* Energy, 96, pp. 625–643.

KOHLHEB, N. – PODMANICZKY, L. – SKUTAI, J. (2009): *Magyarország felszínborítottságának lehetőségei az éghajlatvédelemben*. Ökológiai Intézet a Fejlődésért Alapítvány, 75 p.

LI, F. G. N. - TRUTNEVYTE, E. – STRACHAN, N. (2015): *A review of socio-technical energy transition (STET) models*. Technological Forecasting and Social Change, 100, pp. 290–305.

LIOR, N. (2012): *Sustainable energy development (May 2011) with some game-changers.* Energy, 40, pp. 3–18.

MÁDLNÉ SZŐNYI, J. – RYBACH, L. – LENKEY, L. – HÁMORI, T. – ZSEMLE, F. (2009): *Fejlődési lehetőségek a geotermikus energia hasznosításában, különös tekintettel a hazai adottságokra.* Magyar Tudomány, Volume 170, Issue 8. pp. 989–1003.

MAROSVÖLGYI, B. (2004): *Magyarország biomassza-energetikai potenciálja* 56, pp. 16–19.

MUNKÁCSY, B. – BORZSÁK, S. – EGRI, CS. (2008): *Napenergia*. In: LEDZÉNYI, A. (Ed.) *Megújuló energia – megújuló határvidék (konferencia)*. Esztergom, pp. 1–9.

MUNKÁCSY, B. – KRASSOVÁN, K. (2011): *A környezeti hő felhasználásának lehetőségei 2050-ig.* In: MUNKÁCSY, B. (Ed.) *Erre van előre! Egy fenntartható energiarendszer keretei Magyarországon*. pp. 104–109.

OLABI, A. G. (2010): *The 3rd international conference on sustainable energy and environmental protection SEEP 2009 – Guest Editor's Introduction*. Fuel and Energy Abstracts, Volume 35, Issue 12, pp. 4508–4509.

OLABI, A. G. (2013): *State of the art on renewable and sustainable energy*. Energy, Volume 61, Issue 1, pp. 2–5.

PÁLFY, M. (2005): *A napenergia fotovillamos hasznosításának potenciálja Magyarországon*. Elektrotechnika, pp. 293–295.

PEARCE, D. W. – MARKANDYA, A. – BARBIER, E. B. (1989): *Blueprint for a green economy*. – Earthscan, 208 p.

PERSONAL, E. – GUERRERO, J. I. – GARCIA, A. – PEÑA, M. – LEON, C. (2014): *Key performance indicators: A useful tool to assess Smart Grid goals.* Energy, 76, pp. 976–988.

POPP, J. – POTORI, N. (2011*): A biomassza termelése és energetikai felhasználása Magyarországon*. Agrárgazdasági Kutató Intézet (AKI), Budapest

ROCKSTRÖM, J. – STEFFEN, W. – NOONE, K. – PERSSON, Å. – CHAPIN, F. S. III – LAMBIN, E. – LENTON, T. M. – SCHEFFER, M. – FOLKE, C. – SCHELLNHUBER, H. J. – NYKVIST, B. – DE WIT, C. A. – HUGHES, T. – VAN DER LEEUW, S. – RODHE, H. – SÖRLIN, S. – SNYDER, P. K. – COSTANZA, R. – SVEDIN, U. – FALKENMARK, M. – KARLBERG, L. – CORELL, R. W. – FABRY, V. J. – HANSEN, J. – WALKER, B. – LIVERMAN, D. – RICHARDSON, K. – CRUTZEN, P. – FOLEY, J. (2009): *Planetary Boundaries: Exploring the Safe Operating Space for Humanity.* Ecology and Society, Volume 14, Issue 2, 32 p.

ROWE, R. L. – STREET, N. R. – TAYLOR, G. (2009): *Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK.* Renewable and Sustainable Energy Reviews, 13, pp. 271–290.

RÖDER, M. – WHITTAKER, C. – THORNLEY, P. (2015): *How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues.* Biomass and Bioenergy, 79, pp. 50–63.

SCHOLZ, R. W. (2011): *Environmental Literacy in Science and Society. From Knowledge to Decisions.* – Cambridge University Press, Cambridge, 659 p.

SIYAL, S. H. – MÖRTBERG, U. – MENTIS, D. – WELSCH, M. – BABELON, I. – HOWELLS, M. (2015): *Wind energy assessment considering geographic and environmental restrictions in Sweden: A GIS-based approach.* Energy, 83, pp. 447–461.

SZALAI, S. – GÁCS, I. – TAR, K. – TÓTH, P. (2010): *A szélenergia helyzete Magyarországon.* Magyar Tudomány, Volume 171, Issue 8. pp. 947–958.

SZEREDI, I. – ALFÖLDI, L. – CSOM, G. – MÉSZÁROS, C. (2010): *A vízenergia-hasznosítás szerepe, helyzete, hatásai*. Magyar Tudomány, Volume 171, Issue 8, pp. 959–978.

VADAS, T. (2012): *Magyarország biogáz potenciálbecslése*. Szent István Egyetem, Gödöllő, 69 p.

VAN DAM, J. – FAAIJ, A. P. C. – LEWANDOWSKI, I. – FISCHER, G. (2007): *Biomass production potentials in Central and Eastern Europe under different scenarios.* Biomass and Bioenergy, Volume 31, Issue 6, pp. 345–366.

VAN DEN BERGH, J. C. J. M. (2014): *Sustainable development in ecological economics.* In: ATKINSON, G. – DIETZ, S. – NEUMAYER, E. – AGARWALA, M. (Eds.) *Handbook of Sustainable Development (Second Edition).* – Edward Elgar Publishing, Inc., Cheltenham, UK, pp. 4–54.

VON WEIZSÄCKER, E. – LOVINS, A. B. – LOVINS, L. H. (1998): Factor Four: Doubling Wealth, Halving Resource Use – The New Report to the Club of Rome. – Earthscan, 364 p.

WACKERNAGEL, M. (Ed.) (2005): *Europe 2005 - The Ecological Footprint*. – WWF, 28 p.

WANG, S. – WANG, S. (2015): *Impacts of wind energy on environment: A review.* Renewable and Sustainable Energy Reviews, 49, pp. 437–443.

WELLINGER, A. (1991): *Biogas-Handbuch: Grundlagen, Planung, Betrieb landwirtschaftliche Anlagen*. – Verlag Wirz, Arau

YANIK, S. – SÜRER, Ö. – ÖZTAYŞI, B. (2016): *Designing sustainable energy regions using genetic algorithms and location-allocation approach.* Energy, 97, pp. 161–172.

Electronic sources

ÁNGYÁN, J. – FÉSŰS, I. – PODMANICZKY, L. – TAR, F. (EDS.) (1999): *Nemzeti Agrár-környezetvédelmi Program - a környezetkímélő, a természet védelmét és a táj megőrzését szolgáló mezőgazdasági termelési módszerek támogatására*. Akg-Info [Online] *(pdf)* 22 p. Available at: <http://akg-info.hu/portal/index.php?option=com_phocadownload&view=category&download=11:nemzeti-agrar-koernyezetvedelmi-program-1-resz-&id=30:tanulmany&Itemid=31> [Accessed 25 December 2016]

Ayres, R. U. – Van Den Bergh, J. C. J. M. – Gowdy, J. M. (1998): *Viewpoint: weak versus strong sustainability. centre for the management of environmental resources.* Vrije Universitet Amsterdam [Online] *(pdf)* 18 p. Available at: <http://dare.ubvu.vu.nl/bitstream/handle/1871/9295/98103.pdf?sequence=1> [Accessed 25 December 2016]

Barkóczy, Zs. – Ivelics, R. (2008): *Energetikai célú ültetvények.* NYME [Online] *(pdf)* Erdészeti kisfüzetek. Magán-erdıgazdálkodási Tájékoztató Iroda, Sopron, 88 p. Available at: <http://nyme.hu/fileadmin/dokumentumok/emk/moi/PolitikaEsOkonomia/Kiadvanyok/EnergetikaiCeluUltetvenyek.pdf> [Accessed 20 December 2016]

Besgen, S. – Kempkens, K. (2004): Abschlußbericht 2004 „Projekt Biogas Rheinland"; Ergebnisse messtechnischer Untersuchungen an landwirtschaftlichen Biogasanlagen im Rheinland. Biogas-Infoboard [Online] (pdf) 184 p. Available at: <http://biogas-infoboard.de/pdf/Biogas%20im%20Rheinland.pdf> [Accessed 20 December 2016]

Biomass Energy Centre (2016): *Moisture content*. Forest Research [Online]. Available at: <http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,177178&_dad=portal&_schema=PORTAL> [Accessed 21 December 2016]

CAT (2013): *ZeroCarbonBritain: Rethinking the Future*. Centre for Alternative Technology [Online] *(pdf)* Centre for Alternative Technology, 214 p. Available at: <http://zerocarbonbritain.com/images/pdfs/ZCBrtflo-res.pdf> [Accessed 11 December 2016]

Deutschen Energie-Agentur GmbH (2010): *Integration of Renewable Energie Sources into the German Power Supply System in the 2015–2020 period with Outlook to 2025.* University of Köln [Online] (pdf) 587 p. Available at: <http://www.ewi.uni-koeln.de/fileadmin/user_upload/Publikationen/Studien/Politik_und_Gesellschaft/2010/dena_II-englisch_final3.pdf> [Accessed 23 December 2016]

EEA (2006): *How much bioenergy can Europe produce without harming the environment?* EEA Report No. 7. European Environmental Agency [Online] *(pdf)*. Available at: <http://www.eea.europa.eu/publications/eea_report_2006_7> [Accessed 17 September 2016]

Entranze (2008): *Average floor area per capita*. Entranze [Online]. Available at: <http://www.entranze.enerdata.eu/> [Accessed 25 March 2016]

EUR-LEX (2009): *Amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources*. EUR-Lex [Online]. Available at: <http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32009L0028> [Accessed 23 December 2016]

EUR-LEX (2015): *On the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. EUR-Lex [Online]. Available at: <http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32015L1513> [Accessed 23 December 2016]

FVM (2007): *45/2007. (VI. 11.) FVM rendelet a fás szárú energetikai ültetvények telepítésének engedélyezése, telepítése, művelése és megszüntetése részletes szabályairól, valamint ezen eljárások igazgatási szolgáltatási díjáról.* Wolters Kluwer [Online]. Available at: <https://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=a0700045.fvm> [Accessed 12 December 2016]

FVM (2008): *59/2008. (IV. 29.) FVM rendelet vizek mezőgazdasági eredetű nitrátszennyezéssel szembeni védelméhez szükséges cselekvési program részletes szabályairól, valamint az adatszolgáltatás és nyilvántartás rendjéről.* Wolters Kluwer [Online]. Available at: <https://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=a0800059.fvm> [Accessed 12 December 2016]

GŐÖZ, L. – KOVÁCS, T. (2011): *Vízenergia.* Nyíregyházi Főiskola [Online]. Available at: <http://www.nyf.hu/others/html/kornyezettud/megujulo/vizenergia/Vizenergia.html> [Accessed 27 March 2016]

IDA (2006): *The Danish Society of Engineers' Energy Plan 2030 – Summary*. Fritnorden [Online] *(pdf)* 14 p. Available at: <http://www.fritnorden.dk/NF2007/Energyplan2030.pdf> [Accessed 21 November 2016]

IEA (2015): *Energy and Climate Change, World Energy Outlook Special Report.* International Energy Agency [Online] *(pdf)* IEA, Paris, 200 p. Available at: <https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf> [Accessed 23 December 2016]

IPCC (2012): Renewable Energy Sources and Climate Change Mitigation. IPCC [Online] *(pdf)* 246 p. Available at: <https://www.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf> [Accessed 21 November 2016]

KSH (2016a): *3.8.1. Primer energiamérleg (1990–)*. KSH [Online]. Available at: <http://www.ksh.hu/docs/hun/xstadat/xstadat_eves/i_qe001.html#> [Accessed 28 March 2016]

KSH (2016b): *4.1.25. Állatállomány, december (1995–)*. KSH [Online]. Available at: <http://www.ksh.hu/docs/hun/xstadat/xstadat_eves/i_oma003.html> [Accessed 28 March 2016]

KSH (2016c): *3.8.2. Villamosenergia-mérleg (1990–)*. KSH [Online]. Available at: <http://www.ksh.hu/docs/hun/xstadat/xstadat_eves/i_qe002.html> [Accessed 24 March 2016]

KvVM (2005): *Tájékoztató a szélerőművek elhelyezésének táj- és természetvédelmi szempontjairól*. KvVM [Online] (pdf) 26 p. Available at: <http://www.kvvm.hu/cimg/documents/18__szeleromu_tajekoztato_2005.pdf> [Accessed 19 December 2016]

Loh, J. (Ed.) (2002): *Living Planet Report 2002*. Footprintnetword [Online] *(pdf)* WWF, UNEP, 39 p. Available at: <http://www.footprintnetwork.org/content/images/uploads/lpr2002.pdf> [Accessed 22 December 2016]

Lütkehus, I. – Salecker, H. (2013): *Onshore Wind Energy Potential in Germany. Current study by the Federal Environment Agency on the nationwide area and output potential.* DEWI Magazine [Online] *(pdf)* 6 p. Available at: <http://www.dewi.de/dewi/fileadmin/pdf/publications/Magazin_43/05.pdf> [Accessed 10 December 2016]

MAVIR (2010): *Szélerőművek kihasználtsága Magyarországon*. IPCC [Online] *(pdf)* 6 p. Available at: <https://www.mavir.hu/documents/10258/107815/Sz%C3%A9lkihaszn%C3%A1lts%C3%A1g+tanulm%C3%A1ny+2010.pdf/153d2d78-1c6f-4d54-858e-5bc46f56c352> [Accessed 22 November 2016]

McLellan, R. – Iyengar, L. – Jeffries, B. – Oerlemans, N. (Eds.) (2014): *Living Planet Report 2014*. Footprintnetwork [Online] (pdf) 36 p. Available at: <http://www.footprintnetwork.org/content/images/article_uploads/LPR2014_summary_low_res.pdf> [Accessed 10 December 2017]

MSZT (2010): *Tanulmány a hazai szélenergetikáról*. NRG-Systems [Online] *(pdf)* 13 p. Available at: <http://www.nrg-systems.hu/tanulmany.pdf> [Accessed 01 December 2016]

MVM (2006): *Magyarország energiapolitikai tézisei 2006-2030.* BME [Online] *(pdf)* A Magyar Villamos Művek Közleményei, 68 p. Available at: <ftp://ftp.energia.bme.hu/pub/Tananyagok-archivuma/Egyetemi-kepzes/Ipari-energetika/magy_energiapol_tezisei1.pdf> [Accessed 14 December 2016]

NÉBIH (2015): *Erdővagyon és erdőgazdálkodás Magyarországon 2015-ben*. Gyulaj Zrt. [Online] *(pdf)* Nemzeti Élelmiszerlánc-biztonsági Hivatal, Erdészeti Igazgatóság 2 p. Available at: <http://gyulajzrt.hu/sites/default/files/images/hirek/NEBIH_erdovagyon_gazdalkodas_2015ben_HUN.pdf> [Accessed 10 December 2016]

NFM (2012): *Nemzeti Energiastratégia 2030*. Kormany [Online] (pdf) 136 p. Available at: <http://2010-2014.kormany.hu/download/4/f8/70000/Nemzeti%20Energiastrat%C3%A9gia%202030%20teljes%20v%C3%A1ltozat.pdf> [Available 23 December 2016]

NFM (2014): *Magyarország Megújuló Energia Hasznosítási Cselekvési Terve 2010–2020*. Kormany [Online] *(pdf)* Nemzeti Fejlesztési Minisztérium, Budapest, 115 p. Available at: <http://2010-2014.kormany.hu/download/2/b9/30000/Meg%C3%BAjul%C3%B3%20Energia_Magyarorsz%C3%A1g%20Meg%C3%BAjul%C3%B3%20Energia%20Hasznos%C3%ADt%C3%A1si%20Cselekv%C3%A9si%20terve%202010_2020%20kiadv%C3%A1ny.pdf> [Accessed 09 December 2016]

SCHNEIDER, M. – FROGGATT, A. (2015): *The World Nuclear Industry – Status Report 2015*. World Nuclear Industry Status Report [Online]. Available at: <https://www.worldnuclearreport.org/-2015-.html> [Accessed 10 December 2016]

TÓTH, P. – BULLA, M. – NAGY, G. (2011): *Energetika*. Digitális Tankönyvtár [Online]. Available at: <http://www.tankonyvtar.hu/hu/tartalom/tamop425/0021_Energetika/ch02s02.html> [Accessed 27 March 2016]

VARGA, M. (2013): *H/13094. számú Országgyűlési Határozati Javaslat a Nemzeti Fejlesztés 2030 – Országos Fejlesztési és Területfejlesztési Koncepcióról*. Térport [Online]. Available at: <http://www.terport.hu/webfm_send/4204> [Accessed 11 December 2016]

VON STOKAR, T. – STEINEMANN, M. – RÜEGGE, B. (2006): *Ecological Footprint of Switzerland. Technical Report.* BFS [Online] Federal Office for Spatial Development (ARE), Agency for Development and Cooperation (SDC), Federal Office for the Environment (FOEN), Federal Statistical Office (FSO), Neuchâtel 26 p. Available at: <https://www.bfs.admin.ch/bfs/en/home/statistics/sustainable-development/ecological-footprint.assetdetail.500264.html> [Accessed 21 September 2016]