ENERGY TRANSITION OF AN INDUSTRIAL SETTLEMENT THROUGH THE EXAMPLE OF KECSKEMÉT

Zita Szabó[1], Ágnes Sallay[2]
1 Hungarian University of Agriculture and Life Sciences, Department of Landscape Planning and Regional Development, 2 Hungarian University of Agriculture and Life Sciences, Department of Landscape Planning and Regional Development

1. Abstract

In the context of climate change the reduction of greenhouse gas emissions and the decarbonisation of theenergy sector is the main goal (Masson-Delmotte et al. 2021). There is much research about the impacts of energy resources including fossil fuels and renewables, but there are also questions about the transition and implementation of this knowledge into spatial planning. In this research, we examine the energy transition through the example of Kecskemét. The project area is situated in the Great Hungarian Plain, in the middle of Hungary. It is the eighth largest settlement with the population of 109 651(Hungarian Central Statistical Office n.d.). Geographically, it is a typical example of a lowland settlement with a long history of agriculture. In the last decade, industrial development has changed its characteristics after Mercedes-Benz opened its factory.

Our research goal is to examine the possibilities and barriers of self-sufficient energy production of Kecskemét based on renewable sources. Which energy resources are available in the area? Which environmental effects are related to renewable resources specifically in the research area? Which landscape use tendencies characterize the area, and how do these tendencies affect the availability of renewable energy sources? How has the recent and fast-growing industry affected the land use system? How could landscape architecture improve the use of renewable sources most efficiently?

Firstly, we examine the historical land use characteristics of Kecskemét to identify tendencies and the available renewable resources. Afterwards, the environmental effects of each resource are examined related to the land-use system. To put it into a broader context, we also identify the energy networks and their roles in decarbonisation and self-sufficient energy production. Finally, we present landscape design tools for energy efficiency.

Geographic conditions and land-use systems influence the availability of renewable energy. The research area has a definite potential in solar and wind energy, but both resources are not flexible and controllable. Lack of surface water also limits energy production. Water is not only a renewable energy resource, but also plays a key role in thermal power plants. The study shows that self- sufficiency based on renewable energy has a time and space aspect and existing energy networks play a key role in self-sufficiency. It is also visible that rapid industrial growth causes raises challenges to achieve a balance in energy production. Energy systems of settlement with the same character are more likely to be adaptable on a regional scale.

2. Introduction

The biggest challenge of our time is mitigation of, and adaptation to, climate change, which is necessary to reduce emissions, especially in the field of energy management, as almost 80% of the greenhouse gas emission is relate to energy consumption is directly related to this sector (Eurostat 2020). The transition to new energy sources requires the definition of existing uses, sectors and the amount of energy needed to replace the energy sources currently in use. To be ableto assess the landscape and environmental effects of this, it is worth examining the energy management of a well-defined area, including its development possibilities.

3. Background and Literature Review

Through the example of Kecskemét, we examined potential renewable energy sources of the settlementon an urban scale. The city is the seat of Bács-Kiskun county, the largest settlement in the Danube-Tisza region (Fig. 1.), Its characteristics are not favourable for the development of a settlement: the soil and hydrographic features, its location is not strategically good, and its conditions do not meet protection objectives against military attack. Nevertheless, a settlement with significant agricultural resources was formed with the surrounding settlements, establishing independent settlements in the 1950s (Központi Statisztikai Hivatal n.d.). Although a natural gas field (what is the natural gas field? Needs introduction/explanation here) islocated in the southern part of Kecskemét. There are potential of natural gas reserve near the town that means in the future there is the possibility to extract the energy resource. It has no significant mineral deposits other than three sand mines (Fig. 2.) Its significance has changed by the 21st century (Kecskeméti Városfejlesztő Kft. 2014). The automotive industry plays a significant role in the Hungarian economy, reaching 20% of GDP with small fluctuations (Fig. 3.).

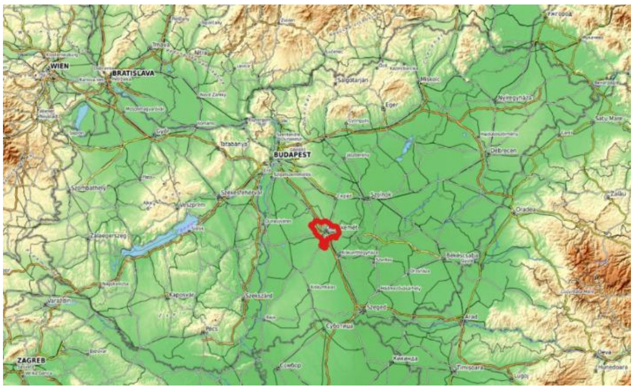

Figure 1. Overview map of Kecskemét in Hungary

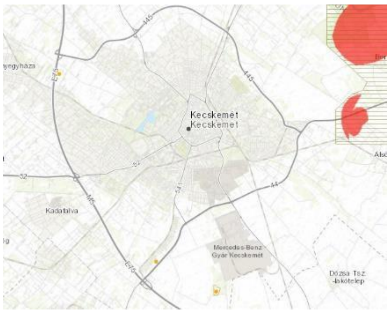

Figure 2. Mineral resources of Kecskemét

('Magyarország Ásványi Nyersanyagai' n.d.)

Figure 3. Share of automotive industry in GDP.
('Hungarian Central Statistical Office' n.d.)

With the advent of industry, the size of the industrial area of Kecskemét has increased significantly, as have residential areas. This is also reflected in the use of energy, which became important as well, as the 400 kV transmission line between Cegléd and Kecskemét became a priority investment by the state to ensure the security of electricity supply (investment by who? For what purpose?) (Korm. rendelet 2017), The question is whether the issue of energy production can besolved at the local level, whether the regional impact can be reduced.

4. Method and Data

In our research, we looked to identify existing renewable energy sources of Kecskemét , whatkind and how much energy can be produced, and on the other hand, we estimated the extent of energy consumption in certain sectors. We compose a new energy mix based on renewable resources available in the settlement and compare with the estimated consumption of the town.

On the one hand, we performed visual analysis using historical maps to show the changes in the energyproduction system over time. Subsequently, calculations were performed to determine the extent of renewable energy production, using several data sourcesto determine the potential of the most renewable energy source as accurately as possible based onthe available data, and then estimating the consumption side (Table 1.) By visual analysis of the maps, we also examined the energy infrastructure of Kecskemét . To summarise the results we collected the characteristics of each renewable resource taking into account environmental and landscape impacts. On the consumption side, we excluded transport, as energy management at themunicipal level can only be partially solved, and electricity consumption in agriculture has been taken into account, as there is no reliable solution yet to replace the internal combustion engines used in the sector (Moreda, Muñoz-García, and Barreiro 2016).

Table 1. Datasets and refrences

Data type	**References**
Energy resources related to weather (sun, wind)	Cattaneo, Bruno. 2018. 'Photovoltaic Geographical Information System (PVGIS)'. Text. EU Science Hub - European Commission. 15 June 2018. https://ec.europa.eu/jrc/en/pvgis.
Slope categories	'EU-DEM — Copernicus Land Monitoring Service'. n.d. Land Section. Copernicus Land Monitoring Service. Accessed 1 June 2021. https://land.copernicus.eu/imagery-in-situ/eu-dem.
Water system	'EU-Hydro - River Network Database — Copernicus Land Monitoring Service'. n.d. Land item. Copernicus Land Monitoring Service. Accessed 1 June 2021. https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-river-network-database.
Biomass	Forestry statistics
Statistical data of population, household, agriculture etc.	'Hungarian Central Statistical Office'. n.d. Accessed 27 March 2022. https://www.ksh.hu/?lang=en.
Energy datasets	'Data & Statistics'. n.d. IEA. Accessed 29 April 2021. https://www.iea.org/data-and-statistics.
Technological data	Scientifical articles, technological descriptions
Spatial data	Agrárminisztérium. 2019. 'Ecosystem Map of Hungary'. Agrárminisztérium. http://web.map.fomi.hu/nosztep_open/.

5. Results

Firstly we examined the historical periods of energy production in the settlement by visually analysing historical maps (Stremke 2013) (Sørensen 2017). On the map sheet of the First Military Survey, which represents the energy system based on wood, charcoal and muscle power (human and animal),a windmill can be identified (Fig. 4.), which disappears in the Second Military Survey with the spread of the steam engine, and the railway network is built (Fig. 5.), shows the economic recoverybased on coal. The military survey conducted in 1941 (Fig. 6.) shows the economy based on electricity, where industrial plants based on this energy were already appearing.

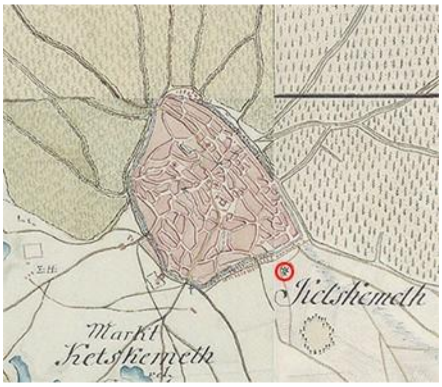

Figure 4. Kecskemét, First Military Survey (‘Magyarország (1782–1785) - Első Katonai Felmérés’ 1782)

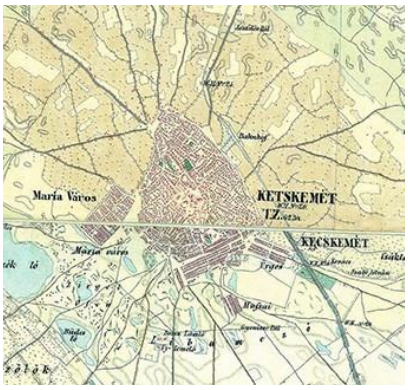

Figure 5. Kecskemét, Second Military Survey (‘Magyar Királyság (1819–1869) - Második katonai felmérés’ 1819)

Figure 6. Kecskemét, Military Survey (‘Magyarország Katonai Felmérése (1941)’ 1941)

First, based on existing data, we exclude two renewable energy sources. The surface water network and topography of the settlement were examined using slope raster analysis with QGIS program (Fig. 7.), for which the slope categories were determined using a surface model (‘EU-DEM — Copernicus LandMonitoring Service’ n.d.) and plotted with the water network (‘EU-Hydro - River Network Database — Copernicus Land Monitoring Service’ n.d.) slope categories, based on which it can be concluded that the area is not suitable for hydropower use. Hydrographic features limit the potential not only for direct power generation but also for thermal power plants, as these power plants, although in many cases highly efficient because of their water consumption and water use (Feeley et al. 2008), are limited applications in the municipality. We also ruled out the possibility of using wind energy, as the average wind speed determined based on the period 2005 and 2020 is 2.67 m / s (Fig. 8.), which does not reach the value of 5-5.5 m / s, which is needed for the efficient useof wind energy.

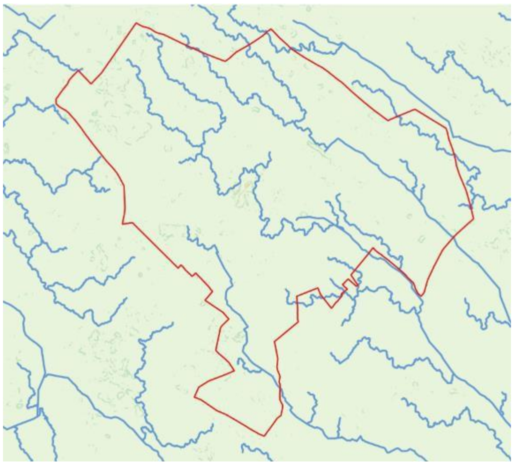

Figure 7. Slope category map with water system

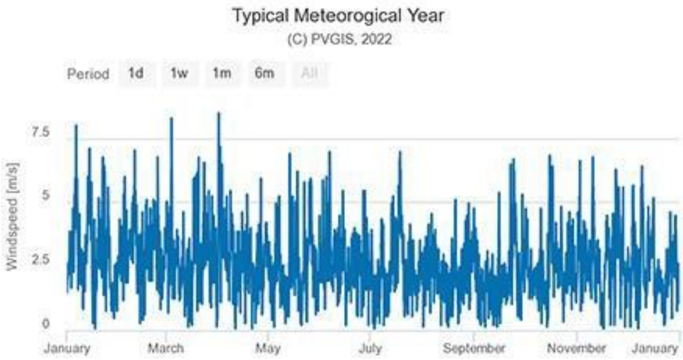

Figure 8. Wind speed in Kecskemét (Cattaneo 2018)

To determine the potential of solar energy and biomass production, we first determined the size of the areas related to energy production using the Ecosystem Map of Hungary and used the analysis of the zonal histogram of the QGIS program on the raster map (Table 2.). In the case of solar energy, the buildings were taken into account, as in this case, it is not necessary to build a new network or to invest in energy in a built-up area. When determining the solar energy potential, we used 30% of the area of the buildings, as the angle of the roof, the shade and the technological conditions can influence the production. According to the measurement data, the electricity produced by a 1 kW solar cell in the settlement is 1240 kWh (Cattaneo 2018), the average efficiency of the solar cells is 18% ('Most Efficient Solar Panels: Solar Panel Efficiency Explained | EnergySage' 2022), in this case the area of 3622080 m^2 can generate 808448256 kWh electricity.

Table 2. Areas of buildings and forests in Ecosystem Map of Hungary

	Area (m2)
Low buildings	10807600
High buildings	1266000
Turkey oak forests	27200
Native poplar dominated forests	10557200
Pioneer forests of hilly and mountainous regions	22400
Pedunculate oak forests, monospecific or mixed with ash	2082000
Forests dominated by other native tree species (without excess water)	227600
Other mixed deciduous forests	548400
Alder forests	22800
Poplar woods outside the floodplain	128000

Conifer-dominated plantations	11869600
Black locust-dominated mixed plantations	22117200
Plantations dominated by non-native poplar and willow species	4639200
Plantations of other non-native tree species	2752400

For biomass production, we considered wood production, the detailed data of which were determined byforestry statistics. We first determined the potential share of energy use, which is 54% based on the annual data for 2010, 2012, 2014 and 2016 (Lett et al. 2018), taking into account that biomass is a conditionally renewable energy source, so we calculated the average annual growth, which is 4 % (Szajkó et al. 2009). Based on this, the amount of usable energy was divided 50-50% for heating and electricity, with an efficiency of 30% in electricity production (Popp József and PotoriNorbert 2011) (Table 3.).

Table 3. Estimated biomass production.

Species	Area (ha)	Annual growh (m3)	Energy use (54%)	Energy (kWh/m3)	Heating (kWh)	Electricity (kWh)
Quercus sp.	210,92	2343	1265	2940	1859831	557949
Hardwood	77,6	600	324	1960	317576	95273
Robinia sp.	2211,72	10328	5577	2940	8198321	2459496
Populus sp.	1519,64	16346	8827	1960	8650148	2595045
Softwood	290,28	1623	876	2100	920201	276060
Pine	1186,96	12477	6738	2240	7546341	2263902
Sum					**27492418**	**8247726**

In the next step, we determined the biogas potential of the settlement from animal manure. For the number of livestock, we used the serial data of the agrarian census of 2020 ('Hungarian Central Statistical Office' n.d.). The annual manure production per animal species was based on literature data (Hartman 2010) (Szendrei 2008). In the case of biogas, we also accounted for 50-50% of heating and electricity production. In the case of biogas, the methane content determines the amount of energy that can be used (Swedish Gas Technology Centre Ltd 2012), we calculated half the amount of manure, taking into account an average methane content of 60%, and average efficiency of 47% for electricity generation (Table5.) (Farooque et al. 2015). Collecting and storing manure is legally regulated, in this case it has a system that can give the basics to involve manure as an energy resurce. We counted only with the 50% of the produce manure. It has 2 basic reason: firstly there is no natural or built energy systems, that 100% efficient (Odum 2007), secondly manure should use in soilmelioration.

Table 3. Estimated biogas production.

Livestock	Size	Manure (pc/t/y)	Manure settlement/year (t)	Biogas m3/t	Biogas (m3)	Biogas heating (kwh)	Biogas electicity (kwh)
cattle	2331,00	8,00	18648,00	225,00	2 097 900	629 370	295 804
pig	3982,00	0,90	3583,80	445,00	797 396	239 219	112 433
sheep	3605,00	0,50	1802,50	225,00	202 781	60 834	28 592
hen	20100,00	0,02	387,93	465,00	90 194	27 058	12 717
goose,turkey	3 200	0	62	480	14 822	4 447	2 090
Sum			**24 484**	**1 840**	**3 203 093**	**960 928**	**451 636**

In the case of waste, we calculated the 10-year average of municipal waste. Based on the average of the period between 2010 and 2019, the amount of municipal waste is 28808.8 t (Kecskemét Megyei Jogú Város Önkormányzata 2019), the value of which is 77783760 kWh, of which 19445940 kWh can be produced, as the incineration efficiency is only 25% (Tempelman, Shercliff, and van Eyben 2014).

Once the production potential was determined, the consumption parameters were next ndetermined. Considering that Kecskemét is a county town with significant industry, so we have doubled the national average in terms of industrial consumption. Table 4 summarizes the consumption and production data of the settlement based on statistical data ('Hungarian Central Statistical Office'n.d.) ('Data & Statistics' n.d.). Additional production is possible in terms of electricity, while themunicipality can only partially cover the heating energy with renewable on-site energy generation. There are several possible solutions for the replacement of fossil fuels: on the one hand, the modernization of buildings (Lucon et al. 2015), the involvement of the surrounding smaller settlements in the energy system,the use of surplus electricity as heating energy, and the utilization of geothermal energy.

Table 4. Estimated consumption and energy balance based on renewable energy

	Residental (kwH)	Industry (kWh)	Commercial and public services (kWh)	Agriculture (kWh)	Non-energy use (kWh)	Sum consumption (kWh)	Sum production (kWh)	Energy balance (kWh)
Total	794300481	1248186470	567357486	0	266117199	**2875961636**	**865046904**	**-2010914732**
Electricity	117028275	355120283	169489226	12106373	0	**653744157**	**836593558**	**182849401**
Heating	677272206	893066187	397868260	12106373	266117199	**2246430225**	**28453346**	**-2217976879**

Surveying existing energy networks is an important part of energy management, as the integration of renewable energy sources at the system level can eliminate design difficulties arising from production. The settlement features are shown on the utility map. It is characteristic of the whole settlement that both the electricity network and the natural gas network are built almost in the whole settlement, only in some discontinuous residential areas the natural gas network is missing. In the centre of the settlement, the district heating network has been partially developed, which also affects the residential areas and the services (Fig.9., 10., 11., 12.). In the regional analysis of the settlement it can be clearly stated that there are no large power plants near the settlement, the Albertirsa substation is the most significant source of energy in terms of electricity supply, to which several high-capacity power plants are connected (Fig 13.).

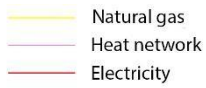

Figure 9. Energy network of centre of Kecskemét ('E-Közmű Lakossági Térkép' n.d.)

Figure 10. Energy network of industrial units of Kecskemét ('E-Közmű Lakossági Térkép' n.d.)

Figure 11. Energy network of continuous residential area of Kecskemét ('E-Közmű Lakossági Térkép' n.d.)

Figure 12. Energy network of discontinuous residential area of Kecskemét ('E-Közmű Lakossági Térkép' n.d.)

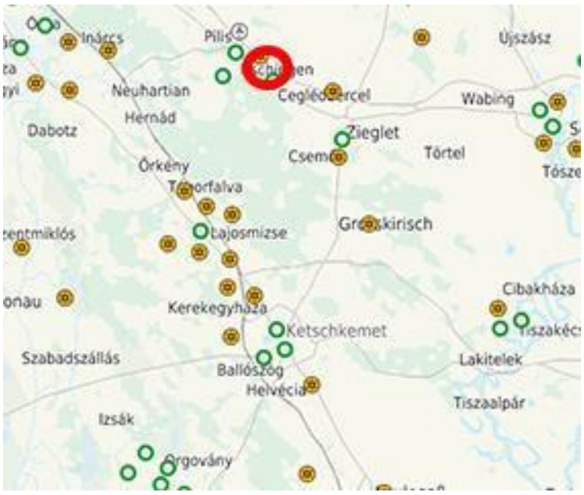

Figure 13. Energy network in regional scale include Kecskemét (123map GmbH & Co.KG n.d.)

It is important to emphasize that with the emergence of renewable energy sources, complex environmental and landscape changes are taking place. The extent of the changes depends on the use of the existing infrastructure and the scale of the applied energy solutions, the conditions of the place. Table 5 summarizes the most important characteristics of renewable energy sources thatcan be used in Kecskemét, which determine the changes. The production and consumption of any energy resources cause complex impacts on the natural and built environment. To decrease the visual impacts of solar energy, in this case, we only count on the roofs of the buildings, which is a small scale impact. Using biomass has a complex environmental effect with ecological disturbance (EASAC 2018), In the long term, biomass should be changed with another energy resource with a lower environmental impact. Biogas production is increasing in the European Union (Farooque et al. 2015). A former study showed that the general environmental conditions improve using biogas, even if it is an industrial development (Börjesson and Berglund 2007). Using waste as an energy resource fits the European Union circular economy plan (European Commission 2015). However, it is an industrial development with complex environmental impacts.

Table 5. Summary table of renewable energy sources

	Type	Production	Network	Scale	Environmental and Landscape effects
Sun	renewable	non-controllable, predictable	fit in	small scale	low-impact, fit into the existing built-up area
Biomass	conditionally renewable	controllable	new power plant	multi scale	air pollution, complex environmental effect related to power plant
Biogas	conditionally renewable	controllable	new power plant	multi scale	air pollution, complex environmental effect related to power plant
Waste	conditionally renewable	controllable	new power plant	from settlement scale	air pollution, complex environmental effectrelated to power plant, high social resistance

6. Discussion and Conclusion

The city of Kecskemét can count on increasing energy consumption due to the recent explosive industrialdevelopment. To be responsible, energy needs must be met increasingly with renewable energy sources to reduce emissions of greenhouse gas. Thisrequires the utilization of the renewable energy resources of the settlement to the maximum extent, increasing energy efficiency, and involving new energy sources in the energy system, preferably involving the surrounding settlements with lower energy requirements. The complex environmental and landscape impacts of switching to renewable energy sources can be reduced byscouring and scaling up the right production sites and making efficient use of existing infrastructure. The direction of the energy system development will be determined by the emphasisof the EU Green New Deal ('Európai zöld megállapodás' n.d.) program in local levels in Hungary.

Decreasing the adverse environmental effects, the scale of the renewable energy systems plays a key role. As an example is essential to mention that we only count on solar energy applicable on roofs. As it is a small-scale industrial development, it also fits into the existing electricity network. Biogas and biomass are also suitable for small scale. However, biomass should not be a long-term solution because of the tremendous environmental impacts during energy production and in biomass production. Using waste as energy resources has high social resistance, even though it is fit the concept of circular economy, and with the newest technology, pollution is also acceptable. Therefore, energy systems based on renewable energy resources should be based on more resources with different characteristics. In conclusion, we can state potential energy resources applicable to the existing system. The main issue is to find out how to replace natural gas as a heat energy resource, which has very high consumption in the current energy mix.

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