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ÉLETTUDOMÁNYI EGYETEM

OPTIMIZATION OF THE ANTHROPOGENIC ENERGY SYSTEM FOR LANDSCAPE PLANNING: CASE STUDIES AT SETTLEMENT AND MICRO-REGIONAL SCALE

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To Mom and Dad

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1. INTRODUCTION

Energy carriers, energy management, renewable energy sources, nuclear energy, coal, and natural gas are concepts frequently used in scientific life and the news daily. In connection with the Russian-Ukrainian war, the issue of energy supply and energy security became a priority. In contrast, nearly 80% of greenhouse gas emissions are related to energy production and consumption, which is closely related to human-caused climate change. The transformation of the energy system can affect not only our present but also our future for centuries.

The first mention of sustainability is in the Burndtland Report 1987 (World Commission on Environment and Development 1987). Twenty years later, the Stern report drew attention to the economic costs of climate change (Stern 2007). We are in 2023, 16 years have passed again, and the trend of greenhouse gas emissions still shows an increase (IEA n.d.), primarily due to energy use.

While for thousands of years, humankind's energy use was primarily based on animal and human muscle power, as well as wood and wood, in the last 250 years, with the spread of the steam engine, the energy system entered new dimensions (Sørensen 2017). With technological development, the environmental effects we only recognized 200 years later, completely new dimensions have opened. Now we must reverse these processes and reduce their effects.

In connection with landscape architecture planning, be it green area planning, urban planning, or reservoir planning. Two concepts are usually mentioned mainly about climate change: adaptation and mitigation. This narrows the action possibilities of our field of science in the fight against climate change. It is very important to adapt to the changed circumstances, but even more important is to stop the process that caused the change.

In my doctoral dissertation, I am looking for the answer to what role landscape architecture, as an applied discipline, can play in increasing energy management efficiency and reducing greenhouse gas use within the energy system. What new design tools should be incorporated into the different design scales? What new practical solutions should be used?

As landscape architects, we must consider the "well-being" of nature and people; we must ensure a healthy environment for all the plants around us: and the animal world, both for humans. There is no question that energy management plays an essential role in this: we are fighting climate change on a global level, but proper energy management can also contribute to improving the quality of the environment at the local and regional levels. Using a very plastic example, eliminating coal power plants can reduce the amount of greenhouse gases entering the air. No new landscape scars typical of coal mining will appear, and local dust pollution from coal burning will also decrease. Landscape architecture also plays a vital role in creating the aftermath of liquidation.

The example of a single energy source clearly illustrates how much a landscape architect has to do in the transformation of the energy system: ensuring a healthy environment and eliminating landscape wounds, but this also includes rural development since energy production typically means prosperity for an area, in the event of its cessation, new functions are needed to give to landscape elements. In my research, I provide a comprehensive answer to these questions.

1.1. Objectives

Energy permeates our lives: without electricity, we could not use computers or mobile phones, but we could still work by candlelight in the evenings. A simple example that clearly shows that the energy system is changing. In English, the term 'energy transition' is used for the current change. This is the starting point of my research, with the help of which I unfold the different layers of the concept from the perspective of landscape architecture.

In the chapter, I formulate my objectives, which can be divided into two parts: in the research, I examine the theoretical background of the topic, and I formulate research questions related to the expression of the energy transition and based on these hypotheses; on the other hand, I formulate the other group of hypotheses with the help of questions that analyse the relationship between planning practice and energy transition. These other problems also raise issues of applicability in practice.

1) Research questions related to the concept of 'energy transition'
    a) Research question:
        i) How can we define the concept in landscape architecture?
        ii) Can the concept be fully identified with decarbonisation?
        iii) Is the definition suitable for use in landscape architecture?
    b) Today, the term 'energy transition' refers to decarbonisation. The term 'transition' includes change. With a historical study, and on the other, and an examination of 'energy' as a phenomenon, it can be revealed whether the concept can be narrowly identified with decarbonisation.

H1: The definition defining the spatial and temporal changes of the energy system includes changes in energy production and consumption in an environmental, economic, social and cultural sense; this can be interpreted in the context of landscape architecture.

H2: The energy transition reinterprets some tools and frameworks of landscape architecture, and new tasks and tools are integrated into the planning processes.

2) Research questions related to practical application:
    a) Research questions:
        i) Can the design of the energy system be integrated into the practice of landscape architecture?
        ii) Can energy planning be integrated into all scales?
        iii) If it can be incorporated, what similarities and differences do the different planning levels show?
    b) The issue can be examined through case studies: it is possible to demonstrate how energy management and landscape planning can be integrated through different scales.

H3: The planning of the energy system can be incorporated into the practice of landscape planning and territorial planning.

H4: Renewable energy sources and their landscape and environmental effects are directly related, thus influencing the energy potential.

H5: The physical characteristics of renewable energy sources can be interpreted on a landscape scale; they must be considered when planning the energy system.

1.2. Structure of the dissertation

In my doctoral dissertation, I formulated the objectives for the first time; based on this, I interpreted the literature related to the topic in the natural sciences, economics and social sciences within the framework of landscape architecture; the research and tools related to the energy system of landscape architecture; the legal framework. Based on this, I define the tasks related to the energy transition of landscape architecture. After that, I defined the doctoral research framework and the sample areas. I developed the research methodology and determined the research material. After presenting the results, I concluded them.

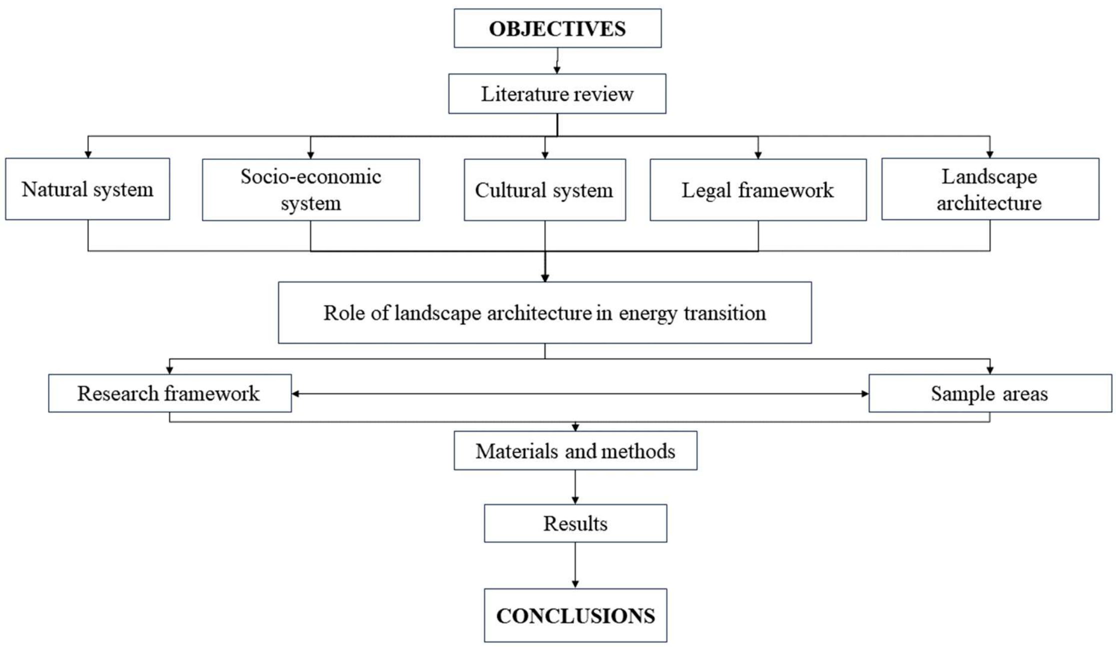


Figure 1. Structure of the dissertation.

2. LITERATURE REVIEW

The literature review lays the foundation for exploring the relationship between energy and the landscape and what landscape architecture as a discipline can investigate in this area. To describe the landscape aspects of the energy system, I start with the concept of landscape. Many people have described the concept of landscape in many ways since the research aims to approach the spatial and temporal changes of energy from a practical point of view and to develop methods that can be used in landscape architecture and spatial planning, with which the system of energy production and consumption can be interpreted spatially. The concept of the landscape described in the European Landscape Convention (LIX. törvény 2018) means the natural or cultural landscape described by man. This interpretation also appears in other disciplines, such as landscape archaeology (Ingold 1993). However, the landscape can also be approached from the point of view of human perception, the landscape can be defined by the feelings and interactions it evokes, but it can also be described objectively with data (Christophe Girot, Imhof 2017). In both cases, the landscape is approached from a human perspective, and although the definitions or questions are simple, the complexity of the concept of landscape is still included.

From the perspective of research, we must approach the relationship between energy and landscape from three sides: nature and the environment, society and economy, and culture. All three aspects are included in Mihály Mőcsényi's definition of the landscape from the point of view of landscape planning. "Landscape is nothing but the contradictory and, therefore, dialectical unity of the interactions between nature and society. The landscape is the material living condition of society, and it is the carrier of high-order visual-aesthetic qualities. Therefore, the history of the interactions between man and nature materialized – manifested in the material world shaped by man. The landscape is an anthropoid-socio-centric concept. Nature and society are a pair of opposites that mutually permeate each other and form an indissoluble unity. In other words, the landscape is a humanized nature, a human environment transformed from the biosphere into the noosphere by social needs." (Mőcsényi 1968) The concept of energy must be approached from several points of view. To place it in the context of the landscape, it is necessary to examine what role it plays in the system of environmental elements, what role it plays in economic and social processes, and what kind of interaction it has with cultural systems.

Several fields of science examine the system of energy production and consumption according to different aspects. The matrix presented in Figure 1 illustrates that energy-related research affects both the social and natural sciences. The individual fields of science are connected and overlap each other. (Lutzenhiser 1992). The system of disciplines affects all three issues (environmental, social, economic, and cultural systems), which I have marked as the starting point of the research based on the concept of landscape. Since the fields of science are directly or indirectly related to each other, landscape architecture, due to its particularity emphasized above, may be able to integrate the results of basic research into practice. Although landscape architecture is not included here, the built environment and engineering sciences are, of which landscape architecture is also a part. The figure also represents the diversity of the topic and the passage between disciplines, so both during the literature review and during research, the knowledge of several disciplines must be incorporated, and the connections between them must be explored.

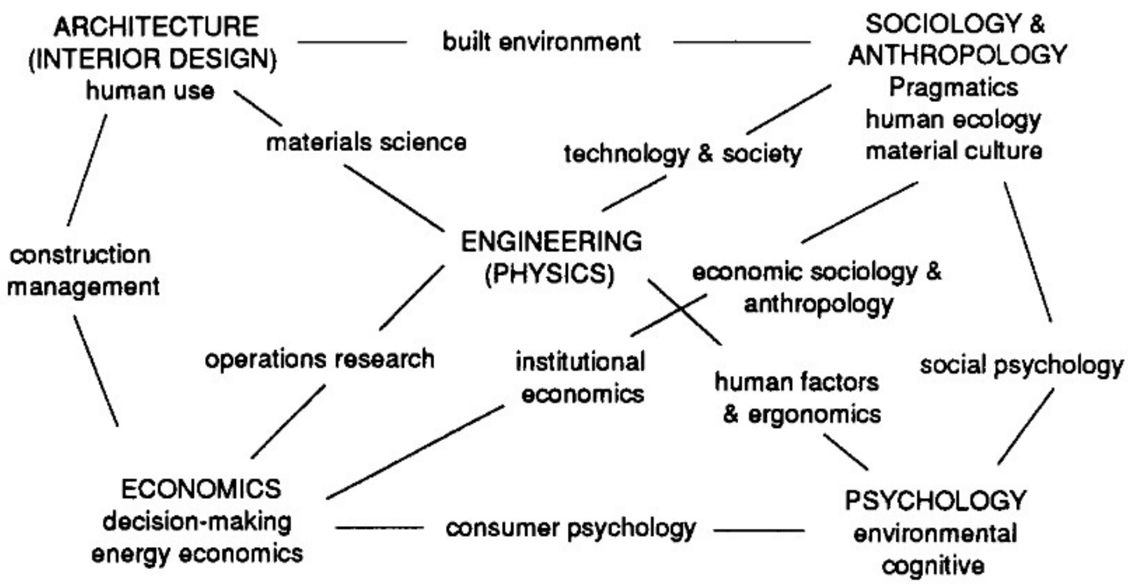


Figure 2. Disciplinary specialties and concepts relevant to the study of human/environment and human/technology relations.(Lutzenhiser 1992)

2.1. Basic concepts

To understand the relationship between landscape and energy, I first clarify the concepts of energy and energy source. Based on the first occurrence in 1545 Oxford English Dictionary interprets the concept of energy as follows: "As a general concept: power, strength, force; the ability or capacity to produce an effect" (‘energy, n. meanings, etymology and more | Oxford English Dictionary’ n.d.) The word was used in a scientific sense for the first time in 1805; its meaning is as follows: “The potential or capacity of a body or system to do work by virtue of its motion, position, chemical structure, etc., frequently regarded as a quantifiable attribute or property which can be acquired, transferred, and expended.” (‘energy, n. meanings, etymology and more | Oxford English Dictionary’ n.d.) The primary meaning is related to physics as natural science. The word of Latin origin is a Greek adaptation, its original meaning is transferred ('functioning, activity, effectiveness'), (Benkő 1984). British polymath Thomas Young was the first in scientific life to use the word energy in a physical sense, but the term spread slowly (Smith 1998). Energy became part of natural science research in the 19th century.

The term energy source can also be related to physics: "A body or equipment that produces, supplies, or a substance in which bound, usable energies are stored." and" In energy sources, the energy that cannot be used directly is transformed into useful energy." (Juhász et al. 1999) The spatially and temporally important features appear here: production, service, storage, and transformation. These expressions relate to change, transformation and conversion: the energy source can change in space and time.

Finally, I examined what the term 'energy transition' means, often used today for transforming the energy system and as a synonym for decarbonization. The energy system has undergone several transformations both in space and time, from the local to the global level, regarding the origin of energy, energy processes and performance (Smil 2010). These changes can be called structural changes in the energy economy, which is currently in decarbonization.

Landscape architecture can influence structural changes in the energy transition with landscape design tools. However, to understand the processes, knowledge related to energy, natural sciences, socio-economics, and the cultural system is necessary. In this, the energy source, matter; energy is the physical process, while structural changes mean environmental, social, economic, and cultural processes taking place in space and time. The relationship between the basic concepts is shown in the third diagram. Inside is the energy source, outside is the energy that uses the energy source during a process involving some energy change, and the outer circle is the energy transition, which examines these processes in space and time.

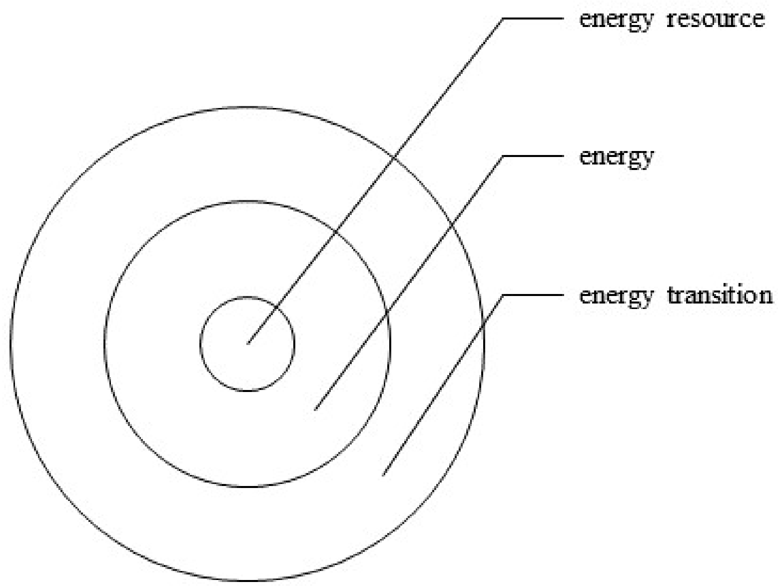


Figure 3. Relation between energy resource, energy, and energy transition.

2.2. Energy and natural system

I previously clarified that the terms energy and energy source is related to the science of physics. In this chapter, I review the characteristics that play an essential role in the changes on a landscape scale. First, I will present the areas of physics related to energy since this knowledge also determines its fundamental role in environmental systems. Then, I focus on physical phenomena, definitions, and laws, especially those that can be adapted to the landscape.

The science of motion, known as kinematics, is the basis of energy-related laws. Motion is interpreted by physics in one dimension: time and space. Energy can be linked to movement in the physical sense since energy is needed for every change in position (Serway, Jewett 2013). This change in position can occur between 2 objects (Fig. 4. a., b., c.) or in a vacuum (Fig. 4. d., e., f.). These basic physical phenomena are also decisive from a landscape point of view. For example, the use of muscle power can be linked to human activity, gravity is responsible for the rotation of the Earth around the Sun or the tidal phenomenon, the Earth itself is a magnetic field, and electricity is a fundamental part of our lives today.

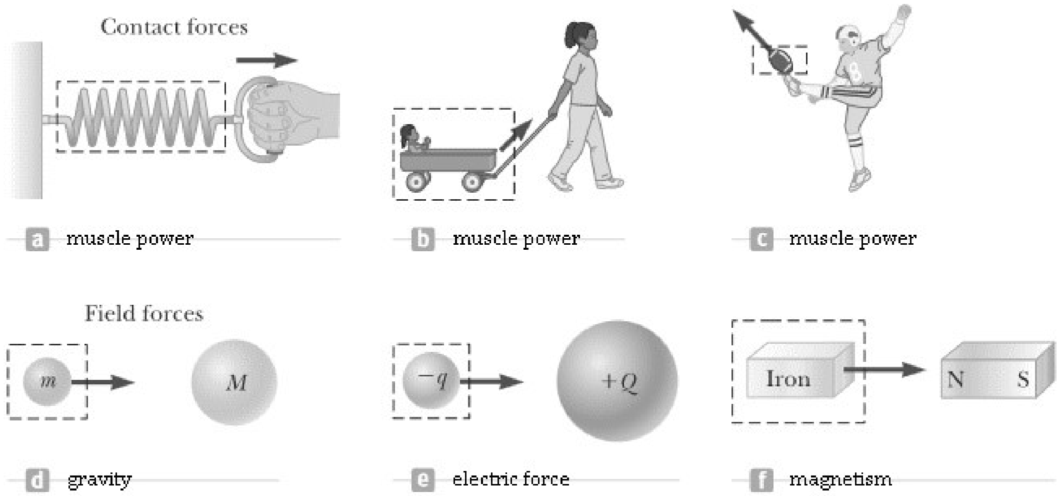


Figure 4. Some examples of forces applied to various objects. (Serway, Jewett 2013)

Newton laid the mechanics foundations, for which he described the relationships between motion and force in three laws. These laws describing classical mechanics influence the environment and the landscape. According to Newton's first law, the velocity of a body is constant as long as no force acts on it. (Fig. 5) According to Newton's second law, the acceleration of a body is directly proportional to the force acting on it and inversely proportional to the body's mass. (Fig. 6) According to the third law, when two bodies interact, the magnitude of the forces acting on the bodies are always equal, and their direction is opposite. (Fig. 7). (Walker et al. 2018)

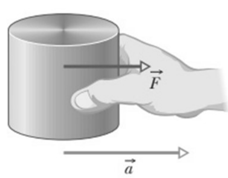


Figure 5. Newton's first law (Walker et al. 2018)

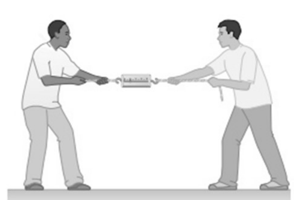


Figure 6. Newton's second law (Serway, Jewett 2013)

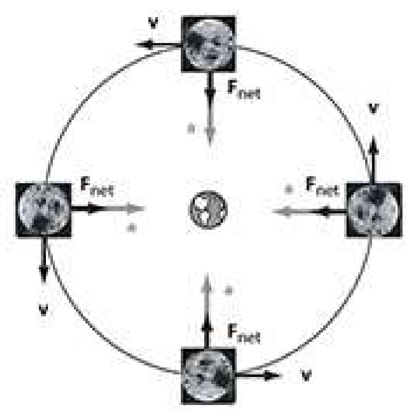


Figure 7. Newton's third law (Zimba 2009)

Energy is also examined at the level of the physics system, which already lays the foundation for the application in environmental science. For energy analysis in physics, the system must first be described to determine the physical characteristics. The system can be characterized as follows:

- the system can be an object or a particle,
- the system can consist of several objects and particles,

– the system can be a delimited part of space,
– it can change in form and shape in its time dimension.

The system's kinetic energy is the sum of the kinetic energy of all the system's constituent elements. The energy of all objects in the system appears as kinetic and potential energy (Serway, Jewett 2013). From a landscape point of view, the term potential energy better expresses the characteristic that this energy is stored in an object of the system. One step from this is the law of conservation of energy, which states that the energy of an isolated system is constant and can be transformed from one form to another but cannot be created or destroyed. (Walker et al. 2018) The everyday examples shown in Figure 8. shows how energy is transformed from one form to another.

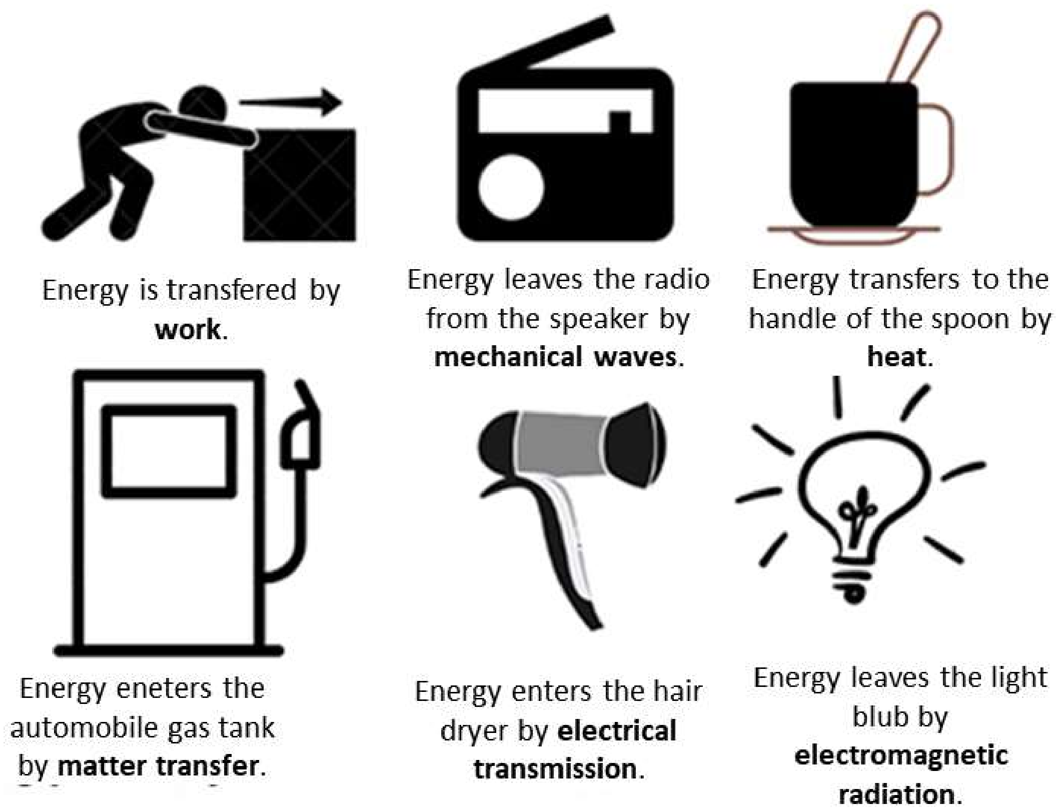


Figure 8. Energy transfer mechanisms. (Serway, Jewett 2013)

After describing the concepts of work and mechanical energy, moving further into the field of physics, I will also examine other relationships of the energy system. James Joule laid the foundations of thermodynamics by summarizing the relationships between heat and work (Serway, Jewett 2013). Four laws of thermodynamics describe the relationship between work and heat. The zeroth theorem can be stated as the equilibrium state is established after a time in a thermodynamic system left alone. The first law of thermodynamics is the law of conservation of energy. Thermodynamic internal energy increases as its temperature increases, and internal energy decreases as work is done. The second theorem dictates the direction of the processes in the thermodynamic system: a closed system heats up only as a result of external work. Or in other words, if a body loses heat, it is not transformed into work. With the introduction of the concept of entropy, this theorem means that the entropy of the thermodynamic system continuously increases during spontaneous processes occurring in nature. (Walker et al. 2018). Related to this is the concept of exergy, which means the maximum useful work that can be achieved from a given system in a specific environment. The thermal conductivity described by Fourier can also be linked to this law, which means that the thermal conductivity of different materials is different. The thermal conductivity is determined by the vibration of molecules and the energy transport of freely moving electrons (Çengel, Boles 2015). A Thermal conductivity is important in the use of materials in architecture (Table 1). These characteristics are also regulated by decree when determining the energetic characteristics of buildings (7/2006. (V. 24.) TNM rendelet az épületek energetikai jellemzőinek meghatározásáról n.d.), and the various thermal properties of materials according to the standard (MSZ-04-140-2/ 1991). According to the third theorem, the entropy of a perfectly crystalline substance is zero at a temperature of absolute zero degrees, but this state cannot be reached. In both mechanics and thermodynamics, entropy represents the degree of disorder (Walker et al. 2018). These characteristics play an essential role in the use of landscape architecture materials.

Material	**Heat conduction coefficient λ (J/(m$\times K \times s$))**
aluminium	221
zinc	120
silver	429
chromium	94
coal	140
iron	80
polystyrene foam between two masonry layers	0,1
polystyrene foam, which is plastered or concreted on	0,42
reinforced concrete	0,29
concrete	0,31
brick	0,52; 0,39; 0,22
cement plaster	0,61

Table 1. Examples of thermal conductivity of materials. (Hack Frigyes et al. 2017) (MSZ-04-140-2/ 1991)

Energy surrounds us in the universe, both in material form and in energy change. From the examples above, our daily life is determined by energy, and every day we encounter phenomena such as force or acceleration, or perhaps electricity. However, energy is a much more complicated concept even in physics, as can be seen above (Serway, Jewett 2013). I highlight a few important features that define landscape-scale analysis:

- energy is process-oriented, the process must be examined;
- the boundaries of the examined system and the objects in it must be defined.
- and the direction of the processes must be determined.

2.3. Energy in the perspective of environmental elements and systems

Moving on from the field of physical science, I examine the role played by energy in environmental sciences. I will cover the built environment in a separate subsection. The environment is a multidimensional system (Cunningham, Cunningham 2020) (Calow 1998), which determines energy sources and the role of energy. In the technical literature, the environmental system is rarely depicted schematically. Figure 9 shows some examples of the most important subsystems of the environmental system and the impact of humans on them. In these very complicated, often overlapping systems, the source of energy and the location of the energy must be determined.

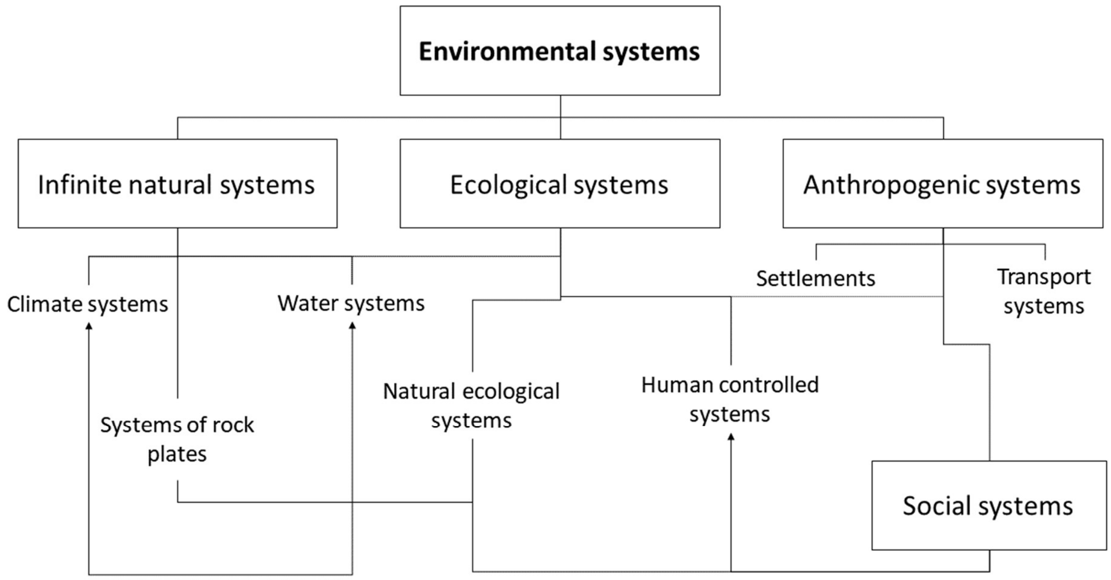


Figure 9. Main groups of environmental systems and their subsystems based on Kerényi (Kerényi et al. 2013)

Environmental elements can be grouped according to several criteria. First, the abiotic factors should be mentioned, which are the physical environment, including temperature, soil and light. Biotic factors include living organisms: they can be single-celled, plants, or mammals (Calow 1998). Table 2 shows some examples of what kind of resources each abiotic or biotic factor can carry, what kind of natural energy change processes take place for these, and how people can use them with different technological processes. It can be seen from the few selected examples that several energy change processes can be connected to the resources inherent in each factor, and these must be determined in the landscape system.

biotic or abiotic factor	resources	energy
light	solar energy	photosynthesis, electricity
wind	air movement	wind erosion, electricity, motion
oil	potenciális energia	fuel, electricity, heating
mammals	muscle power	movement, work

Table 2. Examples of environmental elements and their appearance as energy in nature.

Physics typically examines energy in an isolated system: it determines the system's boundaries, the elements in the system, and the energy changes between them. The environment is a much more complicated and complex system than that. First, it is worth defining the basic properties of the system, the elements, and the basic processes taking place in it. Defining these not only helps energy-related planning, but the application of system theory in landscape planning also provides practical application possibilities for problem-oriented planning, which can respond more effectively to new knowledge and solve new problems in the discipline of landscape architecture (Hedfors, Murphy 2011).

The literature distinguishes three system types: open, closed, and isolated (Table 3). Systems can be characterized by two basic properties: energy change and the metabolic process. So, every system that occurs in nature can be characterized by energy change as a process. In isolated systems, which physics as a science examines, there is neither energy change nor material exchange only within the system. An isolated system does not occur in nature, but the universe can be considered an isolated system. A closed system rarely occurs in nature, but it is typical of some large systems, such as the carbon, nitrogen, or hydrological cycles. Finally, naturally occurring systems are open systems, such as ecosystems, a forest, aquatic or even urban ecosystems (Rutherford, Williams 2015).

System	Energy exchange	Matter exchange	Example
Opened	yes	yes	ecosystems (e.g., forest, water)
Closed	yes	no	hydrological, nitrogen and carbon cycle
Isolated	no	no	univers

Table 3. Natural systems and their exchange of energy and matter. (Rutherford, Williams 2015)

Starting from Mőcsényi's definition of landscape (Mőcsényi 1968) we transform open and closed systems occurring in nature and the environment during landscape planning. It follows that during the planning process, we influence metabolic processes and energy changes in the case of open systems; in the case of closed systems, the energy change. Through landscape planning and design, the energy balance of the planning area is transformed, and the characteristics of the given system determine the qualitative and quantitative characteristics of its change.

In the previous chapter, I reviewed the fundamental physical laws related to energy. However, unlike physical phenomena, the landscape and the environment are not isolated systems, so the phenomena are more complicated than physically isolated systems, and the processes are also partially different. To illustrate the complicated processes in the landscape, I chose the sun as an energy source. The Sun, as a celestial body, plays a decisive role in the physical processes taking place on Earth (Serway, Jewett 2013), consequently in the development and processes of meteorological phenomena (Bartholy et al. 2013), and the fundamental processes of ecosystems, such as photosynthesis (Rutherford, Williams 2015). Figure 9 shows that the Earth encounters the high exergy of the sun, which decreases and loses its energy potential during various processes, and its entropy increases along with it. Energy affects the entire environment around us: be it natural or built. Approximately 30% of the sun's rays are reflected, 50% is converted into heat, most of the remaining energy enters the hydrological cycle - (participates in the rain, evaporation, and air movement -), and less than 1% is used during photosynthesis (Rutherford, Williams 2015).

What processes take place in nature for solar energy, and how do we use the energy of materials formed under the sun's influence? Figure 10. shows how materials are transformed using solar energy and to what extent the exergy of the energy emitted by the sun decreases during the transformation. Green plants live with the help of photosynthesis, which partly produces wood. Fossil energy carriers are created from decomposing organic materials over millions of years. We use them for mining in power plants for electricity, which we use for electrical appliances.

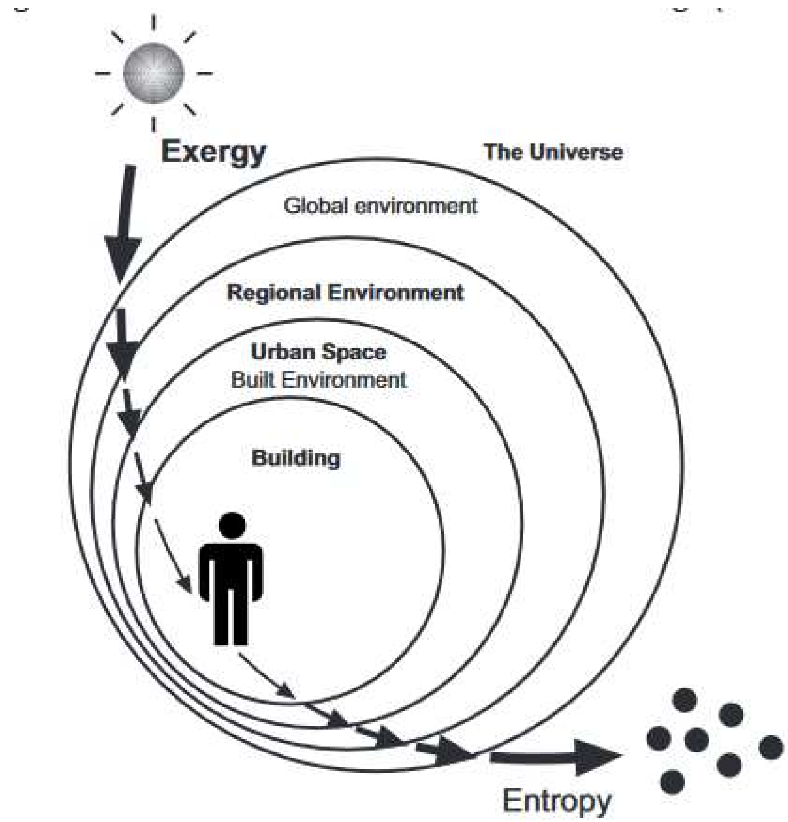


Figure 10. Conceptual illustration of global energy flows. Solar exergy enters the atmosphere and is gradually turned into entropy (Shukuya 2013)

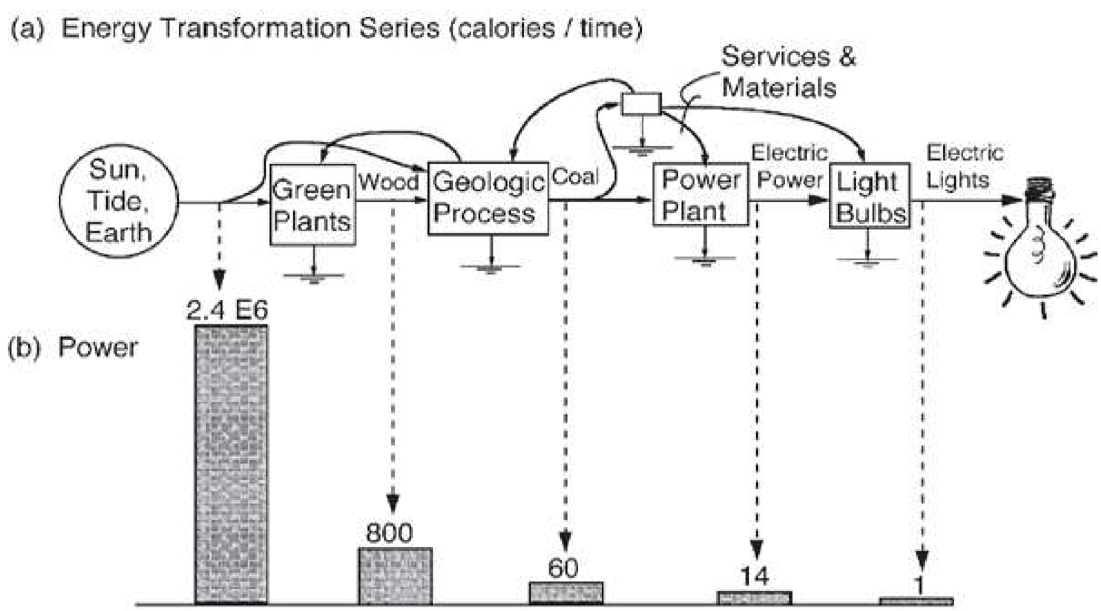


Figure 11. Solar energy transformation. (Odum 2007)

Analysing the process shown in Figure 10 and 11, the rate of utilization of solar energy entering the atmosphere continuously decreases. What happens to this amount of energy? Figure 12 shows how much the exergy of the material decreases during the transformation through two processes.

In a coal-fired power plant, 35% of the useful energy in the coal is converted into electricity. The human body can use 10% of the energy in food. In both cases, a more significant proportion of useful energy is not used. The law of energy conservation described in physics also applies in the natural and built environment, with the restriction that the usefulness (exergy) of the number of energy decreases. Likewise, the law of conservation of matter applies in environmental systems (Boersema et al. 2010).

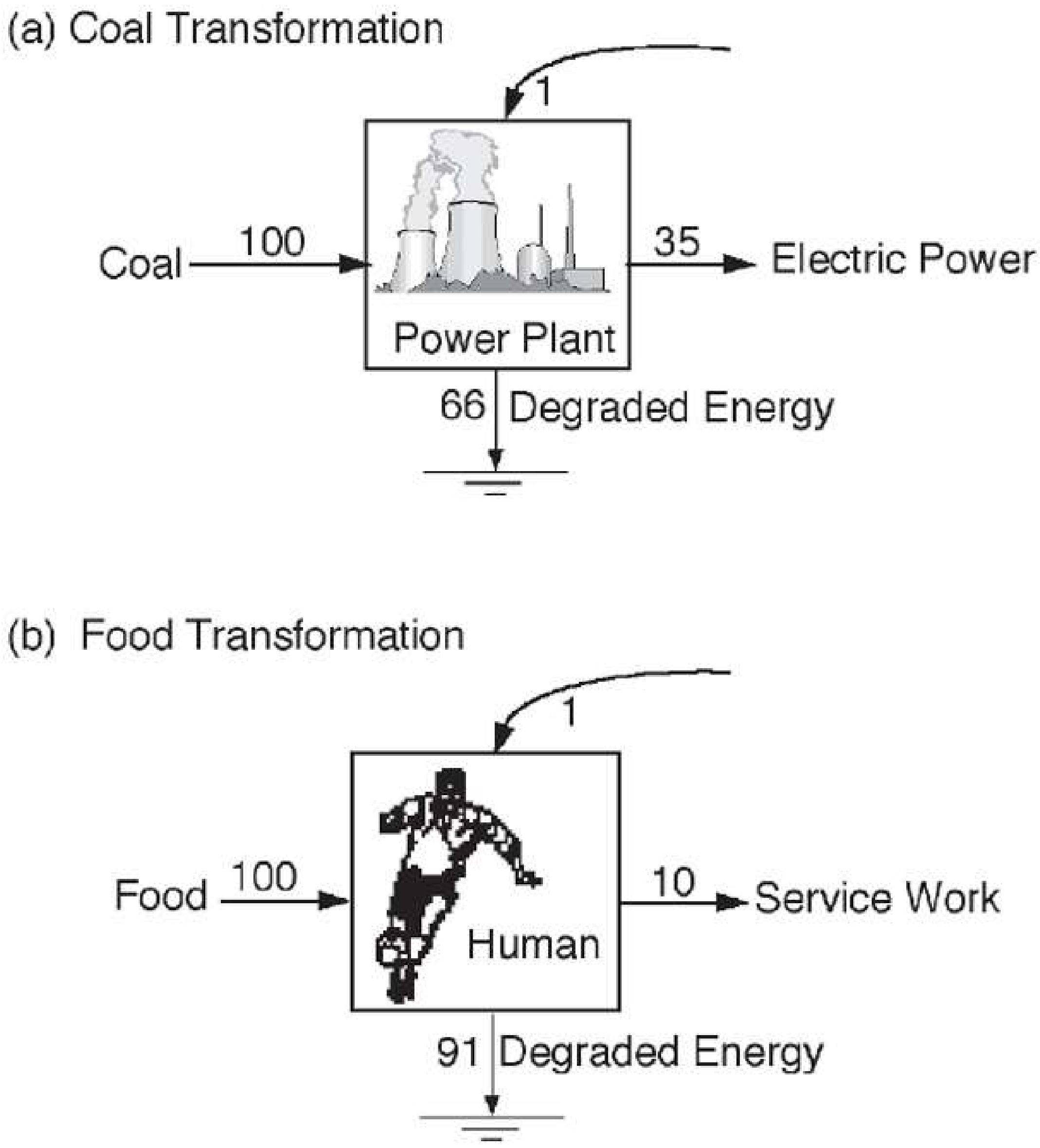


Figure 12. Energy transformation and degraded energy.(Odum 2007)

I have previously stated that exergy decreases during processes while entropy increases. However, the loss of useful energy during each process is not the same: during different processes, the value of unused energy in the energy conversion process is different. Its value is described as a function of the energy gradient, some examples of which are presented in Table 4. In the case of efficiency during energy use, it is also necessary to consider how the value of exergy changes for each process. When planning the energy budget, which is influenced by many different factors and consists of many subsystems built up by a complex system of connections, the exergy value can emphasize the efficiency of a process (Dinçer, Rosen 2013).

Energy carrier	Energy grade function (R)
Electricity	1
Natural gas	0,913
Steam (100 ºC)	0,1385
Hot water (66 ºC)	0,00921
Hot air (66 ºC)	0,00596

Table 4. Values of energy grade function for various energy sources and carriers. Temperature of the reference environment is T_o= 30 ºC. (Dinçer, Rosen 2013)

In summary, we can state that the laws of physics can be interpreted in environmental systems by considering the system's characteristics. Therefore, based on the definition of the landscape, the landscape must be interpreted in terms of environmental systems, and the following aspects related to energy must be considered in the relationship between landscape and energy:

- We can describe and analyse the landscape with open or closed systems since energy changes are characteristic of both systems, so this aspect must be considered in every analysis.
- Closed systems (carbon cycle, nitrogen cycle, water cycle) appear in all landscape units at any scale.
- In each planning unit, several systems must be defined and analysed from the point of view of energy.
- During planning, the exergy and entropy of the landscape unit must be considered when planning the energy-describing processes. As a principle, the exergy of the planning area should decrease as little as possible during the process of energy transformations.
-

2.3.1. Environmental impacts of energy systems

The influence of humans in energy transition processes must be highlighted since our built environment must be interpreted in the energy production and consumption system. From an environmental point of view, as shown in Figure 8, human activity also affects the natural and built elements and systems around us. In the chapter, I review the environmental impacts of energy production and consumption.

In physics and environmental sciences, energy is interpreted as a process in a system, so in this chapter, I also systematize the use of energy related to the built environment. Although, nowadays, it is accepted that the effects of human activities related to energy production and consumption are global. Hence, life cycle analysis serves as a tool for exploring environmental impacts (Dr Tamaska et al. 2001) Therefore, I define the effects of human activities related to the energy system from "cradle to cradle".

The standard definition of life cycle analysis is as follows: "The collection and assessment of inputs, outputs and potential environmental impacts of a product's impact system throughout its entire life cycle."(MSZ ISO 14040 1997). In the research, the landscape provides the framework for the analysis since, according to the definition, it examines a product; therefore, in this case, the following characteristics related to the subsystems must be determined in order to reveal the environmental effects during the analysis:

1. purpose of energy consumption,
2. the energy source,
3. processes of energy change during use,
4. the landscape elements required for each use.

When determining the primary energy consumption goals, statistical data should be considered so that the data can be compared in time and space, and trends can emerge. For this, it is necessary to review three data sources:

1. International Energy Agency (IEA n.d.)
2. Eurostat databases ('Database - Energy - Eurostat' n.d.)
3. Hungarian Central Statistical Office ('Központi Statisztikai Hivatal' n.d.)

Based on the overview of the databases, I determined the sectors of energy use, the form of energy use in the case of each sector, the energy sources connected to them and the objects appearing in the landscape. These are summarized in Table 5. When compiling the table, I took into account the energy used during agricultural and industrial processes (Szendrő Péter, Czupi Imre 2003), and the different forms of transport (United Nations Human Settlements Programme 2013) and the energy consumption of households (Vajda 2014). In this case, the forms of transport do not include pipelines or the electrical network, as these are objects that enable transport that enables energy use. I singled out street lighting because it is a significant consumer, but it cannot be classified in the other categories.

Sector	**Form of consumption**	**Energy resource**	**Object**
Industry	heat supply	fossil/nuclear/renewable	mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery, roads, gas station
	propellants	fossil/nuclear/renewable	
	electricity	fossil/nuclear/renewable	
Agriculture	heat supply	fossil/nuclear/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery, roads, gas station
	propellants	fossil/nuclear/renewable	
	electricity	fossil/nuclear/renewable	
Transport	animal/human driven vehicle	agricultural products (animal/vegetable)	arable land, grassland, agricultural land, food processing plant,
	public road	fossil/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery, roads, gas station

	Form of consumption	Energy resource	Object
	railway	fossil/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery, roads, gas station
Transport	water transport	fossil/renewable	oil well, pipeline, power line, power plant, oil refinery, roads, gas station
	air/space transport	fossil/renewable	oil well, pipeline, power line, power plant, oil refinery, roads
	heating/cooking	fossil/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant,
Household	electric appliances	fossil/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery
	electricity	fossil/nuclear/renewable	
Public lightning	electricity	fossil/nuclear/renewable	forest, agricultural land, mine, natural gas well, oil well, pipeline, power line, power plant, oil refinery

Table 5. Sectors of energy use, forms of use, energy sources and landscape objects.

Based on Table 5, the built energy infrastructure affects all land uses. Each type is part of the energy system when examining the division according to Csemez's landscape types (Csemez 1997) The productive landscape types - be it a productive landscape or an industrial landscape - can appear as both energy production and energy consumption elements. The residential and recreational landscape is primarily an energy-consuming element. Of course, the law of conservation of energy must also be considered in this case. However, from a landscape perspective, it can be determined on the purpose of the landscape use whether the given landscape type is a producer or a consumer. Landscape types appear as patterns in the landscape, which are connected by infrastructural elements. These can be transported line facilities (pipelines, electric lines) or production and consumption line facilities (roads, railways). The infrastructure that ensures the flow of information is also part of the energy economy (Odum 2007).

It can be seen from Table 5 that the production and consumption processes associated with different activities are incredibly complicated; where appropriate several different energy sources are used, and the energy is used in different forms. I will examine road transport as an example.

Figure 13 shows how primary energy sources are transformed into energy sources that can be used for road motor transport. Based on the laws of environmental systems, energy loses its usefulness during the process and becomes more and more disordered (Holden 2012). Nevertheless, energy is converted into a usable form through several stages, and for both electric and internal combustion engines, a wide range of energy sources provide the energy. This also means that each step has an environmental impact and can cause pollution. Renewable energy sources (solar, wind, water, geothermal) from which electricity can be produced directly for electric propulsion have the most negligible environmental impact. Most of the steps are the production of fuel oil required to drive internal combustion engines.

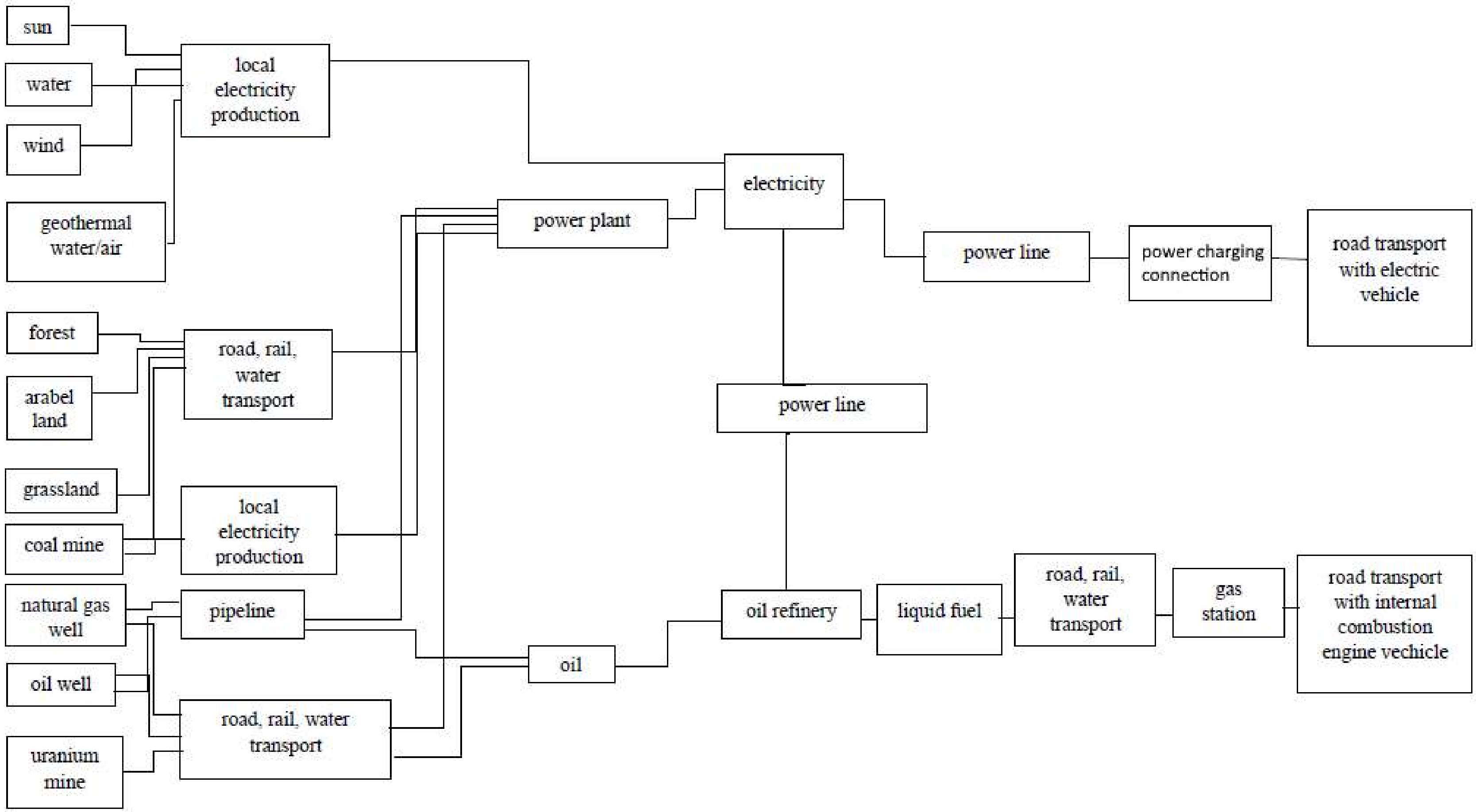


Figure 13. The process of road transport energy consumption.

In conclusion, the energy production and consumption activities related to human activity affect the entire landscape structure. All landscape elements - large-scale patterns or point-like or linear objects - are part of the energy transformation process. These processes affect the environmental systems. In the following, I summarize the human-caused environmental effects of energy conversion.

Environmental sciences typically describe the environmental effects of energy production and consumption primarily according to energy sources. Different energy sources are typically identified as renewable and non-renewable (Rutherford, Williams 2015) (Cunningham, Cunningham 2020), However, the picture should be nuanced based on the characteristics of production and use (Fig. 14).

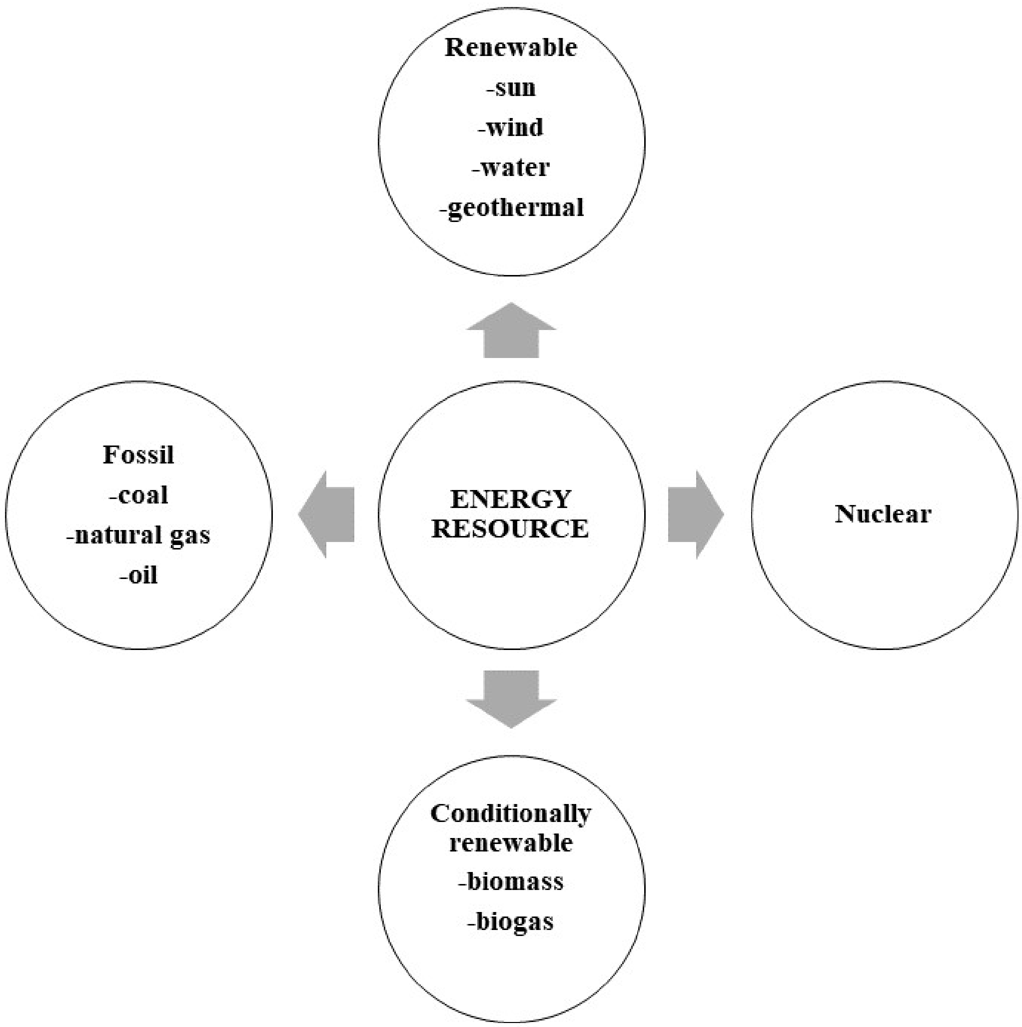


Figure 14. Groups of energy resources)

I divided the renewable energy sources into two worthwhile groups: renewable and conditionally renewable. According to the OECD's definition, only conditionally renewable energy sources, such as rainforests, can reach the point where reproduction becomes impossible. ('OECD Glossary of Statistical Terms' n.d.) Among renewable energy sources, biomass belongs to the latter category. Therefore, their use and reproduction require precise planning. I divided non-renewable energy sources into fossil and nuclear energy. This group is justified by the fact that the two groups must be treated separately in terms of greenhouse gas emissions: no greenhouse gas is produced during nuclear energy production, so the possibility of using it within the energy system is constantly being investigated (IEA 2019), it is also part of the Hungarian climate strategy (ITM 2020a). Nuclear energy currently plays an essential role among low-carbon energy carriers in the world's energy production. It is the source providing the second largest amount of energy after hydropower, more than twice that of wind energy and almost five times that of solar energy (Fig. 15) in 2020. Although the greenhouse gas emissions of nuclear energy are zero during production, they are significant, especially in terms of spent fuel storage (Rafferty 2011). Any unexpected event in production, be it human error or a natural event, has an immeasurable amount of environmental damage (Bourguignon, Scholz 2016) (Steinhauser et al. 2014).

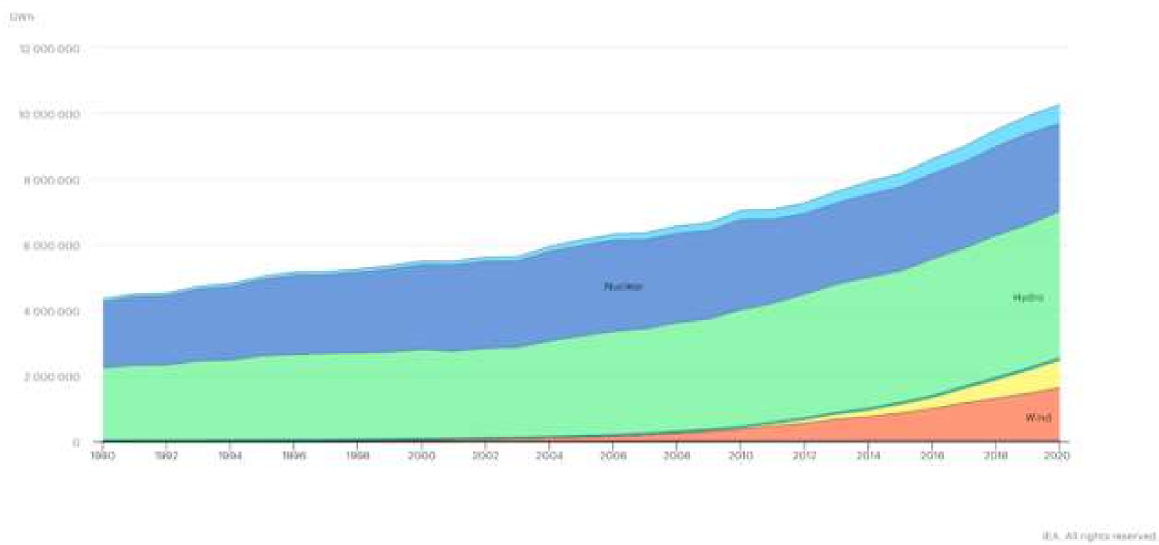


Figure 15. Low-carbon electricity by source. (IEA n.d.)

When examining the effects of different energy sources, in order to meet the requirements of the life cycle analysis, the following phases must be examined:

1. production and mining of materials necessary for energy production
2. establishment of the energy production facility
3. operation of the energy production facility
4. abandonment of the energy production facility
5. the process of using energy.

During the individual processes, the environmental aspects are covered by the 314/2005. (XII. 25.) Hungarian Government Decree I define it in a broader sense based on the Decree on the environmental impact assessment and the unified environmental use licensing procedure (314/2005. (XII. 25.) Korm. rendelet 2005) Therefore, the investigation covers the following:

„*a)* the living world, biological diversity, with particular attention to protected natural areas and values, as well as Natura 2000 areas,

b) the landscape,

c) to the earth, air, water,

d) the climate,

e) the built environment and elements of cultural heritage,

f) the effects of environmental elements on the systems, processes, and structure”. (314/2005. (XII. 25.) Korm. rendelet 2005).

In Annex 6, the legislation details the requirements for the detailed examination of the above. Due to comparability and the available literature, I am partly expanding and narrowing these categories. In the comparison table I created, I compare energy sources according to the following environmental elements and systems:

- wildlife
- landscape
- soil
- geological formations
- air
- water
- climate
- built environment and cultural heritage
- system, processes and structure of environmental elements.

In the established matrix, I examine the environmental effects of the production and consumption of the energy sources shown in Figure 14, which is contained in Annex 2. It follows from the production and consumption of all energy sources that impact environmental elements and systems. However, this impact may differ in the units and intensity of the processes related to the energy source. In addition, mechanisms of action may differ locally. Therefore, the impact can occur locally, regionally, and globally. The primary goal is to reduce greenhouse gas emissions, which affect global climate change, but local or regional effects should not be underestimated (ITM 2018). In the Table 6, I summarized the environmental effects of fossil and nuclear energy sources, from the production of materials to the cessation of energy production. In all cases, complex effects must be considered. From the point of view of greenhouse gas emissions, an important issue is that the nuclear power plant does not pollute the air. However, at the same time, the characteristics of the production have a very significant, complex environmental impact.

		Fossil			Nuclear
		Coal	Oil	Natural gas	
production of materials, mining	living world	X	X	X	X
	landscape	X	X	X	X
	geological formations	X	X	X	X
	water	X	X	X	X
	air	X	X	X	X
	climate				
	built environment, cultural heritage	X	X	X	X
	environmental elements, systems	X	X	X	X

		Fossil			Nuclear
		Coal	Oil	Natural gas	
installation	living world	X	X	X	X
	landscape	X	X	X	X
	geological formations	X	X	X	X
	water	X	X	X	X
	air				
	climate				
	built environment, cultural heritage	X	X	X	X
	environmental elements, systems	X	X	X	X
production	living world	X	X	X	X
	landscape	X	X	X	X
	geological formations	X	X	X	X
	water	X	X	X	X
	air	X	X	X	
	climate	X	X	X	
	built environment, cultural heritage	X	X	X	X
	environmental elements, systems	X	X	X	X
facility abandonment	living world	X	X	X	X
	landscape	X	X	X	X
	geological formations	X	X	X	X
	water	X	X	X	X
	air	X	X	X	
	climate	X	X	X	
	built environment, cultural heritage	X	X	X	X
	environmental elements, systems	X	X	X	X

Table 6. Environmental impacts of fossil energy resources and nuclear energy. (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

2.4. Energy and socio-economic system

The foundations of the economy define our life and environment. In order to be able to analyze the system of energy management on a landscape scale, we need to know what role it plays in economic processes since we have seen that any process taking place in the environmental system involves energy changes. The economy is a complex system that belongs to the social sciences, but at the same time, it describes processes using the laws of mathematics (Kincaid, Ross 2009). What is the role of energy in the economy? What are the connections between economic processes, our environment and the landscape?

According to the Eurostat datasets energy use accounts for approximately 80% of greenhouse gas emissions ('Database - Energy - Eurostat' n.d.) (Eurostat 2020). First, the role of the economy did not arise directly in connection with the energy system in the case of environmental impacts but in the context of climate change. The Stern report completed in 2007 drew attention to the effects of economic processes on climate change and the economic costs of climate change. Some of the points of the report are also important to analyse the energy system on a regional scale:

1. The benefits of strong, early action against climate change outweigh the costs.
2. It has been scientifically proven that increasing climate change's severe, irreversible effects entail additional risk.
3. Climate change threatens the essential environmental elements and systems of people's lives worldwide: access to water, food production, access to a healthy environment, and land and environmental use.
4. The effects of climate change are not evenly distributed geographically. Once the damage appears, it will be too late to reverse the process.
5. Climate change may initially have a positive effect in some developed countries. However, according to climate change scenarios, enormous damage can be expected due to the rise in temperature from the middle of the century.
6. The engine of greenhouse gas emissions is economic growth; according to their calculations, stabilizing the concentration of greenhouse gases in the atmosphere is feasible and consistent with continued growth.
7. The transition to a low-carbon economy presents competitiveness and growth opportunities challenges. Therefore, there is an urgent need to support the development of low-carbon and efficient technologies.
8. Adaptation policies are crucial to addressing the inevitable impacts of climate change but are undervalued in many countries.
1. An effective response to climate change depends on creating the conditions for international collective action. 10. There is still time to avoid the worst effects of climate change if concrete collective action is initiated. (Stern 2007)

Stopping climate change and economic development are overshadowed by the Jevson paradox known from economics. According to the paradox established in the second half of the 19th century: technological progress or government directives increase resource use efficiency (reducing the amount required for one use), but the resource use rate increases due to increasing demand (Jevons 2013) The appearance of renewable energy sources and the increase in energy efficiency do not necessarily come with a reduction in the environmental load. It was examined in connection with energy, and there are spatially definable areas (e.g., Great Britain and France in Europe) where the paradox exists (Polimeni et al. 2008).

The engine of climate change is the economy, and the background of climate change is primarily the energy management system. The question is, where is the place of energy in the economic system? Since the 1980s, Reiner Kümmel has been publishing on the connections between energy and economics. He examined the role of energy from the perspective of the natural sciences and placed energy in the economic system (Fig. 16). The fundamental element of economic processes is energy. From a landscape point of view, the importance of the model is given by the fact that it places the processes in space: it plays an important role in determining the spatial role of individual elements and processes during planning. Furthermore, two actors can generate the inclusion of new energy sources in the processes: one part is capital, which provides the financial source; on the other hand, humans with labour. The scheme also highlights that humans are both energy producers and consumers in the energy economy, expanding the interpretation of the energy system in the economy.

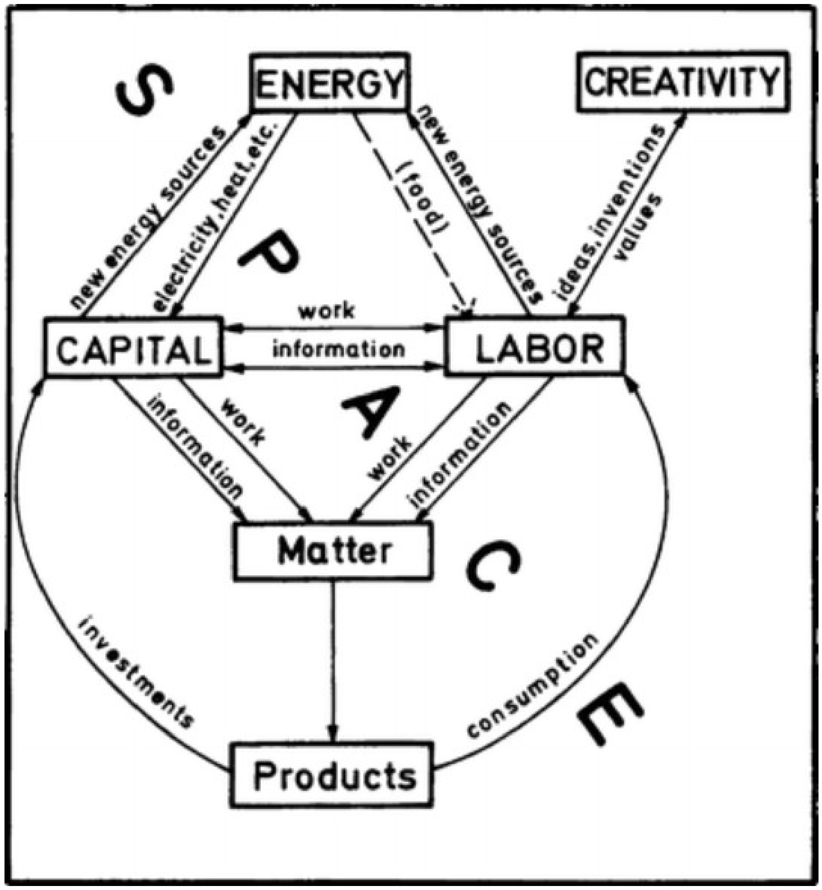


Figure 16. The capital–labor–energy–creativity (KLEC) model of wealth production in the physical basis of the economy. (Kümmel 1980)

A legal framework regulates economic processes, and this system must interpret the structure. The growth of markets can be measured by the financial transactions created during the trade of goods and services. Its actual physical spaces are services, industry and agriculture. On the other hand, since the processes require energy, the possibilities of economic growth are determined by the efficiency of energy's transformability and the entropy's value (Fig 17).

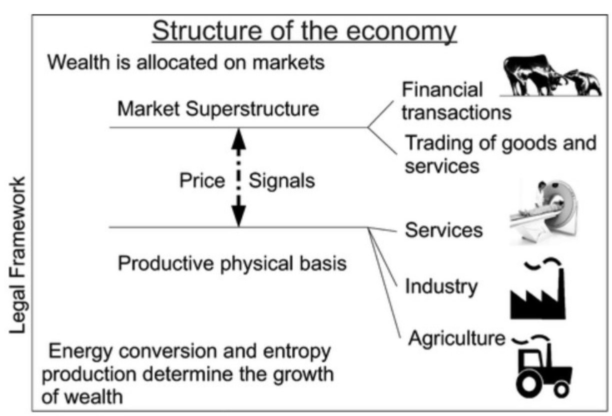


Figure 17. Productive physical basis and market superstructure of the economy (Kümmel 2011)

Based on the Stern report and Kümmel's research, I conclude that the engine of economic growth is energy. However, long-term environmental and social effects must also be considered due to climate change when planning the economy. What guidelines can be envisioned for the future economic model, and what landscape effects will it have? How can the landscape structure change?

In the context I am examining, a new perspective on the economy appeared already in the 1990s: this is industrial ecology, which founded a new approach. Industrial ecology is defined as how "humanity can deliberately *and rationally* approach *a* desirable carrying capacity, given continued economic, cultural, *and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital* " (Graedel, Allenby 2003) Unlike the definition of sustainability in the Burndtland Report (World Commission on Environment and Development 1987), it is essential to emphasize that growth plays an important role in an economic context.

When examining industrial ecology, energy is an important part of the economic system, and this was modelled by Jelinski and his colleagues in the early 1990s with the toolbox of ecology (Jelinski et al. 1992). he economy can be linear (Fig. 18a), where unlimited resources are available and from which unlimited amounts of waste are generated. In the circular model (Fig. 18b), energy is already a priority resource, which, like other resources, is limited in its availability, resulting in a limited amount of waste. Within the system, some subsystems are also connected. This system is not sustainable in the long term. The linear and apparently circular systems are open systems: the resources (material and energy) are available from an external system. In the circular system (Fig. 18c), only energy is available from the outside as an external resource, no waste is generated, and subsystems are interconnected. The circular system interprets the economy as a closed system.

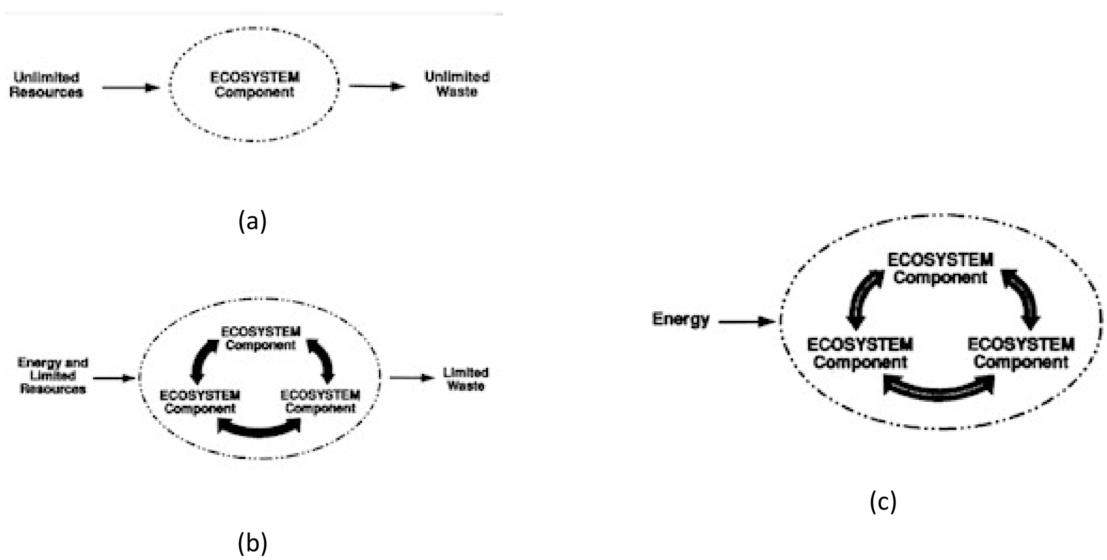


Figure 18. Linear material flows (a) quasi-cyclic material flows (b) cyclic material flows (c) (Jelinski et al. 1992)

According to the circular industrial ecology model, processes occur between the parts of the physical environment. In ecology, these processes are complicated, as we have seen in physics systems, which are isolated systems, and the direction and amount of energy are not influenced by external factors. These energies are called conservative forces in physics. In non-isolated systems, the processes created by energy are also affected by other forces: e.g., friction, time, and mass point speed. These forces are the dissipative forces (Nagy 1993) This also shows the complexity of the self-organizing system (Fig. 19). In the physical environment, self-organizing systems are connected (energy, material and information flow), and an infinite number of processes occur within the system, which also involves energy, material and information flow (Kay 2002). Industrial ecology transfers this approach to the economic space (Allenby 2006).

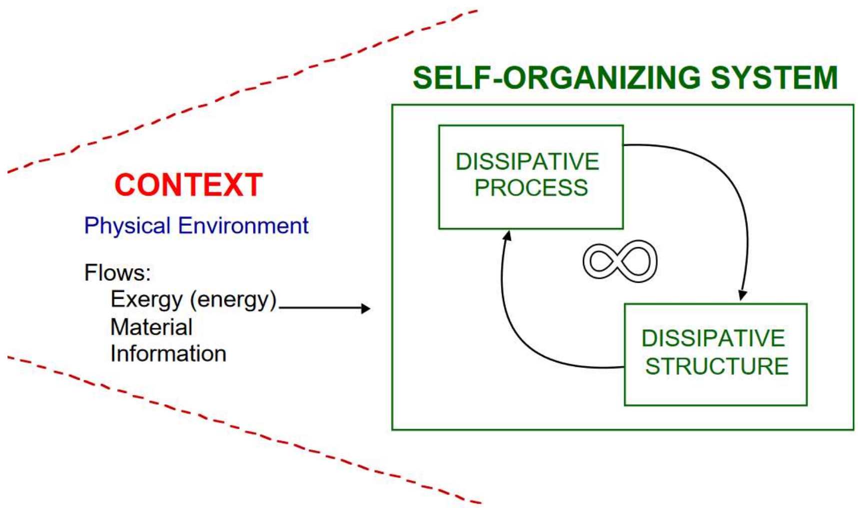


Figure 19. A conceptual model for self-organizing systems as dissipative structures. (Kay 2002)

Ecological interpretation and modelling of the economic system and considering ecological aspects can make energy management more efficient. Applying ecological principles has the following advantages:

1. More useful energy (exergy) is available, so the total amount of available useful energy also increases.
2. Energy can go through several processes within the system, thereby increasing energy use efficiency.
3. Several cycles involving material and energy transformations are created, the length of which also increases. Thus, recycling also becomes more efficient.
4. The approach also applies to food, so longer food chains are created and the efficiency of food use increases.
5. Transpiration increases, which increases the amount of useful energy within the system.
6. The amount of biomass increases.
7. The level of biodiversity increases (Kay 2002).

By adapting ecological principles, the relationship with energy management changes. The interpretation of energy as an external resource is replaced by the circular system, where energy as a resource is partly located outside the system but is used within the system as efficiently as possible, thanks to cyclicality.

This approach has now been integrated into economic policy. In 2015, the European Commission adopted the circular economy package (European Commission 2015), which lays the foundations for future economic processes in the EU. According to the definition of the European Union, in this system, the value of raw materials and resources must be preserved as much as possible during the various processes, thus minimizing the amount of waste. The process can be seen in Figure 20, which also shows the role of energy: energy is the basis of the circular economy processes since no process takes place without it. The model of the European Union can only be considered quasi-circular (Fig. 17) since, in this, the Union is the system, and it minimizes the flow of energy and materials from outside the system and expects minimal pollution.

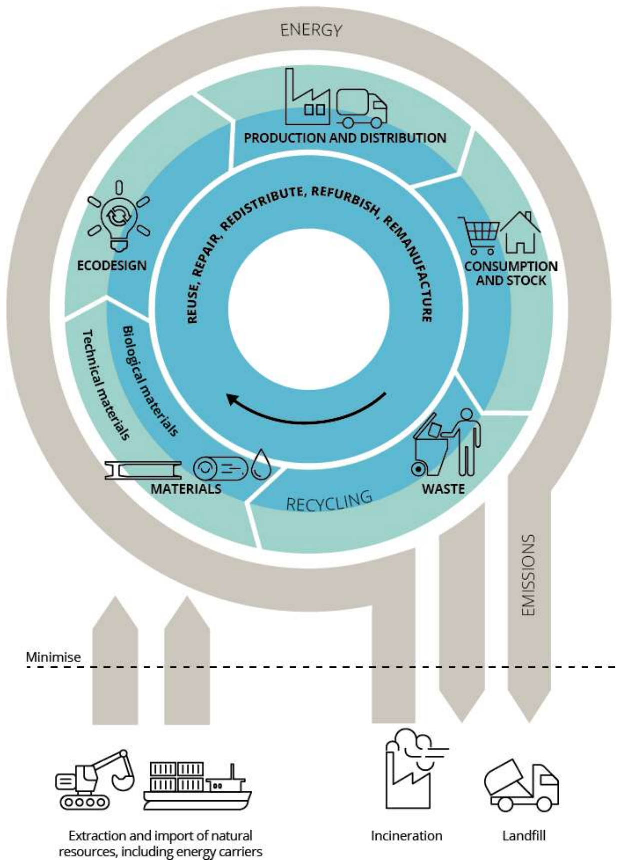


Figure 20. Modell of circular economy. (European Environment Agency 2019)

The foundations of the economy have changed in recent years to reduce the effects of climate change. The change in the economic approach also affects energy management: energy is the resource of economic processes, without which a sub-process cannot take place, and economic processes cannot function without energy sources. With the change in attitude, there was an increase in the efficiency of the use of energy within the system and a radical reduction in the role of fossil energy sources due to the increase in the costs of long-term environmental damage.

2.5. Energy in cultural system

This chapter examines the relationship between energy and the cultural system. First of all, I will clarify the meaning of the cultural system. I approach the cultural system from a sociological point of view, from the perspective of action theory, which examines the micro and macro elements of the system and their connections. The cultural system maps society's cognitive norms, material culture and social actions. It places them in an environmental, economic, and legal framework (Parsons, Turner 2005).

The relationship between the cultural system and the energy system drew attention to the oil crisis of the 1970s (Stephenson et al. 2010), and research and analyses were soon prepared, mainly in the United States (Reizenstein, Barnaby 1977) (Kleinfield 1983). The 1990s drew renewed attention to the energy system's social, economic, and environmental effects due to the Cuban crisis (Gunn 1991) (Rosset 1997). Climate change has brought renewed attention to the Cuban oil crisis: it serves as a real example of the reorganization of the energy system through the radical reduction of fossil energy carriers, which has structural effects on environmental systems, the economy and society (Wright 2011) (Borowy 2013).

The energy-related processes were first examined from environmental aspects, and the ecological approach will also be reflected in the planning of economic processes in the future, so it is worth first examining the relationship between the ecological and social systems (Fig. 21). Within both the ecological and the social system, there are several layers at some levels, these are related to each other, and the individual systems can be divided into subsystems. In this interpretation, the landscape is the largest unit of the ecological system, which can be further divided into communities and species. These systems are related to the social system through various processes (energy flow, material flow, information flow), which can be interpreted more broadly at the settlement level, in smaller units at the neighbourhood level, and in the smallest unit at the individual level. An infinite number of recursive processes occur between the units, and these processes only occur when there is sufficient energy (Kay 2002).

In this model, the scale of landscape planning appears – the scale of landscape architecture plans can range from the object to the regional level (Bastian et al. 2006) (de Groot, Hein 2007) – : processes involving energy changes occur between different scales. It reflects Mőcsényi's definition of landscape: it includes both the natural and the social environment (Mőcsényi 1968). Landscape architecture goes beyond the ecological model by transforming the landscape with planning tools and influencing processes (Brink 2017) (Christoph Girot 2014). The toolset can be diverse; the planning process can also be based on an ecological approach (Murphy 2016) Landscape planning research with a process approach is primarily related to ecology (Liu, Opdam 2014), reflecting the peculiarity of cognitive sciences that examine the process and reflect on the changing environment (Miller 2003).

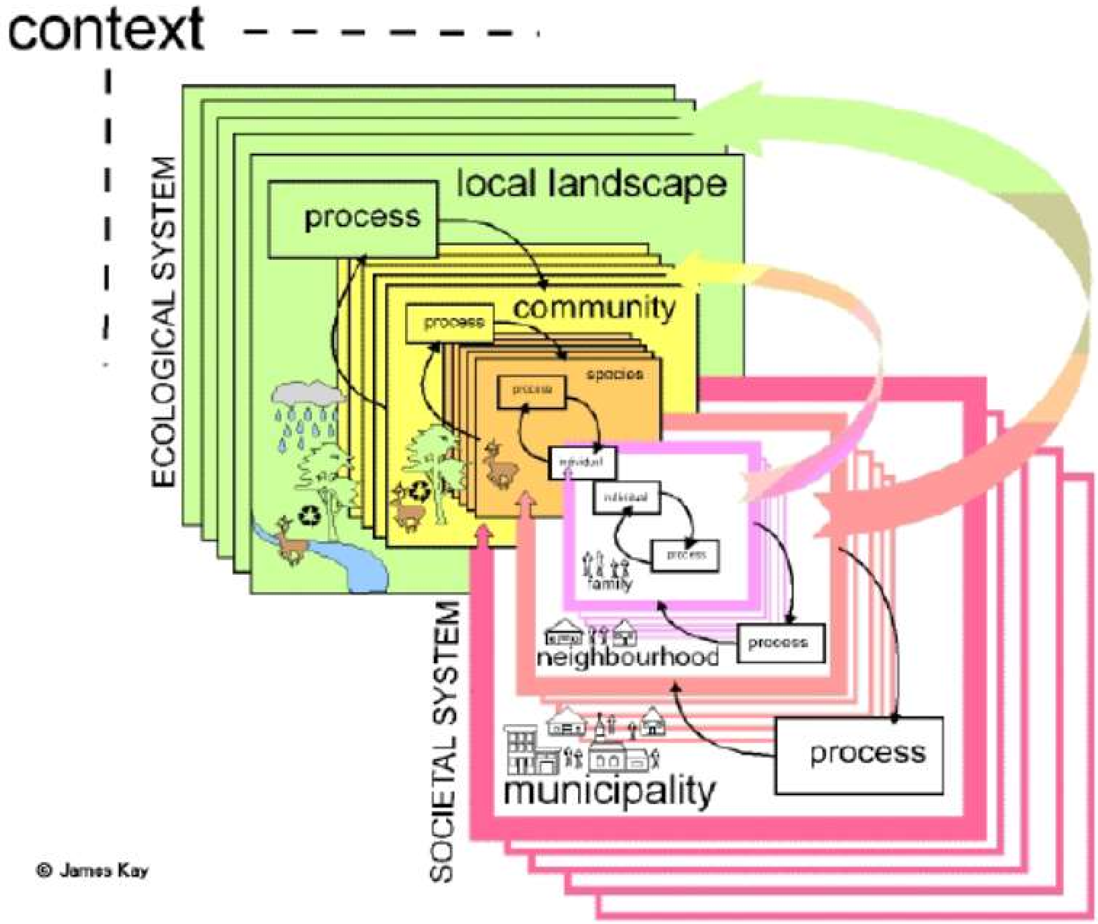


Figure 21. Example of a nested model of the ecological-societal system. (Kay 2002)

The relationship between energy and the cultural system has been examined from several perspectives. From the point of view of research, that several studies have been conducted on energy-related habits of households (Van Raaij, Verhallen 1983) (Hitchcock 1993), some studies also take environmental aspects into account (Wilk 2002). some studies also take environmental aspects into account (Mariola 2008), From an industrial point of view, agriculture, the food industry (Palm 2009) were examined in the context of the cultural system and energy use.

One of the most exciting research projects was conducted in New Zealand and examined the energy consumption habits of households. He placed the results in the triple matrix of the cultural system and defined the aspects that influence energy use within the matrix (Fig. 22) and the influencing factors outside the matrix (Fig. 23). The influencing factors from the inside are related to material culture, which is related from a landscape architecture point of view, the characteristics of the house (in the landscape sense, influencing factors are orientation, landscaping and plant planting that influence the adverse effects of external factors), and cognitive norms, which can be linked to environmental education. The external factors are related to the internal ones. From the point of view of material culture, construction rules and efficiency should be highlighted here, and education affecting internal cognitive norms.

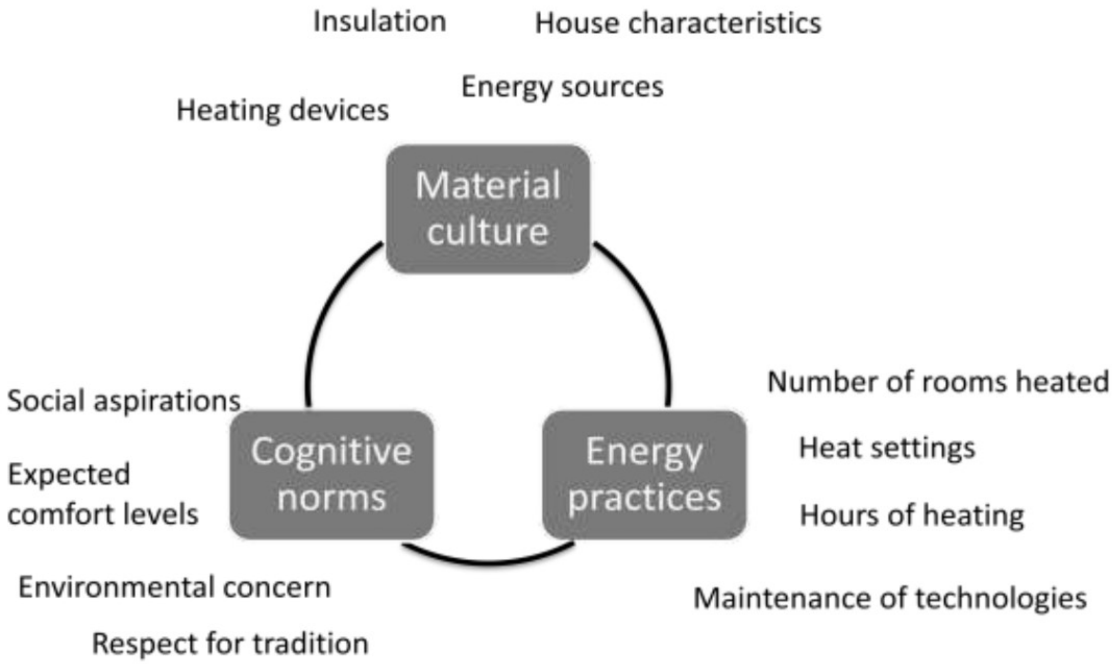


Figure 22. Using the energy cultures framework to characterise some home heating behaviour. (Stephenson et al. 2010)

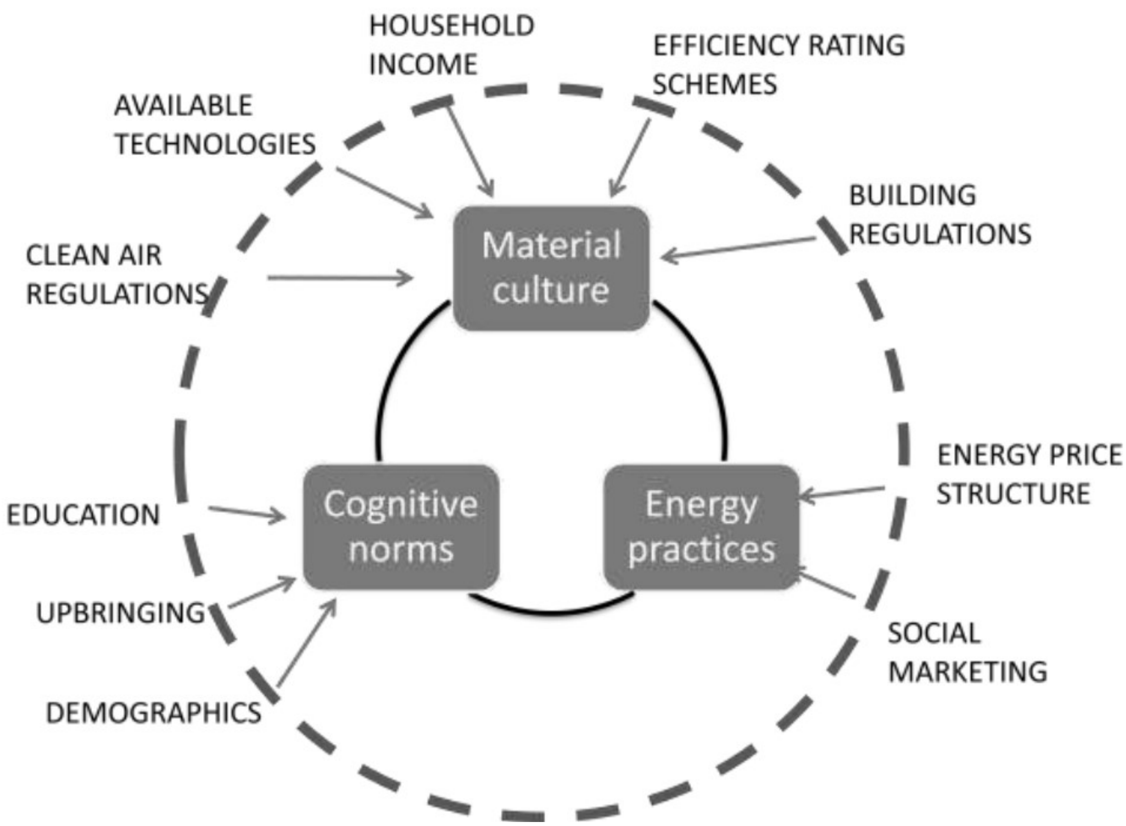


Figure 23. Using the Energy Cultures framework to depict some of the wider systemic influences on behaviour. (Stephenson et al. 2010)

Examining the cultural system, it can be established that, like the environmental and economic systems, the process principle prevails. When examining a subsystem, it can be shown that the factors affecting energy use must also be determined outside the system. The community planning tools used in regional and landscape planning (Wates 2014) (Mahdavinejad, Abedi 2011) can be used during the examination of the cultural system and in the case of individual factors (with particular regard to cognitive norms). Not only can humans influence the use of energy, but human behaviour is also affected by the sight of energy industry facilities; new objects appear in the landscape with the appearance of renewable energy sources, but this does not necessarily mean a positive thing from a visual point of view (Van Raaij, Verhallen 1983).

2.6. Legal framework

The legal framework for energy supply must be separated for electricity and natural gas supply. Regulation takes place nationally on two levels: by laws, and by governmental or ministerial decrees, and there are also European Union laws that must also be applied. The energy transition is contained in ministerial-level plans: these dictate the transition to renewable energy sources at the system level. The elements of the energy system also appear in territorial plans. Although these are considered a given during territorial planning, the elements of the energy system can be minimally influenced during planning. I have summarized the legislation affecting the energy system in Table 7.

At the legal level, natural gas is separately regulated as an energy source and electricity as a form of energy used. At the same level, spatial planning is also regulated. These include plans prepared for regional plans, in which the objects of energy supply appear. However, in terms of spatial planning, in some cases, the development may differ from it, such as the establishment of high-voltage lines. Territorial development is also regulated at this level; in the county territorial development plans, the energy-related plans of the regions are designated: energy sources, scale of energy production objects, energy efficiency support, energy structure transformation (Perger et al. 2012) (Borsod-Abaúj-Zemplén Megyei Közgyűlés 2020) (Heves Megye Területfejlesztési Programja 2021-2027 2021). From the point of view of the energy system, energy efficiency must also be regulated at this level. Environmental protection is regulated at the legal level that can be indirectly linked to the energy system. At the government and ministerial level, the executive decrees related to the laws help the application of the laws. The framework of local scale plans is regulated at this level.

Comprehensive plans for renewable energy sources and the energy system are contained in ministerial-level strategies. The National Energy Strategy (ITM 2020c) assesses the country's fossil resources, dedicating a separate chapter to natural gas and electricity supply. It deals with the energy system's economic, social and legal framework. In connection with climate change, the National Second National Climate Change Strategy (Innovációs és Technológiai Minisztérium 2018), which includes assigning tasks related to decarbonization, is also important. The National Energy and Climate Plan (ITM 2020b) deals in more detail at the national level with the energy structure, energy efficiency, energy market and energy security related to decarbonization. At the European Union level, these plans are linked to the Union's Green Deal ('Európai zöld megállapodás' n.d.).

	Electricity	Natural gas	Energy transition	Territorial planning
Law	2007/LXXXVI. law about elecricity	2008/XL. law about natural gas supply		2018/CXXXIX. law about the territorial planning of Hungary and some of its priority areas
	2015/LVII. law about energy efficiency			1996/XXI. law about territorial development and territorial planning
	2013/LIV. law about the implementation of overhead reductions			
	2013/ XXII. law about the Hungarian Energy and Utilities Regulatory Office			
	2008/LXX. law about some issues relate to electricity	2006/XXVI. law about the safety stockpiling of natural gas		
	1995/LIII. law about the general rules for the protection of environment			
	1991/XLV. about measurement			
Government decree	273/2007. (X. 19.) Government decree about the implementation of electricity law	19/2009. (I. 30.) Government decree about the law of natral gas supply		253/1997. (XII. 20.) Government decree on thea national settlements planning and construction requirements
	382/2007. (XII. 23.) Government decree about the official liscensing procedures for the construction of energy industry	290/2022. (VIII. 5.) Government decree natural gas price reduction for large families		218/2009. (X. 6.) Government decree about the content requirements of the spatial development concept, the spatial development program and the territorial planning plan, as well as the detailed rules for their matching, elaboration, negotiation, acceptance and publication
	31/2014. (II. 12.) Government decree about the rules of construction authority procedures for certain specific industrial buildings	289/2022. (VIII. 5.) Government decree about during an emergency, electricity and ensuring the provision of universal natural gas service under unchanged conditions overhead protection servic		419/2021. (VII. 15.) Government decree about the content of settlement plans, the procedure for their preparation and acceptance, as well as on specific legal institutions for settlement planning
	280/2016. (IX. 21.) Government decree about the necessary measures in the event of a significant disruption of the electricity system and an electricity supply crisis	260/2022. (VII. 21.) Government decree about the creation of the special natural gas reserve		
	299/2017. (X. 17.) Government decree about mandatory take-over and premium support for electricity produced from renewable energy sources	10/2020. (IV. 14.) Government decree about on restrictions on natural gas purchase, natural gas on the use of a safety stock, as well as on other measures necessary in the event of a natural gas supply crisis		
	389/2007. (XII. 23.) Government decree about the mandatory acceptance and acceptance price of electricity produced with energy obtained from renewable energy sources or waste, as well as electricity produced in conjunction	296/2015. (X.13.) Government decree about natural gas final shelter service and a in the event of the natural gas trader's operation becoming impossible, the users applicable as a result of the existence of a situation endangering natural gas supply procedure		

<table>
<tr><th></th><th>Electricity</th><th>Natural gas</th><th>Energy transition</th><th>Territorial planning</th></tr>
<tr><td rowspan="2">Government decree</td><td></td><td>122/2015. (V. 26.) Government decree about the implementation of the law on energy efficiency</td><td></td><td></td></tr>
<tr><td></td><td>54/2008. (III. 20.) Government decree about mineral raw materials and geothermal energy on determining its specific value and the method of value calculation</td><td></td><td></td></tr>
<tr><td rowspan="3">Ministerial decree</td><td>2/2013. (I. 22.) NGM decree about the safety zone of electrical works and production, private and direct lines</td><td>10/2022. (VIII. 4.) TIM decree about on a special natural gas stock, as well as about the conditions necessary for its creation</td><td>ITM Second National Climate Change Strategy (2018)</td><td></td></tr>
<tr><td>40/2017. (XII. 4.) NGM decree about connection and user equipment, as well as electrical protection systems operating in potentially explosive environments</td><td>59/2021. (XII. 15.) ITM decree about the amount of natural gas safety stock</td><td>ITM National Energy and Climate Plan (2020)</td><td></td></tr>
<tr><td>8/2001. (III. 30.) GM decree about the entry into force of the Regulation on Technical Safety Requirements of the Electric Work</td><td>67/2016. (XII. 29.) NFM decree about offered for purchase to universal service providers source of natural gas and the quantity and price of domestically produced natural gas, as well as on the range of those entitled and obliged to use i</td><td>ITM National Energy Strategy 2030 (2020)</td><td></td></tr>
<tr><td rowspan="6">EU directives, regulations</td><td></td><td>Regulation (EU) 2017/1938 of the European Parliament and of the Council of 25 October 2017 concerning measures to safeguard the security of gas supply</td><td></td><td></td></tr>
<tr><td></td><td>Commission Regulation (EU) 2017/459 of 16 March 2017 establishing a network code on capacity allocation mechanisms in gas transmission systems</td><td></td><td></td></tr>
<tr><td colspan="3">Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU</td><td></td></tr>
<tr><td colspan="3">Regulation (EU) No 1227/2011 of the European Parliament and of the Council of 25 October 2011 on wholesale energy market integrity and transparency Text with EEA relevance</td><td></td></tr>
<tr><td colspan="3">Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity</td><td></td></tr>
<tr><td colspan="4">European Green Deal https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_hu. Accessed: 2022. 3. 28.</td></tr>
</table>

Table 7. Legal framework of energy sectors.

2.7. Energy in the context of landscape architecture

In this chapter, I analyse landscape architecture research related more narrowly and broadly to energy. Based on the previous chapters, the oriented interpretation of the energy process became an essential element of scientific research with the recognition of climate change. This is primarily thanks to meteorological research: during the investigation of environmental phenomena in the 1970s, it was established that air pollution has a harmful effect not only on a local scale (Bozó et al. 2006). The process approach has been appearing in landscape architecture for a long time, illustrated by a few examples: at the object level, when composing the vegetation, we take into account the life cycle of plants (Schmidt, Fekete 2005), from the point of view of the history of science, the task and significance of landscape architecture has changed over time and space (Christoph Girot 2014); the relationship between settlements and the landscape, and the landscape-shaping activity of man has also changed in the course of history (Mumford 1989) (Kostof, Tobias 2014). In this chapter, I specifically focus on what role energy, as an element of the landscape planning process, played in the planning practices, either from an environmental, economic, or cultural point of view.

The book Landscape Planning for Energy Conservation, published in 1983, contains landscape planning tools that can influence energy usage habits and make the environment more comfortable. It describes the various meteorological phenomena (e.g., radiation, wind, rain) and the landscape architecture tools that can be used to influence them on both a small and a large scale. (Fig. 24, 25) It deals with the effects of water surfaces: their influence on radiation by time of day. By climate region, it deals with the possibilities of orientation and plant use (Fig. 26), which can influence the adverse effects of the given microclimate and take advantage of the advantages (Robinette, McClenon 1983).

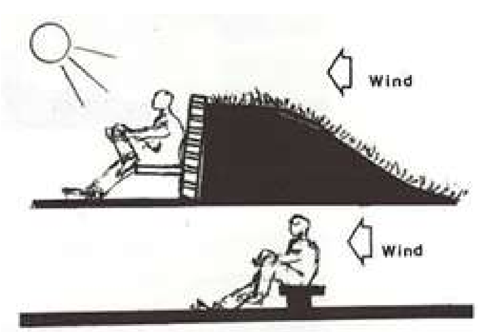


Figure 24. Protection againts wind. (Robinette, McClenon 1983)

Figure 25. Protection againts sun. (Robinette, McClenon 1983)

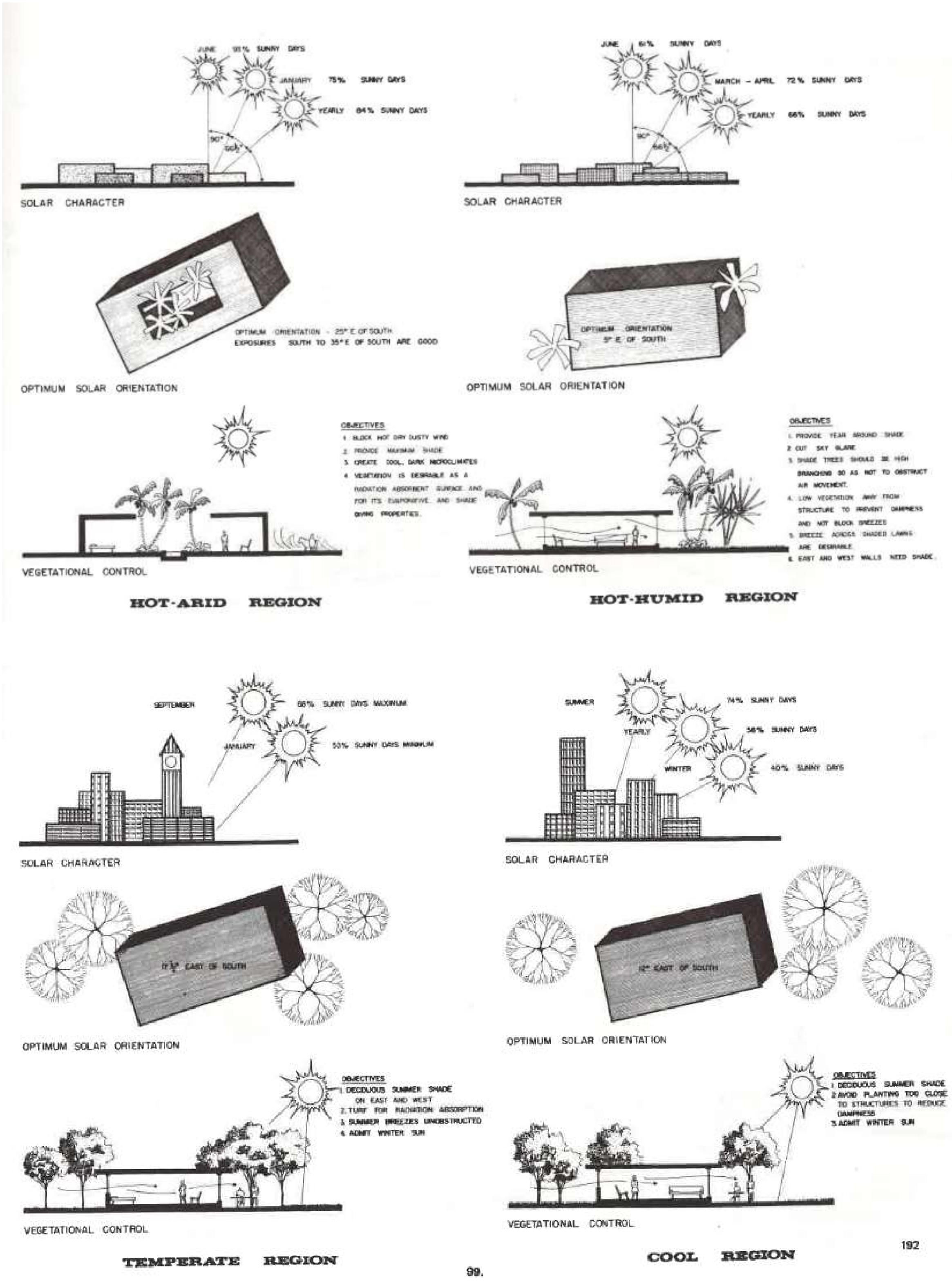


Figure 26. Orientation of buildings in different climate regions taking into account the characteristics of radiation. (Robinette, McClenon 1983)

Also published in 1983 was William M. Marsh's Landscape Planning: Environmental Applications. His book dealt with the connections between solar radiation and heat management. Regarding the effects of the interactions of landscape planning and environmental systems on energy balance, the results are similar to the work of Robinette and McClenon. Depending on the surfaces, geographical location, and topographic features, the sun's radiation causes heat and air movement (Figure 27). It is also influenced by the built environment (Figure 28), which landscape architecture tools can influence. The appropriate planning practice, where the irradiation - by orientation, material use, plant planting, etc. - can influence landscape architecture design, is called passive solar energy use. In connection with heat management, he also addresses the issue of the heat island phenomenon. (Marsh 1983). Later, he also studies the role of energy, heat balance, and temperature within the framework of environmental sciences (Marsh 1987). I analysed these aspects based on other literature when describing environmental elements and systems.

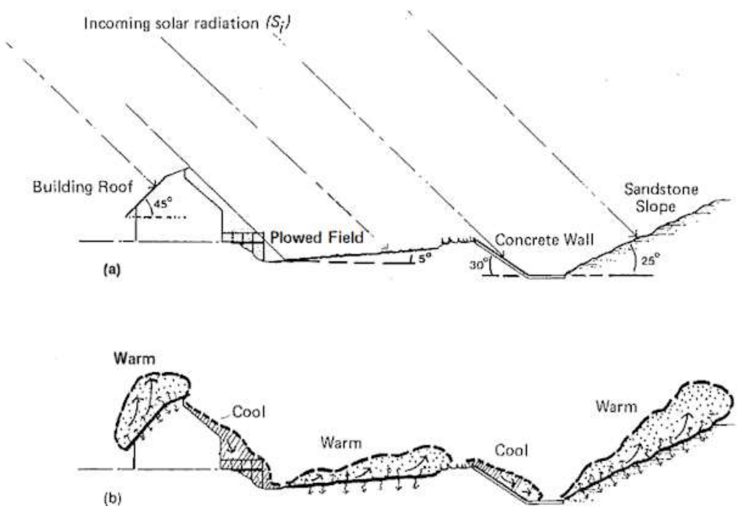


Figure 27. (a) Variation in solar heating related to slope and surface materials. (b) The resultant differences in air heating and movement. (Marsh 1983)

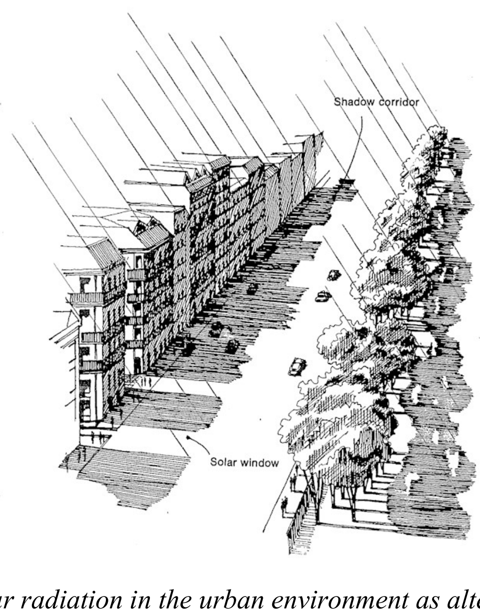


Figure 28. The pattern of solar radiation in the urban environment as altered by tall buildings. (Marsh 1983)

Also published in 1983 was William M. Marsh's Landscape Planning: Environmental Applications. His book dealt with the connections between solar radiation and heat management. Regarding the book of the László, Ghimessy published in 1984. his book interprets the potential as the performance capacity of the landscape. The concept of landscape potential: "The term landscape performance potential is to be understood as the number of people who are supported or can be supported permanently in the given area, at a specific supply level." (Ghimessy 1984) In his interpretation, landscape and man are closely intertwined; he supposes that both the social science and the natural science point of view are necessary for landscape analysis, so much so that he considers creative work as one of the elements of consumption. It divides the landscape into spatial structural elements: spatial structural elements for production, spatial structural elements with a consumption function and spatial structural elements with a protective function (Table 8).

Production function		**Consumption function**		**Protection function**
permanent structure	**cannot be renewed**	**direct**	**indirect**	
agriculture	mining	flat	administration	nature conservation
forest management	industry	retail trade	education	agriculture (gene reserves)
water management		business network	adult education, entertainment	water protection
			health care	wildlife protection
			utilities	industrial area protection zone
			transport	health protection area
			vacation	monument protectio
				scientific institution
				other

Table 8. Spatial structural elements with production, consumption and protection functions (Ghimessy 1984)

The examination of the spatial structure of the energy consumption and production system was already published in the 1980s. Even today, the basis of the system represents a starting point in the spatial interpretation of energy management. Since it quantifies the performance capacity of the landscape so that both production and consumption elements become comparable, it thoroughly examines all spatial structural elements. (Ghimessy 1984) Its shortcoming is that it defines the spatial structural elements rather than the relationship and dynamics between them.

Research and projects dealing with the relationship between landscape and energy have been published since the 2000s, collected by Sven Stremke in his 2013 article, many of which I highlighted in Table 9. According to the conclusion of the research, integrating the relationship between landscape and energy into planning practice has begun, as we have seen numerous examples of it. At the same time, it is necessary to think further about the methodology since the energy system affects the ecosystem, socio-economic, and cultural systems. Further research is needed in the field to explore the landscape-scale processes of the energy system and its integration into landscape architecture plans at different scales (Stremke 2013).

Article	Topic
(Blaschke et al. 2013)	Analysis of the landscape effects of biomass using the GIS method
(Wächter et al. 2012)	Modeling of factors affecting the use of wind energy
(Narodoslawsky, Stoeglehner 2010)	Urban and regional energy system planning with considering the ecological footprint
(Jorgensen 2008)	Transport based on renewable energies
(Burgess et al. 2012)	Local scale energy, food and wood supply
(Coleby et al. 2012)	Environmental impacts of energy grasses in the perspective of ecosystem services
(Möller 2006)	Landscape impacts of wind power plants
(Nadaï, Horst 2010)	It draws attention to the gap in the analysis of energy and landscape relations. The relationship between landscape design and energy is an unprecedented field of research, which is undergoing large-scale changes.
(Selman 2010)	Carbon neutral landscape aesthetic
(van der Horst, Vermeylen 2011)	Territorial and social aspects of biofuel
(Howard et al. 2013)	Possibilities of connecting the energy system and ecosystem services on a landscape scale.

Table 9. Selection of energy-conscious planning and design projects that have been published (Stremke 2013)

In 2010, Sven Stremke defended his doctoral dissertation on a new basis for the previous research. In his work, he interpreted the energy concepts of physics and ecology in the framework of the landscape. He placed landscape planning in the framework of climate change and decarbonization. It examined the potential of renewable energy sources in a specific area (Figure 30). He examined the system of production and consumption at the system level through case studies (South Limburg, Margareten, Southeast Drenthe). He interpreted the energy management issue on a regional scale (Stremke 2010).

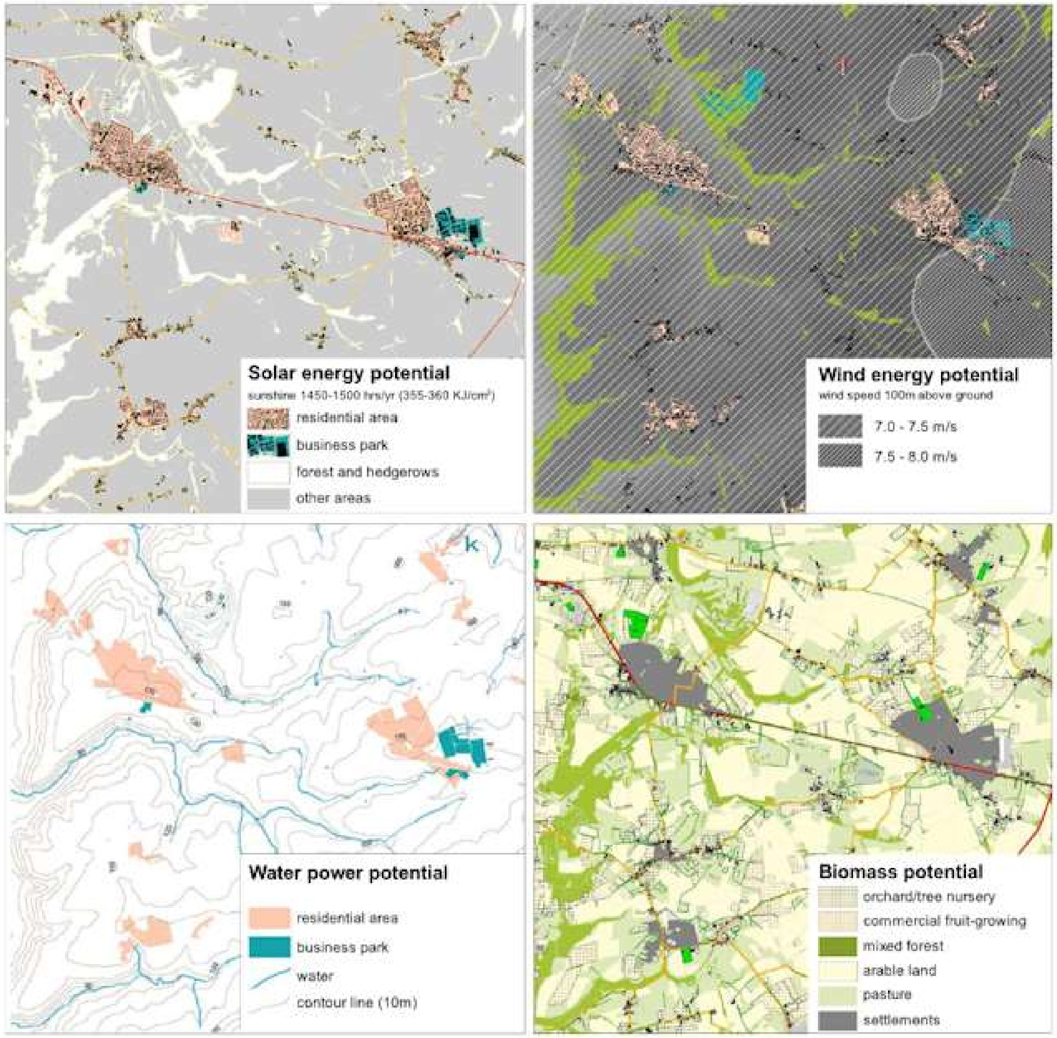


Figure 29. Mapping of the diverse renewable energy potentials can facilitate the discussion on sustainable energy landscapes. Example from the Heuvelland area near Margraten in South Limburg. (Stremke 2010)

Nico Tillie's 2018 doctoral dissertation integrates energy management planning into settlement planning, but it also covers more minor scales (district, block, object) during the planning process. During planning, emphasis is placed on process-oriented planning (flow) and the management of problems related to climate change (water balance, heat balance, energy, ecology) (Tillie 2018). To calculate the energy balance, the regional register of greenhouse gases (GRIP) was used as a basis, which also serves as the basis for the energy balance planning of other large cities (Carney, Shackley 2009) (Kennedy et al. 2011). Like Stremke, he assesses the potential of renewable energy sources and their potential for use and the possibilities of increasing energy efficiency. It examines the possibilities of utilizing unused energy at the block level. (Tillie 2018)

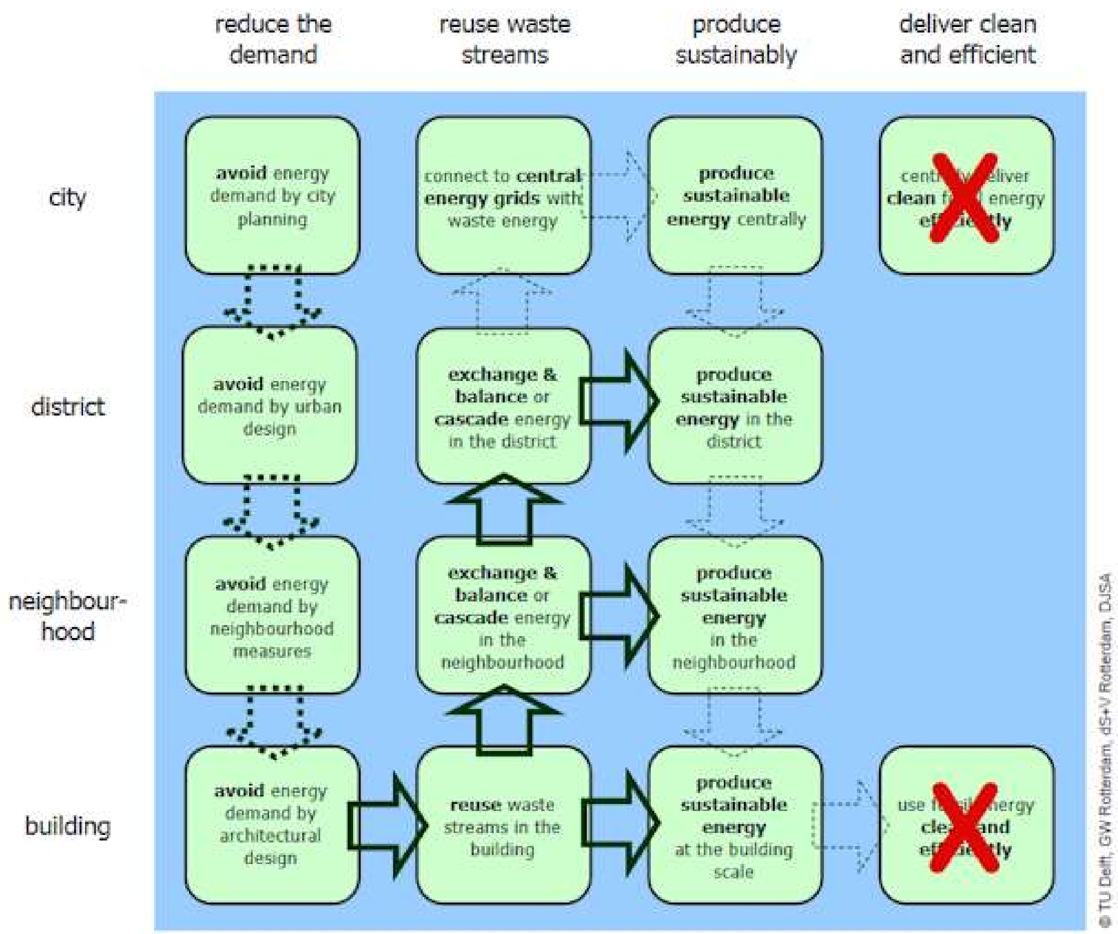


Figure 30. The REAP methodology. (Tillie et al. 2009)

Both Stremke's and Tillie's research points in the direction that energy management questions should be included in the practice of spatial planning and landscape planning. The international (Yang et al. 2021) (Prieto-Amparán et al. 2021) (Gharaibeh et al. 2021) and Hungarian (Drexler et al. 2010) research of recent years still mainly examine the landscape effects of one energy source as the energy budget of a territorial unit. In my doctoral research, I focus on the latter.

It is also important to mention the Autonomous City research, which sought self-sustainability not only from the point of view of energy management but also from an economic, social, and cultural point of view. The project considered ecological aspects during urban planning, both in metropolitan and rural settings. The basis of the sustainability calculation was the ecological footprint. It was considered which renewable energy sources production in the study areas is a realistic possibility (Ertsey 1999) (Ertsey, Medgyasszay 2004).

The activity of the Energy Club is also significant, as they carry out research and information about the energy system. They help local governments prepare an independent settlement plan. They also play an essential role in science communication, regularly giving lectures on renewable energy sources, energy efficiency, and energy poverty, among others. Their significant research is available on their website (‘Tudástár | ENERGIAKLUB’ n.d.).

2.8. Conclusions based on literature review

Based on literature research, it can be determined what tasks landscape architecture design has about the energy transition. Energy management already plays a significant role in planning. The materials used in the design of the object, the planting order and the "orientation" of the plants can contribute to increasing energy efficiency. The angle of irradiation can be influenced by landscaping. Orientation also plays a significant role in the case of townships and settlements. These devices influence the energy systems of environmental elements and systems. The role played in environmental education is essential since, when reviewing the cultural system, we can see that it plays a role in energy use. Finally, it is essential to highlight the environmental impact studies, in which we examine the effects of individual facilities in the energy system. The new challenge emerging in connection with the energy transition is to use landscape architecture tools to estimate the energy potential of an area, considering their landscape and environmental effects. This can help the sustainable development of the energy system (Fig. 31).

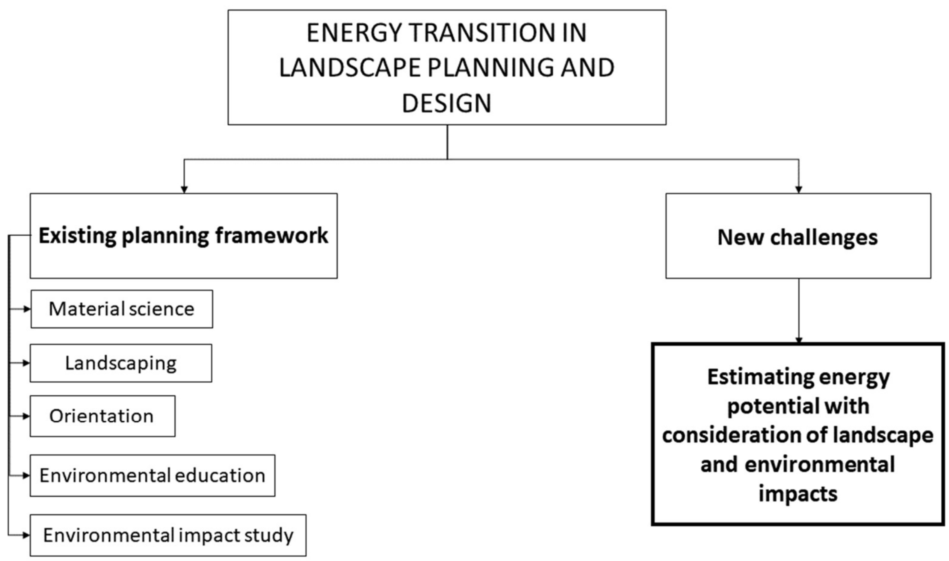


Figure 31. Role of landscape architecture in energy transition

As I stated previously, the design practices used in landscape architecture influence the energy system of environmental elements and systems and the thermodynamic changes related to using materials. Since these processes involve energy changes, the concept of energy transition can be interpreted in landscape architecture for the processes involving energy changes in the natural environment.

3. MATERIALS AND METHODS

Based on the literature review, I defined the tasks of landscape architecture, based on which I determined the methodology of my further research and the data used for it. Several possible research areas are related to the area, as they are focused on determining the energy potential of the landscape and related landscape and environmental effects, so my further research is focused on this. Due to the nature of landscape architecture, I examine the question with the help of case studies. At which planning levels can the energy potential be determined? We can answer this question by examining the available data. I collected the source and nature of the available data in Table 10. The database (Cattaneo 2018) containing multi-year data series relating to solar and wind energy is at the settlement level; the smallest unit of statistical data on which biogas is based is also the settlement level ('Hungarian Central Statistical Office' n.d.). Settlement-level data are also available for waste. Biomass datasets are available national scale, but it is possible to estimate biomass energy potential based on land use area data on a settlement scale. According to the currently available data, the smallest unit of the study area is the settlement level; the reliability of the data is the best at this scale. The question is whether it is worth investigating a larger area. A larger unit can be examined by processing settlement data, so comparative data series of settlements are also available. Based on these, I determined two levels for the study: the settlement and the micro-regional. I determine the energy potential with the help of the materials and detailed methods described below.

First, I present the sample areas with the help of literature, statistics, and maps, which analysis focuses on the factors influencing the energy system of the areas. The visual analysis of the historical maps is also part of the presentation, as the changes in the energy system over time can be identified. I looked for the elements on the maps that indicate that the energy production system has changed. After that, I performed calculations to determine the potential of renewable energy production on a regional scale, for which I used several data sources. After that, I estimated the consumption side and summarized the data source in Table 10. I estimated the consumption side based on the data of the Central Statistical Office, the International Energy Agency and the MVM to compare them with the energy potential data at the local level. Finally, with a visual analysis of the existing energy network of the sample areas, I explored the possibilities of incorporating renewable energy sources into the current infrastructure from a landscape architecture point of view. In the following, I will describe in detail the methodology for determining the potential of each renewable energy source, considering the landscape and environmental effects to minimize the adverse effects. From the consumption side, I examine transport energy from the point of view of whether excess energy is available in the estimated renewable energy potential since energy management can only be partially solved at the settlement level. I did not consider the energy consumption of the internal combustion engine in agriculture, as there is still no reliable solution to replace the internal combustion engine used in the sector. (Moreda et al. 2016). When estimating the energy potential, I considered that energy systems have physical (theoretical), technical and economic limitations (Brueckner et al. 2014) (Fig. 32), the economic limitations must include the internal and external costs of the environment (Zhu, Xu 2023). In my research, I estimated the energy potential of the sample areas by considering landscape and environmental aspects. Finally, I analysed interstitial maps and which networks are found in the sample areas.

Used for	Data type	References
Energy resources related to weather (sun, wind)	Weather statistics	CATTANEO, B. (2018, June 15): Photovoltaic Geographical Information System (PVGIS). In: [Text] https://ec.europa.eu/jrc/en/pvgis. Accessed: 2021. 5. 2.
Slope categories	Map	EU-EU-DEM — Copernicus Land Monitoring Service. In: (n.d.) Land Section. Copernicus Land Monitoring Service
Water system	Map	EU-Hydro - River Network Database — Copernicus Land Monitoring Service. In: (n.d.) Land item. Copernicus Land Monitoring Service
Biomass	Forestry statistic data	Magyarország erdeivel kapcsolatos adatok. In: (n.d.) https://nfk.gov.hu/Magyarorszag_erdeivel_kapcsolatos_adatok_news_513. Accessed: 2023. 4. 28.
Statistical data of population, household, agriculture etc. of consumption	General statistic data	Központi Statisztikai Hivatal. In: (n.d.) https://www.ksh.hu/energiagazdalkodas. Accessed: 2021. 3. 25. MVM ~ Átlagos éves fogyasztás. In: (n.d.) https://www.mvmnext.hu/aram/pages/aloldal.jsp?id=550565. Accessed: 2021. 6. 2.
Energy datasets of consumption	Energy statistics	Data & Statistics. In: (n.d.) https://www.iea.org/data-and-statistics. Accessed: 2021. 4. 29.
Potential energy production	Technological data	Scientifical articles, technological descriptions
Defining energy potential of solar energy and biomass	Spatial data of land use categories	AGRÁRMINISZTÉRIUM (2019): Ecosystem Map of Hungary. In: Agrárminisztérium
Energy network	Map	Lakossági Térkép. In: (n.d.) Lechner Nonprofit Kft.

Table 10. Datasets and references.

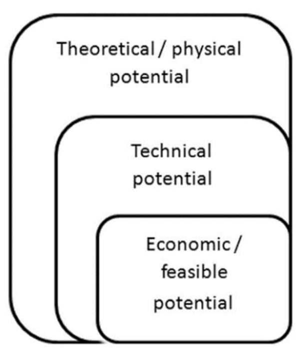


Figure 32. Types of potential. (Brueckner et al. 2014)

3.1. Estimating solar energy potential

I used the Basic Map of Hungary's Ecosystem, a raster-based map, to estimate the solar energy potential. To determine the size of the area, follow these steps using the QGIS program:

1. I downloaded the Ecosystem Map of Hungary from the following website: http://alapterkep.termeszetem.hu/ (Agrárminisztérium 2019)
2. I have defined the study area.
3. Among the raster analyses, I used the zonal histogram, which gives the number of pixels of each area used as a table in the demarcated area.
4. I saved the received data in an Excel table.
5. Since one pixel covers an area of 20x20 meters, I multiplied the pixels of each area used by 400, thus obtaining the size of the area used in square meters.

The installation location of the solar panels can be limited by land use, and different land uses have different landscape and environmental effects. In my research, I considered two land uses: buildings and areas. In the case of solar panels, the landscape and environmental effects are significant in the mining of the materials required for solar panels and in the production of solar panels; this must be considered in the case of both land uses. In Table 11, I summarized the effects of solar energy production in the case of built-up and lawn areas, considering the environmental impact assessment legislation (314/2005. (XII. 25.) Korm. rendelet 2005). There is a significant difference during the installation and dismantling of the solar panels. In the case of lawn areas, installing and removing solar panels involves significant earthwork, which means a complex environmental impact, which is different for buildings. Since the planting area is more significant in the case of lawn areas, a larger capacity must be expected, which may also require the development of the electrical network, which may involve additional earthwork; the new high-voltage lines fragment the habitats (Fig. 33), limit agricultural production (NGM 2013), can have a landscape effect. There is no significant effect during production in either case. Since landscape and environmental effects are less significant in built-up areas, I considered 10%, 20% and 30% of the building area in the calculations, as the installation can be influenced by the orientation of the building, the shape of the roof, other structures placed on the roof, nearby vegetation, and buildings. In the calculations, I only considered the area of the buildings, but there may be buildings inside and outside that may be suitable for solar panel installation, e.g., public lighting (Fig. 34). I did not count on using solar energy for heating purposes since the technological features and the knowledge of building mechanics go beyond the possibilities of landscape architecture (Varga 2005). On a small scale, the environmental effects of using a solar collector in the built environment are the same as those of solar cells.

Figure 33. Paks-Pécs high voltage line.

Figure 34. Solar panels on lamp post, Gyál, Hungary.

		Grassland	Built-up area
production of materials, mining	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
installation	living world	X	X
	landscape	X	
	geological formations	X	
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
production	living world	X	X
	landscape	X	X
	geological formations		
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
facility abandonment	living world	X	X
	landscape	X	X
	geological formations	X	
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

Table. 11. Environmental impacts of solar panels. (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

After that, I queried the data on the solar energy potential of the investigated settlements from the PVGIS page. Various parameters can be set on the page: database, solar panel technology, angle of incidence, and network connection (Fig. 35) Since the examined area is at the settlement level and there are no significant differences, the calculations are performed with crystalline silicon technology, with an angle of incidence of 35 degrees, with network connection I counted. The data can be downloaded in image or pdf format broken down into months (Fig. 36). I use annual data in my research. I calculated the average efficiency of the solar panels found on the market, which is currently 18% (Zito, Pelchen 2023). Based on the insolation and the technical characteristics of the solar panels, I determined the following formula to estimate the solar electricity potential of a given area, and c:

$$W = E_e \times A \times \eta, \text{ where}$$

W: work (kWh)
Ee: in-plane irradiation (kWh/m2)
A: area
η: energy conversion efficiency

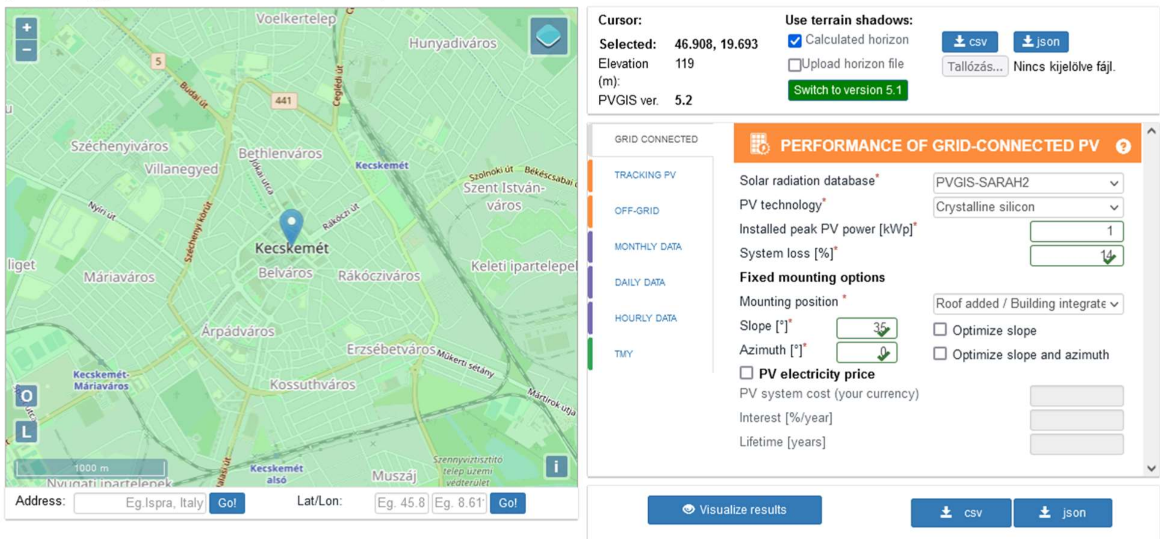


Figure 35. Data query of radiation interactive tools of PVGIS. (Cattaneo 2018)

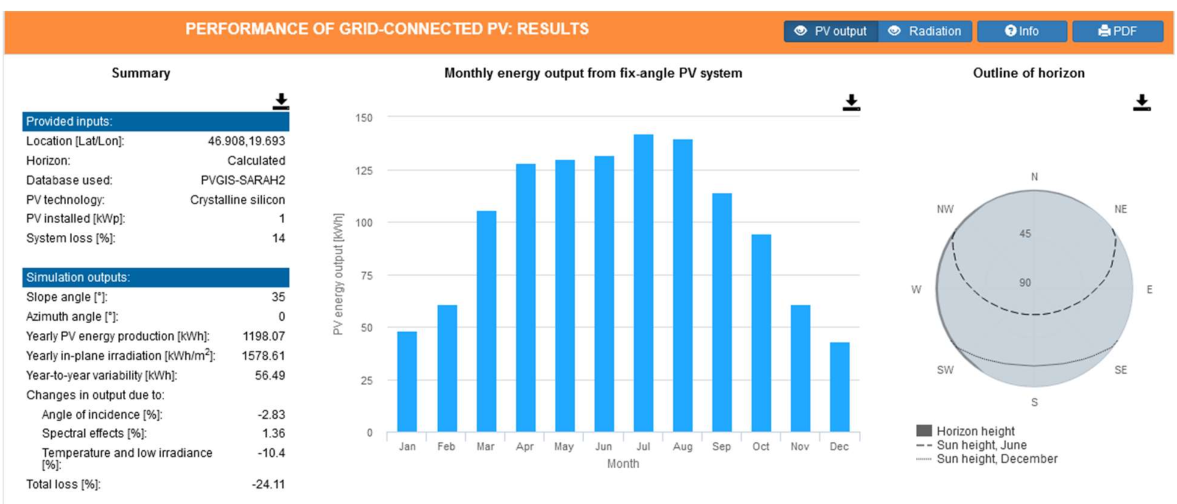


Figure 36. Results of radiation of PVGIS (Cattaneo 2018)

Based on PVGIS data, the production is 1578.61 kW/m2/year at 100% capacity, which means 284.15 kW annual actual production with 18% efficiency. To compare, based on the electricity production data of the International Energy Agency , 0.14% of the country should be covered with solar panels to cover the total electricity production in Hungary in 2021 (IEA n.d.). Can we count on an increase in the efficiency of producing electricity from solar energy? However, there are physical limits to the increase in performance. According to the laws of thermodynamics, energy conversion always involves energy loss (Kleidon et al. 2016), which is also true for environmental systems (Odum 2007). Research is currently being carried out in two directions for the development: to increase the lifetime of solar panel systems (El-Khawad et al. 2022), or the efficiency can be increased by possible cooling of the systems (Siecker et al. 2017) (Peng et al. 2017), but we cannot accurately count on these contingencies at the moment.

3.2. Estimating biomass energy potential

In the case of biomass, I used firewood as the energy source. Statistical data series going back several years are available (Nemzeti Földügyi Központ 2022). Complex environmental effects can significantly influence other biomass sources, such as agriculture (Harsányi et al. 2021) (Mohammed et al. 2022), so estimating their amount is an energy potential more complex. In order to determine the energy potential, similar to solar energy; I calculated the area data of certain tree species groups from the area data of the Ecosystem Map of Hungary (Agrárminisztérium 2019) To determine the size of the area, I performed the following steps using the QGIS program:

1. I downloaded the Ecosystem Map of Hungary from the following website: http://alapterkep.termeszetem.hu/ (Agrárminisztérium 2019)
2. I have defined the study area.
3. Among the raster analyses, I used the zonal histogram, which gives the number of pixels of each area used as a table in the demarcated area.
4. I saved the received data in an Excel table.
5. Since one pixel covers an area of 20x20 meters, I multiplied the pixels of each area used by 400, thus obtaining the size of the area used in square meters.

After that, based on forestry statistical data (Nemzeti Földügyi Központ 2022) I determined the average amount of live wood per hectare and the percentage of the amount of wood harvested for energy purposes in one year based on data from 2019, 2020 and 2021. Based on the statistical data, the stock of live wood is increasing. The energy source is replenished above the extracted amount. I project the national average data to the settlement and micro-regional level so that local anomalies do not affect the data. The energy that can be used can be divided into heating and electricity, with an efficiency of 30% (Popp, Potori 2011) in the latter case. Since different tree species and groups of trees have different energetic properties, I also considered this in the calculation. The Ecosystem Map of Hungary and forestry statistical data define different species groups, so I grouped them for the calculations considering the available energy data (Table 12). The summary of the calculations of the averages calculated from the national data serving as the basis for the calculations can be found in Appendix M2. Based on forestry statistical data (annual wood harvest for energy purposes per hectare, volume of live wood per hectare), area data and energy data of firewood, I determined the following formula to estimate the biomass potential of a given area for firewood, and I defined the specific variables with which it can be used in landscape planning:

$$W=V\times A\times \%\times H, \text{ where}$$

W: work (kWh)
V: volume of live wood per hectare derives from national statistical data (m^3/ha)
A: area
%: proportion of wood harvested for energy purposes
H: calorific value of wood species or group of wood species (kWh/m^3)

If electricity is produced from biomass, I modified the formula depending on the average efficiency of the biomass power plant:

$$W=V\times A\times \%\times H\times \eta, \text{ where}$$

W: work (kWh)
V: volume of live wood per hectare (m^3/ha)

A: area
%: proportion of wood harvested for energy purposes
H: calorific value of wood species or group of wood species (kWh/m^3)
η: energy conversion efficiency

Forestry statistics	**Ecosystem Map of Hungary**	**Energetic groups**	**Energy potential (kWh/m3)**
Quercus robur	Turkey oak forests	Quercus sp.	2940
Quercus petraea	Pedunculate oak forests, monospecific or mixed with ash		
Other Quercus sp.	Downy oak forests		
Quercus cerris			
Fagus sp.	Forests dominated by other native tree species (without excess water) Beech forests	Other hardwood	1960
Carpinus sp.	Other mixed deciduous forests, Pedunculate oak-hornbeam forests		
Acer sp.			
Ulmus sp.			
Fraxinus sp.			
Other hardwood	Alder forests		
Robinia sp.	Black locust-dominated mixed plantations	Robinia sp.	2940
Plopii hibrizi	Plantations dominated by non-native poplar and willow species	Populus sp.	1960
Native Populus sp.	Native poplar dominated forests		
	Poplar woods outside the floodplain		
Salix sp.	Pioneer forests of hilly and mountainous regions, Willow woods outside the floodplain	Other softwood	2100
Alnus sp.			
Tilia sp.			
Other softwood	Plantations of other non-native tree species Forests dominated by other native tree species with excess water		
Pinus sylvestris		Pine sp.	2240
Pinus nigra			
Picea abies			

Larix decidua			
Other pine species	Conifer-dominated plantations		

Table 12. Tree species and species groups (Nemzeti Földügyi Központ 2022) and their potential energy.

Biomass is a conditionally renewable energy source, as I determined based on the statistical data of the amount of the resource in Hungary. At the same time, the composition of the forest and the applied forestry technologies (Pápai 2014) can significantly influence the environmental effects of forests (Polgár et al. 2018) (Tölgyesi et al. 2020), which can be influenced by landscape planning tools (Bell, Apostol 2008). Using traditional forestry technologies would be much more beneficial from an ecological point of view (Varga et al. 2020). The third table summarizes the complex environmental and landscape effects of firewood, and I analysed the aspects also in the case of heating use and biomass power plants. Air pollution must be taken into account during operation in both cases; at the same time, the establishment of the power plant has a complex environmental impact and increases the proportion of industrial areas, and a line of adequate capacity must be provided to transport electricity. This can also cause landscape and environmental problems, which I have already detailed with solar energy. Air pollution can be reduced with different filters, even on a small scale (Villeneuve et al. 2012) It is also important to note that energy conversion involves a loss of useful energy, which in this case is 70%. When using biomass for heating purposes, it is also necessary to consider the topography to prevent possible smog (Ferenczi et al. 2020).

		Heating	**Electricity**
production of materials, mining	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
installation	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

		Heating	Electricity
production	living world	X	X
	landscape	X	X
	geological formations		
	water		X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
facility abandonment	living world	X	X
	landscape	X	X
	geological formations	X	X
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

Table. 13. Environmental impacts of biomass as energy resource. (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

3.3. Estimating electricity potential of waste

In the case of waste, we calculated the 10-year average of municipal municipal waste. The amount of municipal waste is based on average amount, that I detail in the results, as it is depending of the research area. Waste can produce electricity and district heat, or biogas, described in the biogas subsection. In my research, I estimate the production of electricity. In the case of district heating, several factors have to be taken into account that go beyond the tools of landscape architecture (Descombes, Boudigues 2009), However, according to experience and measurements, 550 kWh of electricity can be produced from 1 ton of waste (Themelis 2012). Since the collection of waste is defined by law (2012. évi CLXXXV. törvény 2012), building on an already existing infrastructure is possible. In my research, I only considered electricity use since several factors can influence heat utilisation (Brueckner et al. 2014), However, in Hungary, waste is also used for the production of both electricity and district heat (Energetikai Szakkollégium 2013). Based on the available quantitative statistical data and the average energy potential data of the technological descriptions, I determined the estimation of electricity or biogas potential of the waste in the following formula, where I defined the specific variables with which it can be used in landscape planning:

W=F×H, where

W: work (kWh)
F: mass of waste (t)
H: calorific value of waste per unit (kWh/t)

The construction of the waste power plant means a complex environmental and landscape impact, as it involves the construction of a new industrial facility, these impacts are summarized in Table 14. Concerning the operation of the power plants, mainly due to air pollution, there is generally significant social resistance ('Tiltakozás a Győri Hulladékégető újabb kapacitásnövelése ellen' 2007). Measuring air pollution is a complex process, and defining the measurement points, the materials to be measured, and the methodology is necessary. The currently tested materials do not exceed the limit values for the measured materials in the case of a waste utilization plant that complies with the current standards (Lonati et al. 2022). From the point of view of the energy system, waste is essential because it is a renewable energy source, the production of which can be controlled compared to the much less polluting sun and wind, whose production cannot be controlled. In addition, it fits into the circular economy model (European Commission 2015).

		Electricity
production of materials, mining	living world	X
	landscape	X
	geological formations	X
	water	X
	air	X
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
installation	living world	X
	landscape	X
	geological formations	X
	water	X
	air	X
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
production	living world	X
	landscape	X
	geological formations	
	water	
	air	X
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
facility abandonment	living world	X

	landscape	X
	geological formations	X
	water	
	air	
	climate	
	built environment, cultural heritage	X
	environmental elements, systems	X

Table. 14. Environmental impacts of waste power plant. (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

3.4. Estimating energy potential of biogas

The source of biogas can be waste, sewage, vegetable waste from agriculture and animal manure (Balat, Balat 2009). In my research, I considered two sources of biogas: animal manure and municipal waste. The reason for this is that in both cases, the law regulates the collection (2012. évi CLXXXV. törvény 2012) (45/2012. (V. 8.) VM rendelet a nem emberi fogyasztásra szánt állati eredetű melléktermékekre vonatkozó állategészségügyi szabályok megállapításáról 2012), on the establishment of animal health rules for animal by-products intended for non-human consumption, 2012), in this way, the collected quantity can be coordinated, and statistical data are also available. In the case of Kecskemét research area, I also added biogas and electricity production from sewage, as the settlement using them, and the datasets are available. For the number of livestock, we used serial data from the 2020 agricultural census settlement ('Hungarian Central Statistical Office' n.d.). I took literature data as a basis for the annual manure production per animal species (Hartman 2010) (Szendrei 2008). In the case of biogas, I considered several scenarios. In the case of waste, I calculated based on the data provided by the National Waste Management Coordinating and Asset Management Private Limited Company in the case of the micro-region and the Kecskemét data based on the assessment of the environment of the settlement (Kecskemét Megyei Jogú Város Önkormányzata 2019). In the case of biogas, the methane content determines the amount of energy that can be used (Swedish Gas Technology Centre Ltd 2012), I calculated half of the amount of manure, in which I took into account an average methane content of 60%, the energy amount of which is 6 kWh/m3 ('Biogas FAQ' n.d.) (Table 15). In the case of waste, I calculated 25% of the collected waste, this value was taken into account entirely for heating use since electricity can also be produced from waste by burning it, but the multiple energy conversion involves multiple energy losses due to the laws of physics (Odum 2007). The content of one ton of waste biogas is optimally between 7-12 m3, of which I calculated the median value, which is 9.5 m3, the energy amount of 1 m3 of biogas is between 14-17 MJ (Woperáné Serédi, Tanka 2011), the median of which is 15.5 MJ, which is 4.3056 kWh, so the potential of biogas produced from 1 ton of waste is rounded to 41 kWh. I calculated an average efficiency of 47% for electricity production (Farooque et al. 2015). Since 550 kWh of electricity can be produced directly from one ton of waste, the potential of the biogas that can be extracted is 41 kWh, and the energy potential of converting it into electricity is only 19.27 kWh, so in the case of the biogas produced from waste, I calculated the direct use. I clarified the estimation of the energy potential of biogas using the following formula, which I determinded based on the available statistical data and technological knowledge and specified variables with which it can be used in landscape planning:

$W = F \times V \times Q \times H$, where

W: work (kWh)
F: annual amount of manure of a specific livestock species (t)
V: biogas content of the manure of a given farm animal (m^3/t)
Q: unit number
H: calorific value of biogas per unit (kWh/m^3)

If electricity is produced from biogas, the formula changes as follows:

$W = F \times V \times Q \times \sigma \times \eta$, where

W: work (kWh)
F: annual amount of manure of a specific livestock species (t)
V: biogas content of the manure of a given farm animal (m3/t)
Q: unit number
H: calorific value of biogas per unit (kWh/m^3)
η: energy conversion efficiency

	Manure (pc/t/y)	Biogas (m3/t)	Biogas (kWh/m3)	Biogas (kWh/t)	Biogas (kWh/pc)
cattle	8,00	225	6	1350	10800
pig	0,90	445	6	2670	2403
sheep/goat	0,50	225	6	1350	675
hen	0,02	465	6	2790	56
goose/turkey	0,02	480	6	2880	58

Table. 15. Amount of energy in biogas from manure

Looking at the environmental and landscape effects (Table 16), I considered two uses of biogas, for heating and the for electricity production. In both cases, the air pollution generated during the combustion of methane must be considered. In the case of heating use, a small-scale network must be established for supply, which may involve significant earthworks (Hengeveld et al. 2016). According to research, establishing a biogas plant typically improves the general environment of the area (Börjesson, Berglund 2007). In the case of electricity production, the design of the power plant means a complex environmental impact, it increases the proportion of industrial areas, and the connection to the electrical network must be ensured. These complex effects have already been described in the case of biomass. Biogas fits into the circular model of the economy, as it is a renewable energy source and reduces the release of methane into the atmosphere (European Commission 2015).

		Heating	**Electricity**
production of materials, mining	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

		Heating	Electricity
installation	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
production	living world	X	X
	landscape	X	X
	geological formations		
	water		X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
facility abandonment	living world	X	X
	landscape	X	X
	geological formations	X	X
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

Table. 16. Environmental impacts of biogas (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

3.5. Estimating energy potential of wind

Several data sources are available to determine the wind energy potential. In the PVGIS database (CATTANEO 2018), radiation and data series of wind speeds going back several years are available (Fig. 37). In this case, the average wind speed can be calculated based on data series of several years. The data can be downloaded in CSV and JSON formats, which can be used for further calculations. The annual wind speed values can be displayed in the figure, where the wind speed changes can be visually seen at an annual resolution (Fig. 38).

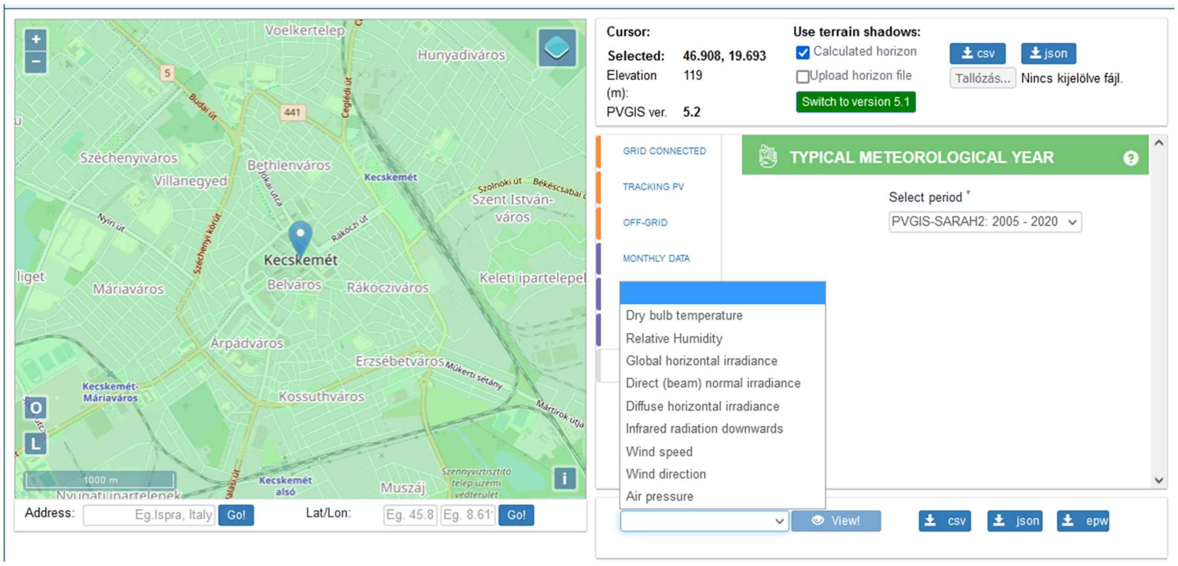


Figure 37. Data query of meteorological interactive tools of PVGIS. (Cattaneo 2018)

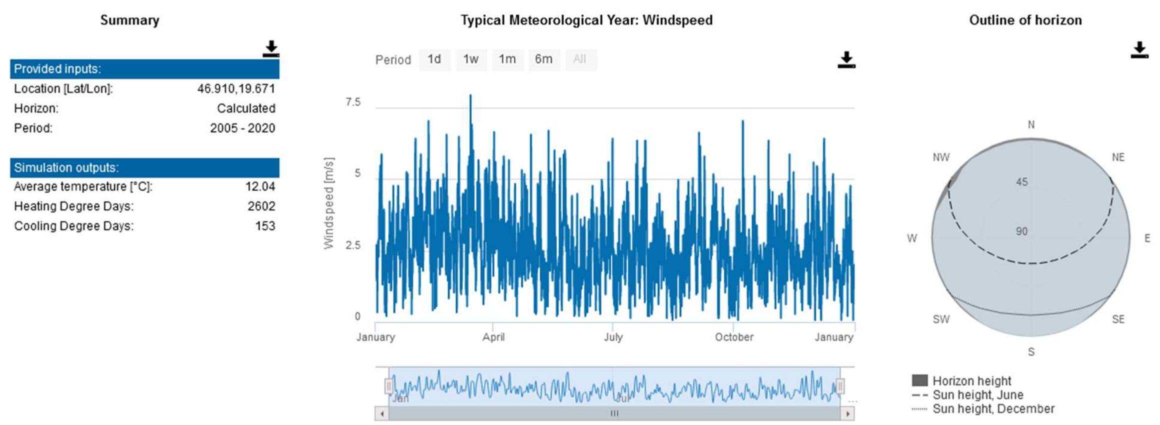


Figure 38. Results of wind speed in Kecskemét PVGIS. (Cattaneo 2018)

Map databases (Fig. 39), such as Global Wind Atlas, are already available Atlas (‘Global Wind Atlas’ n.d.), which can be used to query detailed data on wind speeds at a regional level, which can be downloaded as GIS data, but also as a table in the case of a selected area. In the latter case, the height of the turbine can be selected on the website (10, 50, 100, 150, and 200 meters). I get detailed data related to the wind speed that affects the production (Fig. 6). Based on the data, the energy potential of wind energy projected onto the area can be estimated similarly to biomass and solar energy. During spatial planning, it is essential to consider wind energy production, but at the same time, I used other methods in my research. Since the Wind Atlas also contains data on mean power density per area unit, I determinded the following formula to estimate the electricity potential of wind, where and I specified the variables with which it can be used in landscape planning:

$W = U \times A$, where

W: work (Wh)
U: mean power density of wind (W/m2)
A: area (m2)

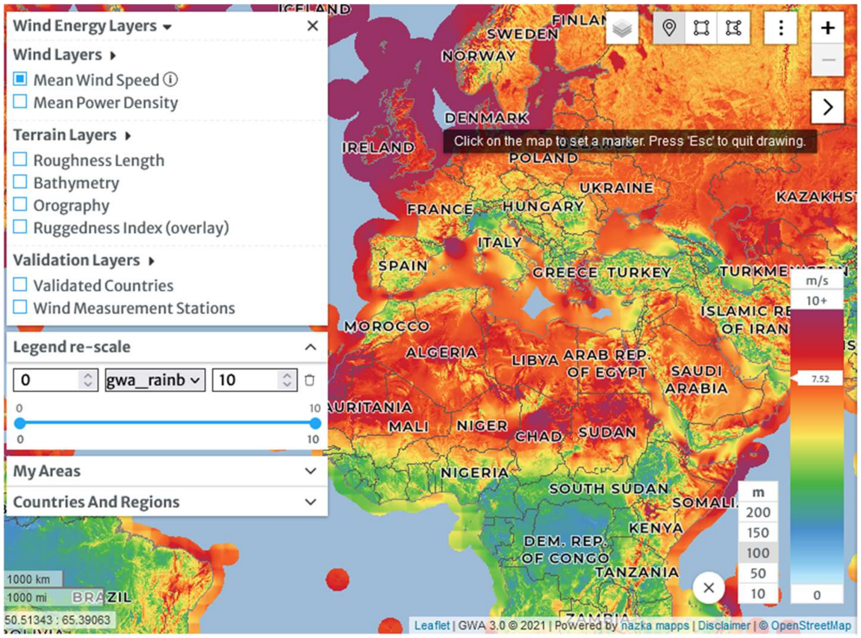


Figure 39. Map of Global Wind Atlas. ('Global Wind Atlas' n.d.)

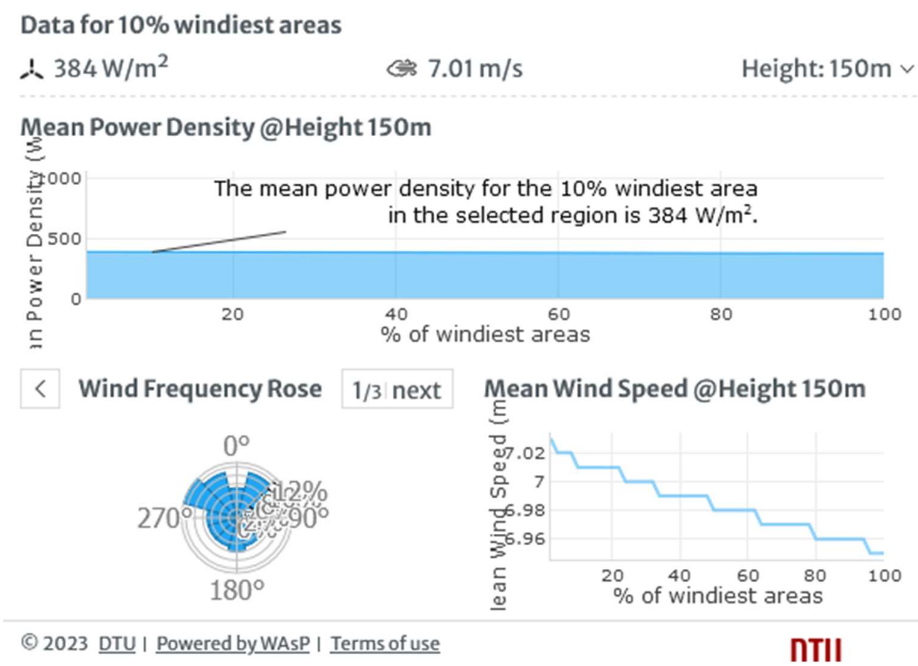


Figure 40. Results of wind data. ('Global Wind Atlas' n.d.)

Since the environmental effects during wind energy production are minor, it can be essential to the energy mix (Table 17). The characteristics of production are examined by the excellent complementarity of wind and sun in terms of energy production (Couto, Estanqueiro 2020) (Gallardo et al. 2020) (Ren et al. 2019). The dunkelflaute phenomenon (Li et al. 2020) (Li et al. 2021), must also be considered in the energy calculations, which is the absence of events when neither solar nor wind energy is produced. With the appearance of low-speed turbines (Fig. 41), electricity can be produced even on a household scale with wind energy, and its environmental and landscape effects are smaller than those of large-scale turbines. In this case I linked the number of households to the production. I calculated two scenarios: 10% and 20% of households are supplied with electricity by a small-scale wind turbine. In the Table 17, I compared the impacts of low-speed turbines and typical turbines.

Regarding the environmental effects, I highlight two things. Due to their height, traditional, high-performance wind turbines (Fig. 42) require a substantial concrete foundation, which significantly impacts the ground. The other study of significant landscape impact goes back decades in Hungary (Drexler et al. 2010) (Jombach, Sallay 2021).

		Low speed wind turbine	Typical wind turbine
production of materials, mining	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
installation	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate	X	X
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
production	living world	X	X
	landscape	X	X
	geological formations		
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems		
facility abandonment	living world	X	X
	landscape	X	X
	geological formations	X	X
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

Table. 17. Environmental impacts of wind (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

Figure 41. Low speed wind turbines in Renewable Energy Centre, Hárskút, Hungary. (‘Hárskúti Megújuló Energia Központ’ 2007).

Figure 42. Wind turbines in Burgenland, Austria.

3.6. Defining of potential locations for the use of hydropower

I examined the surface water network and topography of the sample areas with a geospatial tool, for which I determined the slope categories using a surface model (‘EU-DEM — Copernicus Land Monitoring Service’ n.d.) and represented it with the water network (‘EU-Hydro - River Network Database — Copernicus Land Monitoring Service’ n.d.). I followed these steps:

1. I downloaded the Digital Elevation Model from the following website: https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=download (‘EU-DEM — Copernicus Land Monitoring Service’ n.d.).
2. I downloaded the River Network Database of the area from the following website: https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-river-network-database?tab=download (‘EU-Hydro - River Network Database — Copernicus Land Monitoring Service’ n.d.)

Among the raster analyses, I used the slope analysis and modified the obtained result with the style settings to correctly display the slope categories.

With the help of the slope category map, it is possible to visually select the places whose natural slope may make it suitable for establishing a small-scale hydropower plant. For further investigation, I used the Profile Tool to draw the cross-sections of the watercourses on the EU-DEMoverlay so that the points and sections suitable for hydropower utilization could be selected. Since the ecological impact of hydropower plants is significant, I limited the further investigation compared to the county planning plans.

The use of water energy has a significant environmental impact, and the establishment and operation of the power plant significantly impact environmental elements and systems. The long-term environmental effects of large-scale dams can be catastrophic (Moran et al. 2018). Nevertheless, the use of water as an energy source must be considered for two reasons: it is a controllable energy source, and the most efficient form of electricity storage, according to our current knowledge, is the pumped hydroelectric power plant (Breeze 2018).

production of materials, mining	living world	X
	landscape	X
	geological formations	X
	water	X
	air	X
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
installation	living world	X
	landscape	X
	geological formations	X
	water	X
	air	
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
production	living world	X
	landscape	X
	geological formations	X
	water	X
	air	
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X
facility abandonment	living world	X
	landscape	X
	geological formations	X
	water	X
	air	
	climate	X
	built environment, cultural heritage	X
	environmental elements, systems	X

Table. 18. Environmental impacts of hydro energy (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

The hydrographic properties limit not only the possibilities of direct electricity production but also thermal power plants since these power plants, although in many cases extremely efficient, due to their water consumption and water use due to technology (Feeley et al. 2008), their application possibilities in the settlement are limited.

3.7. Defining ground heat potential

Regarding geothermal energy potential, Hungary has significant resources that have not yet been integrated into the energy mix (Mádlné Dr. Szőnyi et al. 2008). The potential is also available in map form through the National Geothermal System (‘Országos Geotermikus Rendszer’ n.d.). Geothermal energy can be used in several ways: electricity production, district heating or domestic heating-cooling system; this also means the environmental effects may differ. (Rosen, Koohi-Fayegh 2017). The environmental impacts are the smallest for household systems since, in this case, there is no need to establish a new industrial area, there is no need to build new pipes for the heating system, and it uses geothermal heat as a source, so there is no impact on the water base either (Table 19). due to the available technological knowledge, I count on household systems in the research. In the case of the heat pump, electricity is used to transport the heat, and 1 kW of electricity can deliver at least 3 kW of thermal energy (‘A hőszivattyúk elektromosáram-felhasználása’ n.d.), so I calculated with this value and calculated with a part of the electrical production of renewable energy sources that I estimated. I examined four scenarios where the constant values are 50% of the energy potential of biomass, in the case of waste also 50%, in the case of biogas, 50% of animal-derived biogas is the source of electricity; variable factors are:

1. solar energy with 10% coverage of buildings, wind energy with 10% of households
2. solar energy with 20% coverage of buildings, wind energy with 10% of households
3. solar energy with 30% coverage of buildings, wind energy with 10% of households
4. solar energy with 10% coverage of buildings, wind energy with 20% of households.

Through the scenarios, I will show the proportion of heating and electrical energy that the households in the examined sample areas can use for different proportions of electricity.

		Electricity	District heating	Household heating-cooling
production of materials, mining	living world	X	X	X
	landscape	X	X	X
	geological formations	X	X	X
	water	X	X	X
	air	X	X	X
	climate	X	X	X
	built environment, cultural heritage	X	X	X
	environmental elements, systems	X	X	X
installation	living world	X	X	
	landscape	X	X	
	geological formations	X	X	
	water	X	X	
	air	X	X	
	climate	X	X	
	built environment, cultural heritage	X	X	X
	environmental elements, systems	X	X	
		Electricity	District heating	Household heating-cooling
production	living world	X	X	

	landscape	X	X	
	geological formations	X	X	
	water	X	X	
	air			
	climate			
	built environment, cultural heritage	X	X	X
	environmental elements, systems			
facility abandonment	living world	X	X	X
	landscape	X	X	X
	geological formations	X	X	X
	water	X	X	X
	air	X	X	X
	climate	X	X	X
	built environment, cultural heritage	X	X	X
	environmental elements, systems	X	X	X

Table. 19. Environmental impacts of geothermal energy (Spellman 2015) (Rutherford, Williams 2015) (Scipioni et al. 2017) (Singh et al. 2013) (Apergis et al. 2010)

3.8. Estimating the consumption

I also estimated the consumption side based on statistical data, the source of which is the data series of the Central Statistical Office and the International Energy Agency. I chose 2016 as the base year since there was a micro census, so household data is available for this year. Considering the trends of total consumption (Fig. 43) and electricity consumption (Fig. 44) of the energy sectors, there was an exceptional electricity consumption in the industry in 2012; apart from this, consumption typically fluctuates slightly and increases in Hungary except tha period of the COVID pandemic.

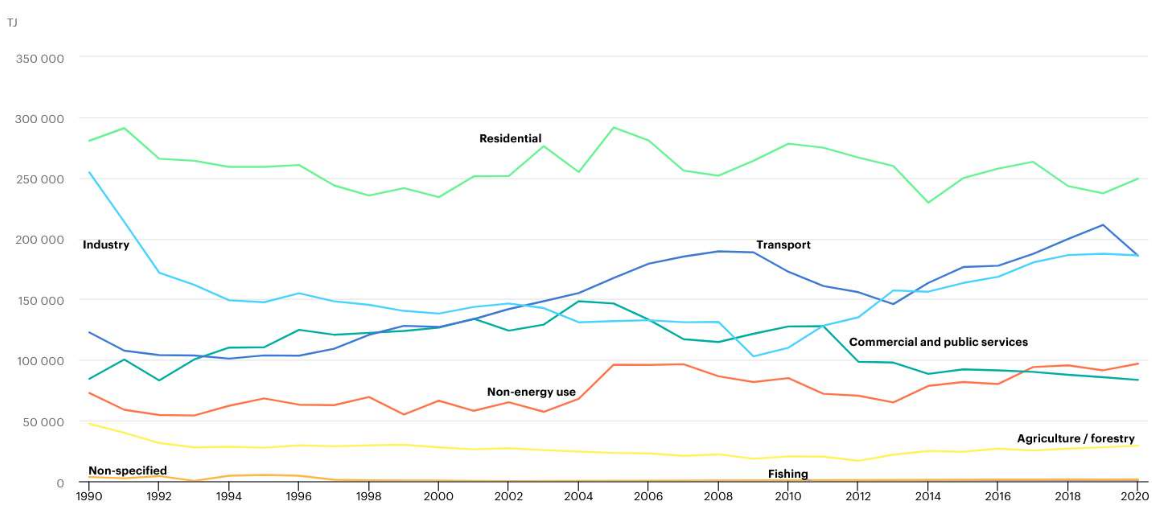


Figure 43. Total consumption by sector. (International Energy Agency 2022b)

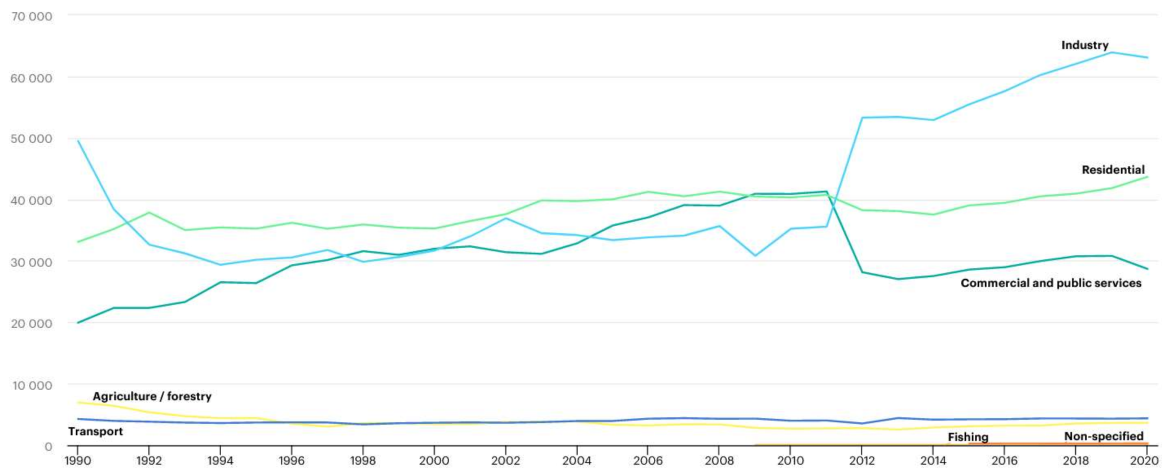


Figure 44. Electricity consumption by sector. (International Energy Agency 2022b)

On the consumption side, I considered residential, industrial, trade and services, and agriculture. I calculated the population data by household, where a significant part of the energy consumption is heating. The use of electrical devices and cooling also appear (Fig. 45). Based on the data, it can be calculated that household consumption was distributed as follows in 2016: 13,166 kWh cooling, 1,644 kWh appliance use and 21 kWh cooling. I examined the electricity consumption of households, which is 2724 kWh on average in the base year, which means that the 1059 kWh of electricity consumed is used for heating, which is 8% of the total heating consumption. When calculating household consumption, I determine the annual consumption of electricity at 2,724 kWh, the heating energy at 131,166 kWh, of which 8% is electricity (Table 20).

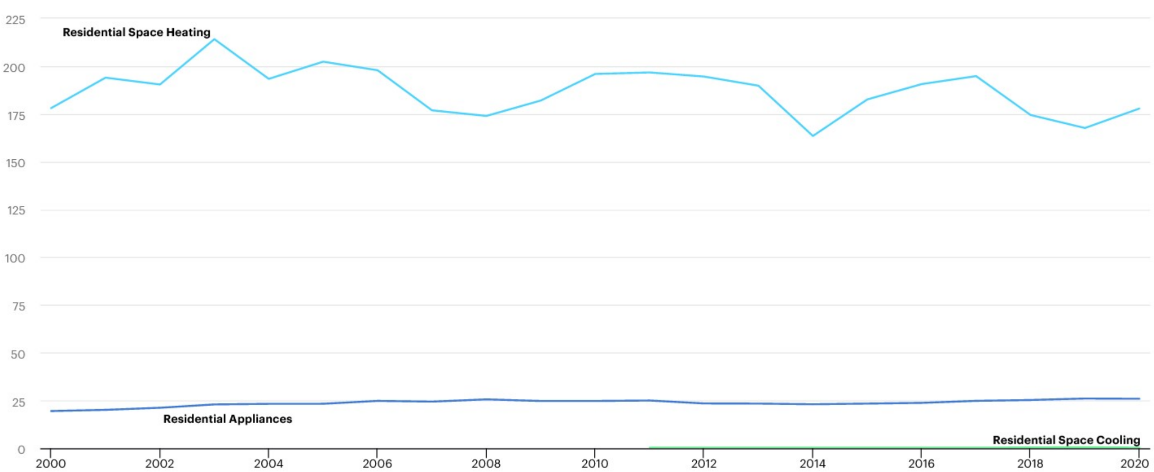


Figure 45. Residential total consumption by end use. (International Energy Agency 2022b)

	Consumption (PJ)	Consumption (kWh)	Number of households (2016)	Consumption/households (kWh)
Residential space heating	190,6	52944444449	4021296	13166
Residential appliances	23,8	6611111112	4021296	1644

Residential space cooling	0,3	83333333	4021296	21
Residential electricity	39	10953897652	4021296	2724

Table. 20. Residential total consumption by end use in 2016.

I use averages calculated for one household as a basis for energy consumption by industry, trade services, agriculture, transport, and fishing. There are also other calculations, for example, for the energy consumption of sectors by area (Bayer et al. 2020), which is also used by the Energy Club in the case of municipal energy plans (‘Spóroljon az önkormányzat’ 2022), standards may differ, and these may also affect energy consumption. Since the energy systems of the two investigated sample areas show a significant difference, I weighted the energy consumption of industry, commerce and services and transport. In the case of Kecskemét, I doubled the energy consumption calculated per household since the county's seat is an industrial centre, and several services are used by the people living in the small settlement (e.g., hospitals, educational institutions, public administrative institutions, cultural institutions). In the case of the micro-region, I took as a basis half of the energy consumption calculated for one household since the consumption in these sectors is small in small settlements.

Industry, commercial and public services, and agriculture provide more diversified data on the energy consumption of agriculture (Table 21). However, the data series of the Central Statistics Office (‘Központi Statisztikai Hivatal’ n.d.-b) contains the amount of the energy carrier not only used for energy purposes, so I calculated only the aggregated data. Natural gas is one of the raw materials for fertilizer production (Sauchelli, Hamor 2013), so this industry uses a significant amount, which is not included in the data series. At the territorial level, I analyse the consumption of individual energy sources. In contrast, on the consumption side of the sample areas, I calculate the consumption of electricity and other energy from an agricultural point of view.

Energy source	2016	2016 (kWh)	Energy consumption/households (kWh)
Electricity	900	900000000	224
Coal (t)	1000	8141000	2
Wood (t)	51000	270300000	67
Gasoline (t)	4000	54800000	14
Diesel oil (t)	334000	4392768000	1092
Propane-butane gas (t)	29000	341887380	85
Natural gas (m3)	178000000	1961560000	488
District heating (TJ)	15	4166667	1
Biogas (TJ)	50	13888889	3
Geothermal (TJ)	1 372	381111111	95

Table. 21. Energy sources used by agriculture in 2016.

I divided the energy consumption of industry, commerce and services and fishing, which currently has negligible energy consumption, into two parts: electricity consumption and consumption for other purposes. The latter may include heating and the operation of internal combustion engines, for which there are no diversified data, so I can count on the surplus I calculated in the energy mix. For the calculations, I used the data series of the International Energy Agency (International Energy Agency 2022a) (International Energy Agency 2022b). Since the International Energy Agency calculates, together with agriculture and forestry, the energy consumption of forestry was 3,335,534,821 kWh in 2016, which is an average of 829.47 kWh per household, and the total energy consumption of agriculture is 3,273,359,355 kWh. I have presented the total consumption of the sectors per household in Table 22 and the data series for electricity in Table 23.

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Consumption (kWh)	Consumption/household (kWh)
Industry	168557	57607	110950	30819469100	7664
Commercial and public services	91409	28962	62447	17346402766	4314
Transport	177661	4237	173424	48173371872	11980
Agriculture/Forestry	26982	3190	23792	6608894176	1643
Non-specified	1471	266	1205	334722490	83
Fishing	98	50	48	13333344	3
Non-energy use	80174	-	-	-	-

Table. 22. Energy consumption by sectors in 2016.

	Consumption (TJ)	Consumption (kWh)	Consumption/household (kWh)
Industry	57607	16001957246	3979
Commercial and public services	28962	8045006436	2001
Transport	4237	1176945386	293
Agriculture/Forestry	3190	886111820	220
Non-specified	266	73888948	18
Fishing	50	13888900	3

Table. 23. Electricity consumption by sectors in 2016.

By estimating the consumption, I show the extent to which the energy potential of renewable energy sources can cover the consumption side through four scenarios. In the case of biomass, waste and biogas, I used the same ratios in all cases. In the case of biomass, consumption is divided 50-50 between electricity and heating. In the case of waste, electricity is generated from 50% of the collected waste. In the case of biogas, 25% of the waste is utilized, which is used entirely as heating energy; 50-50% of manure is used to generate electricity, and it is used directly as heating energy. I use geothermal energy to heat the households, so I first check what percentage of the households can supply the calculated amount of biomass and biogas, and I make up the remaining deficit from geothermal energy with the help of electricity. In both cases, variable energy sources such as the sun and wind play a role in producing electricity. In the energy mix, similarly to geothermal energy, I consider the following four scenarios:

1. solar energy with 10% coverage of buildings, wind energy with 10% of households
2. solar energy with 20% coverage of buildings, wind energy with 10% of households
3. solar energy with 30% coverage of buildings, wind energy with 10% of households
4. solar energy with 10% coverage of buildings, wind energy with 20% of households

After that, it can be determined to what extent the renewable energy potential determined with landscape architecture tools can cover the consumption side.

3.9. Summary of materials and methods

Based on the collection of data related to the energy system and the developed methods, I determined the potential of some renewable energy sources and introduced their environmental and landscape effects. In Table 24, I have summarized each energy source in which cases I was able to determine the potential of the given renewable energy source with landscape architecture tools, and related to this, to connect and influence the production of the given energy source at the settlement level. In the case of solar and wind energy production, I limited the available energy potential; the limitation was tied to land use; in both cases, the production can be estimated numerically. Regarding biomass, waste, and biogas, I numerically determined both the heating and electricity potential. However, due to the nature of the production, I did not limit the energy potential to land use, as it can be interpreted at the object level. In one case, I could quantify geothermal energy potential in the case of geothermal energy, where I used the previously estimated electric current potential as a basis. Only potential areas of water energy production can be identified; the production potential cannot be estimated.

Energy resource	Use	Estimation	Connection between energy potential and environmental impacts
Sun	electricity	yes	yes
	heating	no	no
Biomass	electricity	yes	no
	heating	yes	no
Waste	electricity	yes	no
	heating	no	no
Biogas	electricity	yes	no
	heating	yes	no
Wind	electricity	yes	yes
Hydro	electricity	no	no
Geothermal	electricity	no	no
	district heating	no	no
	household heating/cooling (ground heat)	yes	no

Table. 24. Connection between energy potential estimation and environmental impacts

In my research, I use the case study tool to examine the possibilities of transitioning to renewable energy sources at settlement and microregional level from a landscape architecture perspective. In Table 25, I have summarized the most important properties of the described energy sources, which influence their environmental impact and place in the energy system. These properties are the type, production characteristics, networking possibilities, scale and impact. In the table, I also collected the physical characteristics of energy sources, which influence production and impact the design of energy mixes (Saygin et al. 2015). This represents a technological limitation that is not related to the energy source but to the energy system. In the case of solar and wind, if we plan on a small scale, the production can be integrated into the current system; it does not involve the creation of a new power plant. On the other hand, in the case of biogas, biomass and waste, a power plant is needed to produce electricity. Different renewable energy sources have different landscape and environmental effects.

	Type	Production	Network	Scale	Environmental and Landscape effects
Sun	renewable	non-controllable, predictable	fit in	multi 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 effect related to power plant, high social resistance
Wind	renewable	non-controllable, hardly predictable	fit in	multi scale	low impact (noise), fit into the existing built-up area
Hydro	conditionally renewable	controllable, most efficient electricity storage	new power plant	multi scale	complex environmental effect related to power plant depending on scale,

Table. 25. Summary table of renewable energy sources

4. RESULTS

Based on the methodology described in the previous chapter, I determined the potential of renewable energy sources in two sample areas. I examine the energy potential on two scales: at settlement and micro-regional levels. In the case of both selected sample areas, the energy system has changed significantly in the past decades, so they are significant from the point of view of the investigation, the background of which will be described in detail during the presentation of the sample areas. In this chapter, by summarizing the results of the sample areas, I formulate general conclusions regarding the landscape architecture design of the energy system.

4.1. Results of the sample areas

4.1.1. Renewable energy potential of Kecskemét

Through the example of Kecskemét, I examined the renewable energy sources of the settlement at the urban scale. The city is the seat of Bács-Kiskun County, the largest settlement between the Danube and Tisza (Fig. 46), characterized by specific features. Its characteristics were not conducive to forming a settlement: the soil and hydrographic properties, its location is not strategically favourable, and its properties do not meet protection goals. Despite this, a settlement with significant agricultural resources was formed by annexing the surrounding settlements.

The settlement is the largest settlement of the Kiskunság loess ridge. The soil is typically loess or sand. The duration of sunlight per year is between 2030 and 2050; the difference between the summer and winter periods is significant, while in the former case, it is 800 hours, while in the winter, it is 190 hours. The annual rainfall is 510-530 mm, and the prevailing wind direction is northwest, but the south is also common. The groundwater is sinking, and the settlement's flood wells are at 50 °C. From the view of vegetation, the forest cover must be low, native forests are not typical, and open loess-oak associations have entirely disappeared (Dövényi 2010). Although there is a natural gas deposit in the southern part of Kecskemét, its importance is negligible; apart from three sand mines, it has no other mineral deposits (Fig. 47).

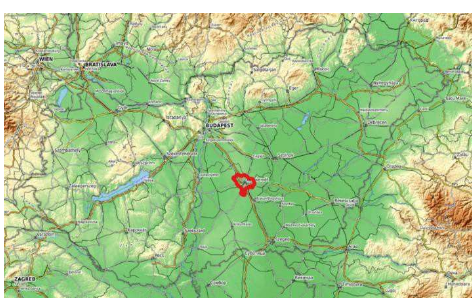


Figure 46. Overview map of Kecskemét in Hungary

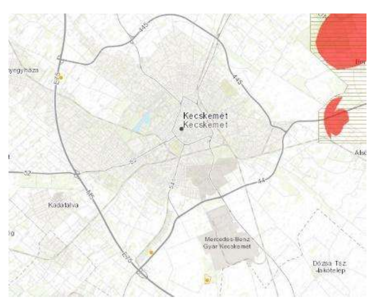


Figure 47.Mineral sources of Kecskemét (‘Magyarország ásványi nyersanyagai’ n.d.).

The town's structure is zonal, typical of the plain market towns; after the metropolitan core comes to the small-town narrow streets, then the garden-town zone, and then the farm world (Dr. Lovas 2015). Kecskemét is both a road and rail junction. The M5 motorway passes here, part of the E75

European motorway. Main road lines start radially from the settlement and connect to the highway. The railway network is part of the Budapest-Szeged electrified line (Dövényi 2010).

I present the land use structure through the data of the Ecosystem map. The area of arable land is the largest (almost 42%), and the proportion of built-up areas (23.7%) and forests (22.2%) is approximately the same. The proportion of lawn areas is approx. 12%. The area of rivers and stagnant waters is 0.24%. (Fig. 48). Land use affects energy management: forest areas are significant biomass sources, while water can limit energy production.

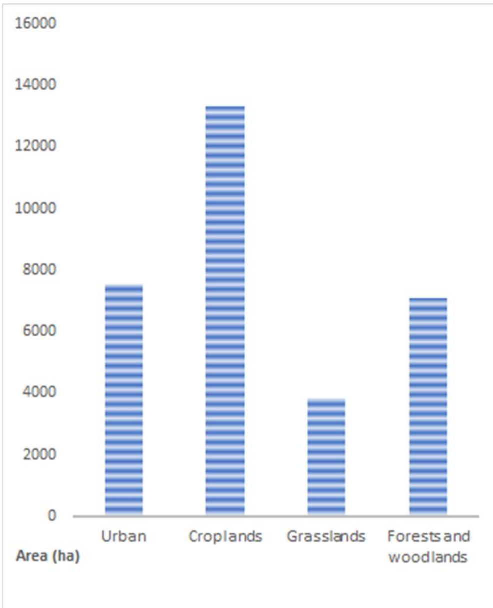


Figure 48. Land use structure of Kecskemét.

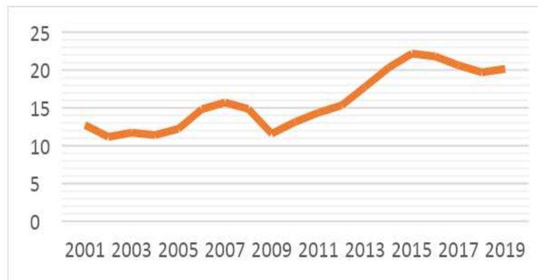


Figure 49.Share of automotive industry in GDP.

ts importance changed in the 21st century, as the town's industrial character was strengthened by the construction and commissioning of a central industrial facility in 2012 (Kecskemét Megyei Jogú Város Önkormányzata 2019). The automobile industry plays a significant role in the Hungarian economy; with minor fluctuations, it reaches 20% of GDP based on data from the Central Statistical Office (Fig. 49). Of the 100 companies with the highest revenue in Bács-Kiskun county, 40 are located in Kecskemét, the first being Mercedes-Benz Manufacturing Hungary Kft. In addition, Knorr-Bremse and Autoflex-Knott, which are related to the automotive industry, also have production plants in the settlement (Orosziné Varga 2022).

With the appearance of industry, the extent of the industrial area increased significantly, and the residential areas increased with it. This also manifested itself in the use of energy, which also became significant at the legislative level since the 400kV transmission line established between Cegléd and Kecskemét became a priority investment (Korm. rendelet 65/2017. (III. 20.) 2017), consequently not only at the local level but there was also a regional landscape effect due to the significant industrial investment. In this case, the energy demand has significantly increased and is increasing both in the case of industry and residential use.

By visual analysis of the historical maps, the historical eras of energy production (Stremke 2013) (Sørensen 2017) in the settlement. A windmill can be identified on the map sheet of the First Military Survey, which represents the energy system based on wood, charcoal and muscle power (Fig. 50), which disappears in the Second Military Survey with the spread of the steam engine. At the same time, the railway network began to be built (Fig. 51), which means signs of economic recovery based on coal. The military survey in 1941 (Fig. 52) shows the electricity-based economy, where industrial plants operated by electricity, such as the cannery, already appear.

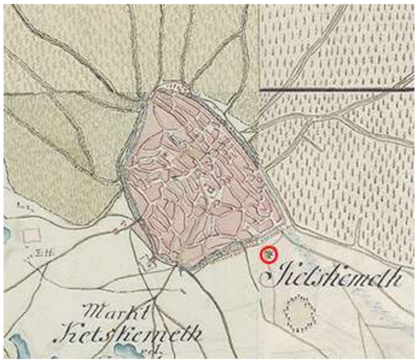


Figure 50. Kecskemét, First Military Survey (‘Magyarország (1782–1785) - Első Katonai Felmérés’ 1782)

Figure 51. Kecskemét, Second Military Survey (‘Magyar Királyság (1819–1869) - Második katonai felmérés’ 1819)

Figure 52. Kecskemét, Military Survey (‘Magyarország Katonai Felmérése (1941)’ 1941)

In order to determine the potential of solar energy and biomass production, I first determined the size of the areas related to energy production using the Hungarian Ecosystem Map, using the zonal histogram analysis of the QGIS program on the raster map (Table 26). In the case of solar energy, we took buildings into account since it is not necessary to build a new network, and the energy investment is carried out in a built-up area. To determine the sun's energy potential, I took the area of the buildings as a basis and calculated the energy potential for 10, 20 and 30% coverage. Because the angle of the roof, the shadow, and technological features can influence production, new calculations are required at the object level. Based on the measurement data, the electrical energy that can be produced in the settlement with a 1kW solar panel is 1578.61 kWh/m^2 (Cattaneo 2018), the average efficiency of the solar panels is 18% (Zito, Pelchen 2023), so in case of 10% coverage 343,071 MWh, in case of 20% 686,142 MWh, and at 30% 1,029,213 MWh of electricity can be produced. Kecskemét's annual irradiation is broken down by month in Appendix M3, and the table on which the area calculations are based can be found in Appendix M4.

	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

Table. 26. Areas of buildings and forests of Kecskemét.

For biomass production, I took wood production as a basis, the averages of which were determined using forestry statistics, the area of each tree species and tree species groups based on the Ecosystem Map of Hungary. Examining the stock of living trees in the settlement (Fig. 53), it mainly represents planted tree species (Robinia sp., Populus x hibridii, Pine), which are a problem from an ecological point of view (Palkó et al. 2020) (Tamás et al. 2003). This also means that, from an ecological point of view, these areas must be redesigned primarily with native tree species, which in the long run may partially transform the structure of the energy source.

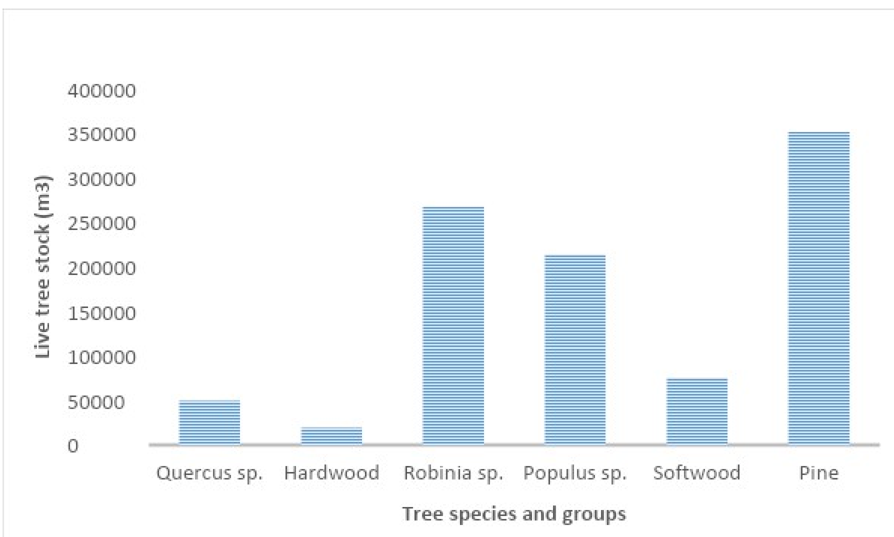


Figure 53. Tree livestock by species and species groups in Kecskemét.

The energy potential of Kecskemét's biomass is 18,606,783 kWh, calculating the raw wood stock of individual tree species and tree species groups and the annual amount extracted from it for energetic use. I summarised the results of the calculation in Table 27. Biomass can primarily be used for heating. This amount of energy can cover the annual heating energy of 1,413 households, which is 2.8% of the number of households in Kecskemét. Biomass can also be used to produce electricity, which is 30% efficient. In the case of Kecskemét, if 100% of the biomass potential is used for electricity generation, then 5,582,035 kWh of electricity can be produced, supplying 4.1% of the households in the settlement. The biomass potential can be divided into different proportions for heating and electricity use (Fig. 54). The table of calculations on which the figure is based can be found in Appendix M5. Although the production of electricity involves significant energy loss since the average heating energy consumption of a household is 4.8 times the electricity consumption, so with a consumption of 60% heating and 40% electricity, the heating and electricity consumption of almost the same number of households can be ensured with biomass in Kecskemét. An important aspect of heating and power generation is the consideration of dust pollution, which according to environmental studies, is also a problem ('Déli Iparterület, Területi Hatásvizsgálat' 2015) (Kecskemét Megyei Jogú Város Önkormányzata 2019).

Group of species	Area (ha)	Average live tree stock/ha (m3)	Live tree stock (m3)	Annual timber production of firewood (%)	Annual timber production of firewood (m3)	Energy (kWh/m3)	Energy potential (kWh)
Quercus sp.	211	236	49777	0,8	398,22	2940	1170758
Hardwood	78	253	19633	1,02	200,25	1960	392499
Robinia sp.	2212	121	267618	1,52	4067,80	2940	11959319
Populus sp.	1520	141	214269	0,48	1028,49	1960	2015845
Softwood	290	262	76053	0,64	486,74	2100	1022157
Pine	1187	296	351340	0,26	913,48	2240	2046205
Sum	**5497,12**		**978690,8**				**18606783**

Table 27. Biomass energy potential of Kecskemét.

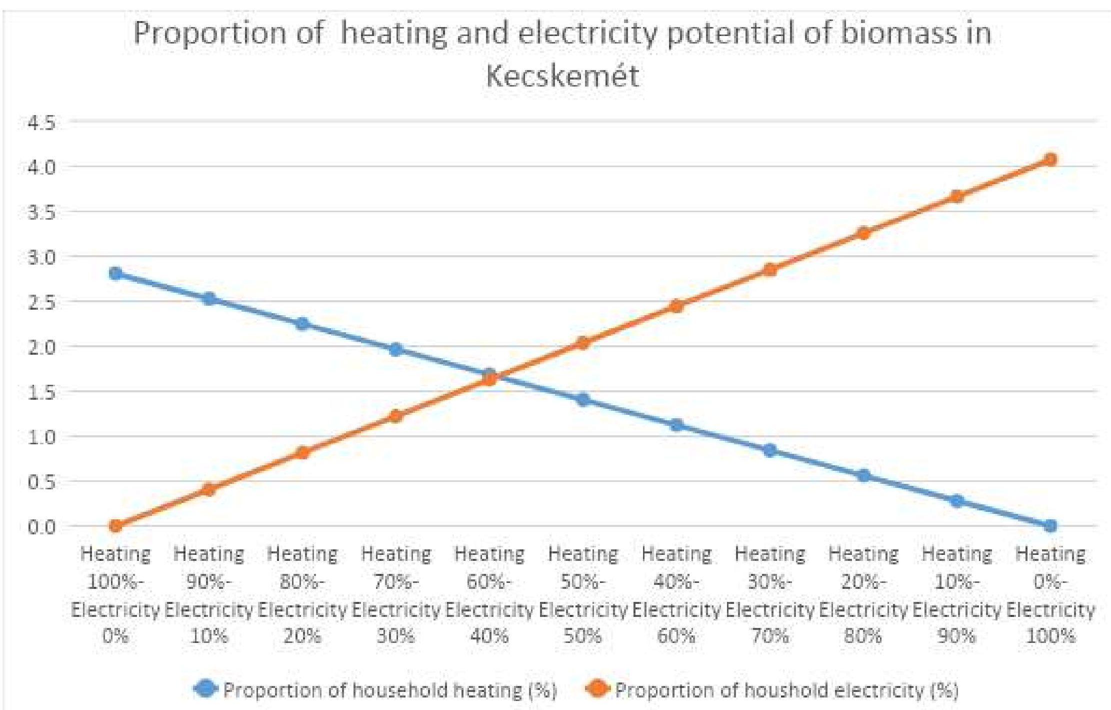


Figure 54. Proportion of heating and electricity potential of biomass in Kecskemét.

In the case of waste, we calculated the 10-year average of municipal municipal waste. Based on the average for the period between 2010 and 2019, the amount of municipal waste is 28,808.85 t (Kecskemét Megyei Jogú Város Önkormányzata 2019), it is essential to note that the amount varies in a relatively wide range on an annual basis (Fig. 55). The table of calculations on which the figure is based can be found in Appendix M6. The biogas that can be produced from waste, which can be used for heating purposes, I described the results of this in the following subsection. Electricity can also be produced in waste incineration plants. In my research, I calculated that electricity is produced from 50% of the waste and biogas from 25%. So, 7,922 MWh of electricity can be produced from 14,404.425 t of waste.

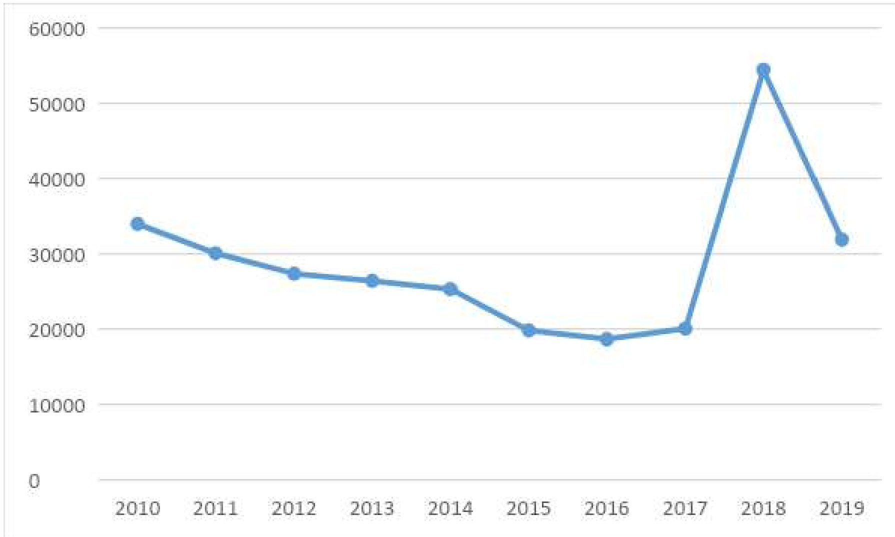


Figure 55. Amount of municipal waste in Kecskemét between 2010 and 2019.

In the next step, I determined the settlement's biogas potential from animal manure, waste and settlement wastewater. For the number of livestock, I used serial data from the 2020 agricultural census settlement (‘Hungarian Central Statistical Office’ n.d.). I calculated that biogas is produced from 50% of animal manure. The total energy potential of biogas is 19,241,411 kWh (Table 28).

	Size	Manure (pc/t/y)	Manure (t)	Biogas (m3/t)	Biogas (m3)	Biogas 50% (m3)	Biogas energy potential (kWh)
cattle	2331	8	18648	225	4195800	2097900	12587400
pig	3982	0,9	3583,8	445	1594791	797396	4784373
sheep/goat	3605	0,5	1802,5	225	405563	202781	1216688
hen	20100	0,02	402	465	186930	93465	560790
goose/turkey	3200	0,02	64	480	30720	15360	92160
					6413804	**3206902**	**19241411**

Table 28. Biogas energy potential from manure of Kecskemét.

In the case of waste, I calculated the amount collected at 25%. This is 7,202.2125 t, which has an energy potential of 295,291 kWh. Since the efficiency of direct electricity production in the case of waste is much higher, I calculated the total biogas production using it for heating purposes. In the case of wastewater, biogas has been integrated into the energy system of the settlement. The environmental assessment of Kecskemét completed in 2019 includes the biogas production of the wastewater plant and the amount of electricity and thermal energy produced from it (Kecskemét Megyei Jogú Város Önkormányzata 2019) (Fig.56). The use of biogas for energy purposes shows a continuous increase with minor stagnations. In the energy mix, I calculate with the data of 2016, since the statistical data are available for that year, which is 2,694,000 kWh for electricity and 3,352,000 kWh for thermal energy.

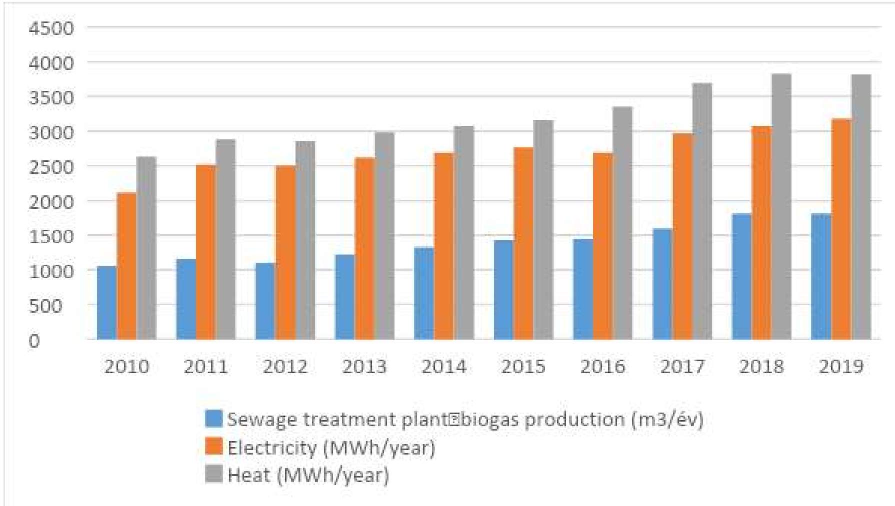


Figure 56. Biogas production of sewage treatment plant of Kecskemét between 2010 and 2019.

Biogas can also be used as heating energy, and electricity can also be produced from it. Similar to biomass, there is a significant difference here, too, if we examine it from the point of view of household energy consumption (Fig. 57). Since electricity can be produced more efficiently from biogas, the scissors open more significantly than in the case of biomass (Fig. 54), when different scenarios are examined in percentage resolution. In the case of biomass, the trend reverses at 60% heating energy and 40% electricity, in the case of biogas at 80%-20%. The energy conversion efficiency significantly affects the possibilities of composing the energy mix. The table of calculations on which the figure is based can be found in Appendix M7.

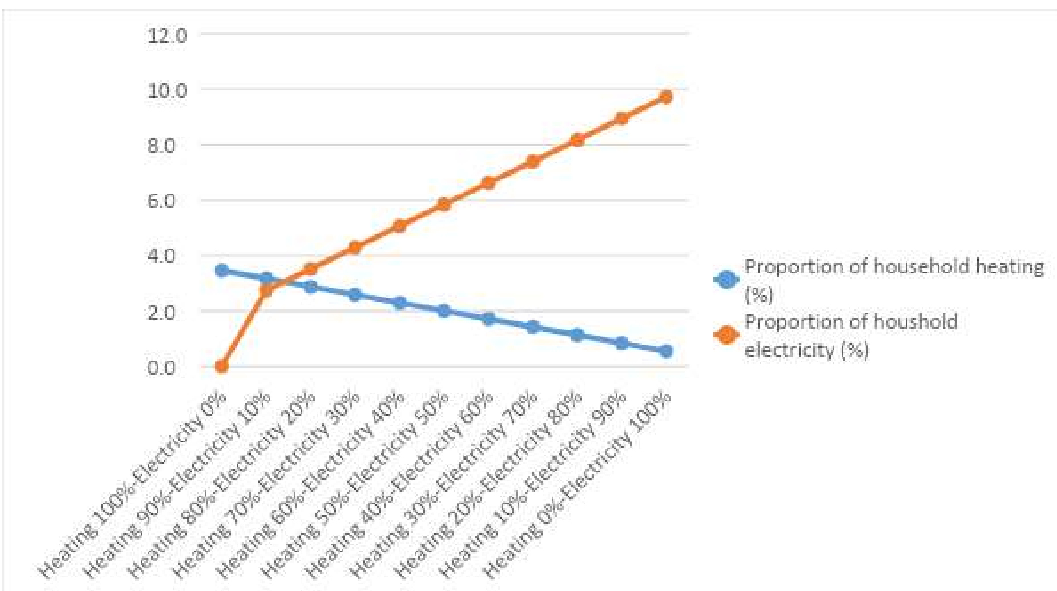


Figure 57. Proportion of heating and electricity potential of biogas in Kecskemét.

Before performing the calculations described in the methodology chapter, I looked at wind energy's potential in two databases containing wind speed data. First, I calculated an average based on the PVGIS (CATTANEO 2018) data series. Based on the data for 2005 and 2020, the average wind speed value is 2.67 m/s (Fig. 58), which does not reach the value of 5-5.5 m/s, representing the efficient use of wind energy. There were 50,337 households in Kecskemét in 2016 (Central Statistical Office n.d.), and the electricity consumption per household was 2,724 kWh/year. I calculated two scenarios: 10 and 20% of households are supplied with electricity by wind energy. In the case of 10%, the annual production is rounded to 13,713 MWh; in the case of 20%, it is 27,422 MWh.

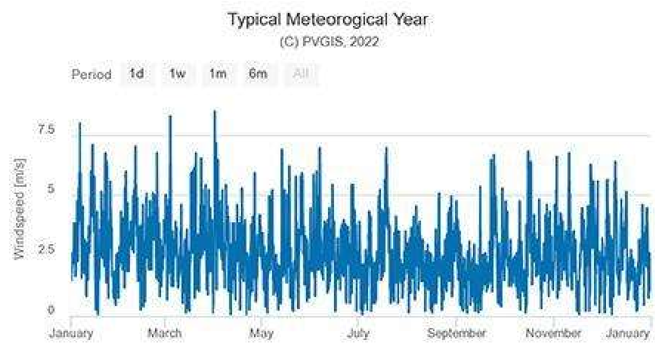


Figure 58. Wind speed in Kecskemét. (Cattaneo 2018)

The Global Wind Atlas (‘Global Wind Atlas’ n.d.) contains altitude-related data. As the altitude increases, the wind speed increases (Fig. 59) and the estimated electrical power per square meter (Fig. 60). Although I excluded tall wind turbines from the study due to the environmental effects on the landscape and soil, it is crucial from what height these facilities can be used, since the power projected onto the area can be estimated, similar to biomass and solar energy. In the case of Kecskemét, the speed at a height of 100 meters is 5.98 m/s, which reaches the minimum for efficient use. However, simultaneously, with the continuous development of technology, producing wind turbines located at lower altitudes can become more and more economical. In the figures, I have compared them with the data of the Gols settlement, where there is significant wind energy production. Here, the lowest turbine is 158 meters, and the highest is 242 meters (Windkraft 2021). Comparing the two settlements, there is a difference of 170 W at 100 meters, 183 W at 150 meters and 218 W at 200 meters in the estimated energy potential per square meter, which is significant. The table of calculations on which the figure is based can be found in Appendix M8.

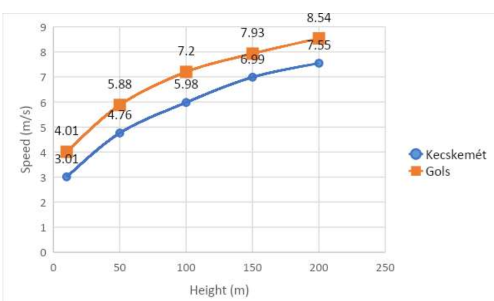


Figure 59. Wind speed in different heights in Kecskemét and Gols.

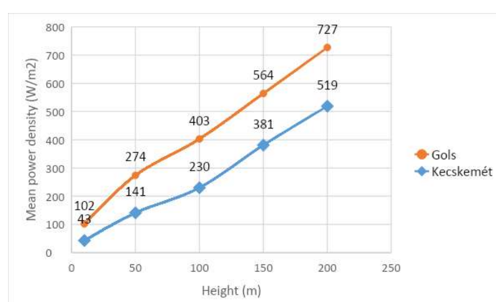


Figure 60. Mean power density in different heights in Kecskemét and Gols.

After that, I determined the renewable energy potential of the settlement. First, based on the existing data, I ruled out a renewable energy source. The surface water network and topography of the settlement were examined with a GIS tool (Fig. 61), for which I determined the slope categories using a surface model (‘EU-DEM — Copernicus Land Monitoring Service’ n.d.) and depicted it 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. The hydrographic properties limit not only the possibilities of direct electricity production but also thermal power plants since these power plants, although in many cases extremely efficient, due to their water consumption and water use due to technology (Feeley et al. 2008), their application possibilities in the settlement are limited.

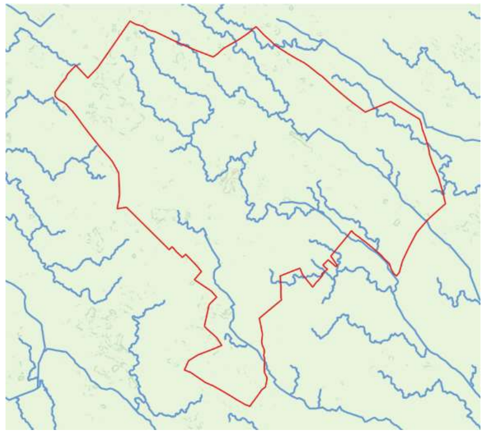
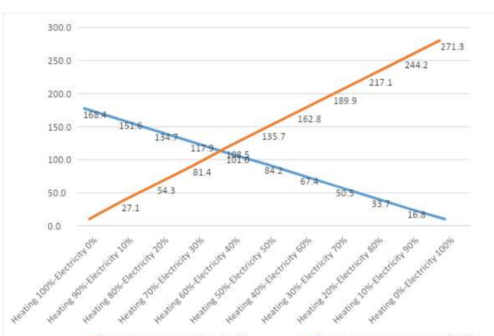
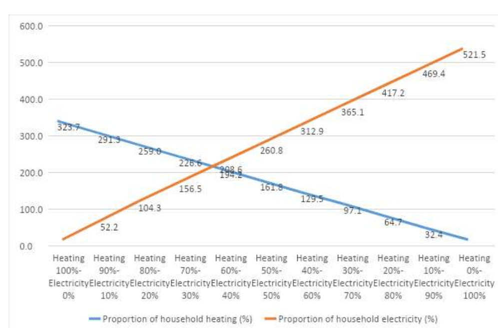


Figure 61. Slope category map of Kecskemét.

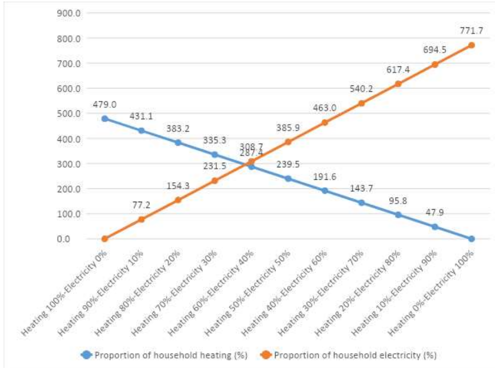
Ground heat potential is based on the potential of geothermal energy for heating purposes. This requires the use of electricity. According to the methodology, I calculated four scenarios (Fig. 62 a, b, c, d). Using geothermal energy can significantly increase the heating energy potential of the settlement. Considering the first scenario, which calculates the production of the least amount of electricity (Fig. 5. 62), in the case of total use, it can supply 168.5% of households with heating energy. In the case of the most favourable scenario (Fig. 62 d), this ratio is already 485.2%. Since in all cases, I counted on increasing the ratio of wind and solar energy so the environmental impact does not increase significantly, in the case of both energy sources, I calculated that the location of the production is the built-up area, where the electricity production can be directly connected to the already existing networks. In addition to increasing the heating energy efficiency of residential buildings, the broadest possible inclusion of geothermal energy can reduce harmful emissions. Since it requires significant electricity, developing the electrical network in parallel is important. The table of calculations on which the figure is based can be found in Appendix M9.



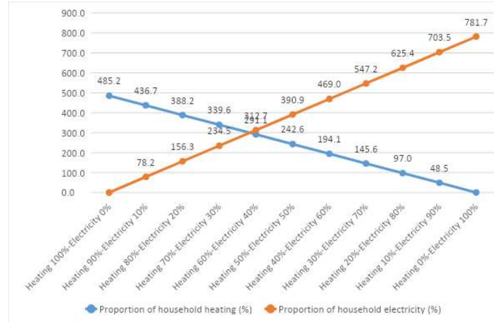
(a)



(b)



(c)



(d)

Figure 62. Ground heat potential of Kecskemét by propotion of household heating and electricity. (a) Solar panel coverage of buildings 10%, wind energy covers 10% of households (b) Solar panel coverage of buildings 20%, wind energy covers 10% of households (c) Solar panel coverage of buildings 30%, wind energy covers 10% of households (d) Solar panel coverage of buildings 10%, wind energy covers 20% of households.

4.1.2. Consumption and energy balance of Kecskemét

After defining the production side, the consumption parameters follow to examine the extent to which the renewable energy potential can cover the consumption. Considering that Kecskemét is a county-owned city with significant industry, I took into account twice the average per household in terms of industrial consumption, services and trade. Figure 63 shows the settlement's energy consumption, on which fishing and unspecified energy use are not included, as their proportion is insignificant overall. However, I took them into account during the calculations of the energy balance. In each examined sector, the proportion of electricity consumption is significantly lower and almost insignificant in the case of transport, agriculture, and forestry. The unspecified energy consumption in the case of households is heating, presumably also in the case of services and trade. Heating is the other significant consumption; heating and the use of internal combustion engines are also significant in the industry. Transport consumption is primarily limited to internal combustion engines. In the case of agriculture/forestry, the detailed data on agriculture (Fig. 64) shows that energy consumption is primarily based on internal combustion engines since the proportion of diesel is more than 50%. Using natural gas is also significant, but in that case, it is a raw material for fertilizer production. The unspecified energy consumption in Kecskemét is 2,505,660,488 kWh annually (this is 76.6% of the total consumption), the electricity consumption is 766,062,141 kWh (23.4% of the total consumption), which is a total of 3,271,722,629 kWh. When examining the consumption, it is essential to consider that electricity is significantly lower in current consumption when compiling the energy mix. However, at the same time, an increase is expected, and how it can be replaced with the examined renewable energy sources.

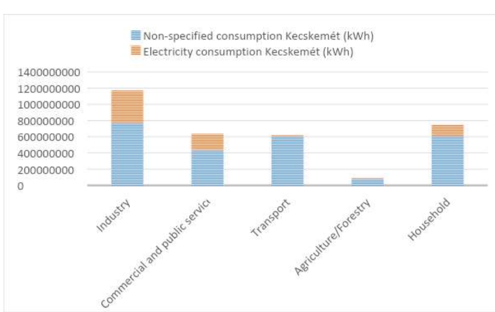


Figure 63. Consumption of Kecskemét by sectors.

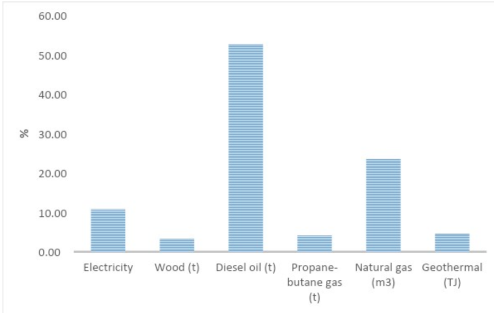


Figure 64. Proportion of energy sources in agriculture in Kecskemét.

First, I examine the electricity balance of the settlement since consumption can be determined in all sectors. The estimated total electricity consumption of the settlement is 766,062,141 kWh per year, and a significant part of the electricity production based on renewable energy sources examined in four scenarios is solar energy (Fig. 65). In the case of the first scenario, the system can provide 59% of the estimated electricity consumption of the settlement. In the case of the second scenario, production exceeds consumption by 14%. In the third scenario, the excess production is 68%, while in the fourth, it is 70%. Since the electricity demand is expected to increase in the long term, it is worth considering the third and fourth scenarios.

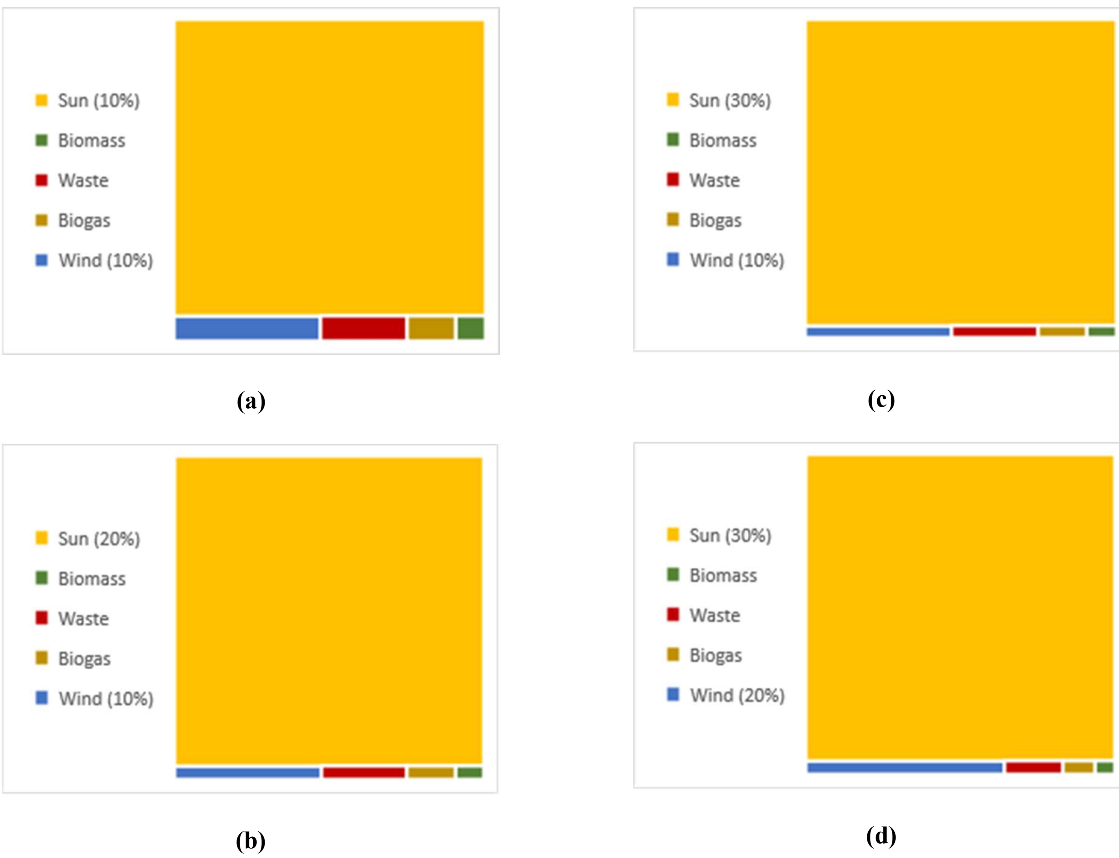


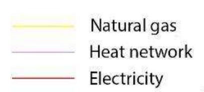
Figure 65. Electricity potential of Kecskemét (a) Solar panel coverage of buildings 10%, wind energy covers 10% of households (b) Solar panel coverage of buildings 20%, wind energy covers 10% of households (c) Solar panel coverage of buildings 30%, wind 10% (d) Solar panel coverage of buildings 30%, wind 20%.

After that, it is necessary to examine how the surplus sources of electricity from renewable energy sources and other energy sources can cover the unspecified part of the consumption. First, I examine to what extent its heating energy potential can cover the consumption side, and then I examine the geothermal potential of excess electricity production. Heating consumption means the consumption of households; and it is assumed that other commercial and service sector consumption is mainly heating energy. The total consumption of the two sectors is 1,043,988,867 kWh per year, of which 2.2% can be provided by biomass and biogas. The remaining consumption can be provided most efficiently from geothermal energy. Even with the last two scenarios, geothermal energy cannot ensure the heating consumption of 340,472,493 kWh. In the case of the third scenario, the electricity system produces a surplus of 292,098,609 kWh, so 48,373,884 kWh are missing; in the case of the fourth scenario, 34,664,884 kWh are missing for the geothermal supply. If we look at the energy balance (Table 29), the non-specified energy consumption is still significantly negative, mainly represented by industry, transport, and agriculture. The detailed version of consumption of Kecskemét is in Appendix M10. For the balance sheet, I calculated that the excess electricity is used to extract geothermal heat. Considering the third scenario, the remaining shortfall is 1,606,775,272 kWh, which is 64.1% of unspecified consumption and 49.1% of total consumption. In the fourth scenario, 62.5% of the deficit and 47.9% of total consumption are undetermined. Modernization of buildings is important to improve the ratio (Lucon et al. 2015).

		Sum consumption (kWh)	Ground heat consumption (kWh)	Sum production (kWh)	Energy balance (kWh)
Third scenario	Electricity	766062141	292098609	1058160750	0
	Non-specified	1629346661		22571389	-1606775272
Fourth scenario	Electricity	766062141	305807609	1071869750	0
	Non-specified	1588237661		22571389	-1565666272

Table 29. Estimated consumption and energy balance based on renewable energy.

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.66, 67, 68, 69.). 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 70).



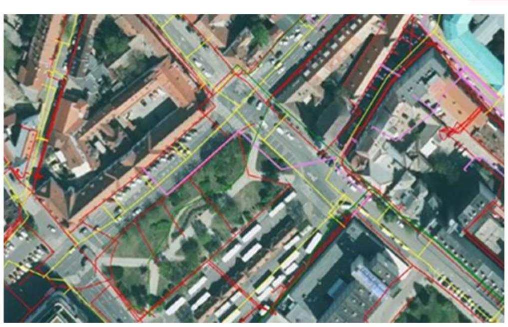


Figure 66. Energy network of centre of Kecskemét (‘E-Közmű Lakossági Térkép’ n.d.)

Figure 67. Energy network of industrial units of Kecskemét (‘E-Közmű Lakossági Térkép’ n.d.)

Figure 68. Energy network of continuous residential area of Kecskemét (‘E-Közmű Lakossági Térkép’ n.d.)

Figure 69. Energy network of discontinuous residential area of Kecskemét (‘E-Közmű Lakossági Térkép’ n.d.)

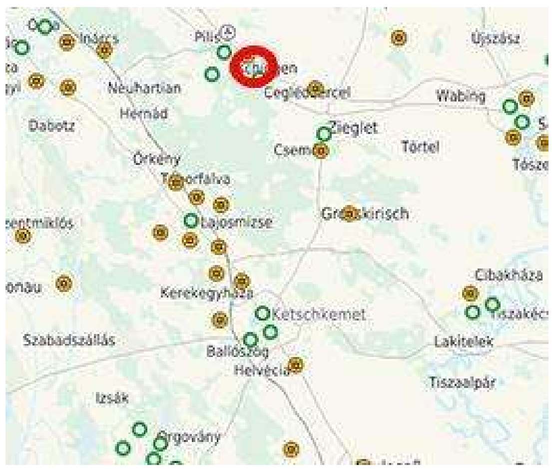


Figure 70. Energy network in regional scale include Kecskemét (123map GmbH & Co.KG n.d.)

4.1.3. Renewable energy potential of microregion in Bükk

The issue of rural development and decarbonization is partly intertwined in Hungary; the energetic modernization of the municipalities and enterprises of the decarbonized regions was part of the Regional and Settlement Development Operative Program (Nemzetgazdasági Minisztérium 2014) starting in 2014. According to rural development research conducted in Hungary, the spread of renewable energy sources can also be a breaking point for regions that are falling apart (Lukács 2008) (Lukács 2009).

Renewable energy sources are essential not only to stimulate the economy in the declining regions but also to eradicate energy poverty affecting the energy system. Decarbonization is also an economic, social, and cultural issue (Ürge-Vorsatz, Tirado Herrero 2012) (González-Eguino 2015). The concept itself has not yet been defined: energy poverty can mean that the household spends more than 10% of its total income on heating or does not have sufficient income to ensure the appropriate temperature. One of the means of eliminating energy poverty, which is more common in the case of falling regions, can be the integration of renewable energy sources into energy production at the household level, with the proviso that this alone is not sufficient, the renovation of the housing stock is also necessary (Fülöp, Lehoczki-Krsjak 2014).
In the subsection, I present the possibilities of determining the energy potential through a micro-regional sample area. The sample area consists of 7 settlements in Bükkmogyorósd, Csernely,

Csokvaomány, Lénárddaróc, Nekézseny, Sáta Borsod counties, while Nagyvisnyó is located. During the selection, I considered the 290/2014. (XI. 26.) Government decree on the classification of beneficiary districts and 105/2015. (IV. 23.) Government decree on the classification of beneficiary settlements and regulations on the criteria for classification. The settlements are in two districts: Bükkmogyorósd, Csernely, Csokvaomány, Lénárddaróc, Nekézseny, and Sáta belong to the Ózd district, while Nagyvisnyó belongs to the Bélapátfalva district. The Ózd district is one of the districts to be developed with a complex program based on the government decree; it has the 10th worst economic indicators. The Bélapátfalv district is one of the districts to be developed; it has the 56th worst economic indicators on the index (Fig. 71) (290/2014. (XI. 26.) Korm. rendelet 2014). Among the examined settlements, 5 (Bükkmogyorósd, Csernely, Csokvaomány, Lénárddaróc, Sáta) are settlements benefited from a socio-economic and infrastructural point of view and settlements affected by significant unemployment; Nekézseny is a settlement affected by significant unemployment; Nagyvisnyó was not classified in any category (105/2015. (IV. 23.) Korm. rendelet 2015). Although Nagyvisnyó is not on the list of disadvantaged settlements, the regional environment determines its economic situation (Fig. 72).

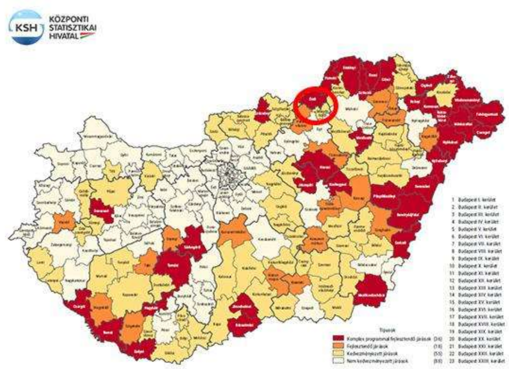


Figure 71. Discounted fares according to 290/2014. (XI. 26.) based on government decree. ('Hungarian Central Statistical Office' n.d.)

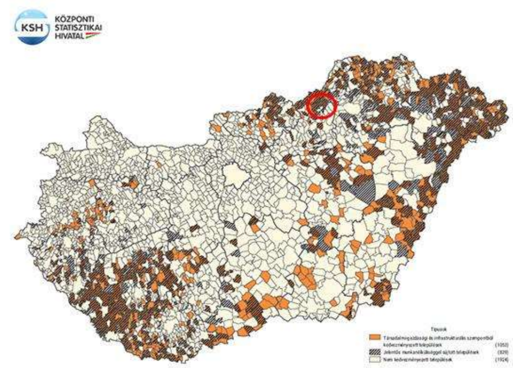


Figure 72. Beneficiary settlements under 105/2015. (IV. 23.) based on government decree. (Central Statistical Office n.d.)

The classification according to the aspects of the government decree is significant for two reasons: we can assume that energy poverty is typical for settlements, and European Union subsidies are expected for the development of the regions. The subsidies can come from two significant sources: from the regional fund, in which the "green economy" and innovation are among the essential aspects (‘European Regional Development Fund’ n.d.), and from the cohesion fund, in which case renewable energy is also among the key aspects (‘Cohesion Fund’ n.d.). In the case study, I show how green investments can contribute to the development of settlements from the point of view of landscape planning and spatial planning.

Examining the historical maps revealed that hydropower played an essential role in the life of the settlements. In Figure 73, I highlighted the settlement of Sáta, through which I show the characteristics of the settlements. The inner areas of the settlements are in the valleys on both sides of the rivers. The historical maps show that the settlements expanded into the valleys, typically on both sides of the river, The use of water as an energy source can only be identified in the first military survey: at the end of the 18th century, water mills operated in Sáta (Fig. 74), Nekézseny, Lénárddaróc and Nagyvisnyo in the investigated settlements. These mills lost their importance with the spread of coal.

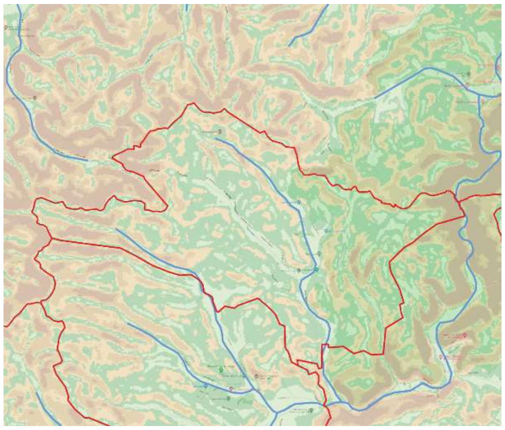


Figure 73. Slope category map of Sáta based on EU-Dem and EU-Hydro.

Figure 74. Sáta on First Military Survey. ('Magyarország (1782–1785) - Első Katonai Felmérés' 1782)

Water is one of the most important renewable energy sources today. However, there are limitations in settlements that prevent its efficient use. It can be observed from the historical maps that river waters were regulated, thereby changing the fall, the coastline, and the possibilities of using hydropower. (Fig. 75) Water mills disappearing due to river regulation are typical for the entire territory of Hungary (Ortutay, Nagy 1977). races of river regulation in the study area already appear on the pages of the Second Military Survey map ('Magyar Királyság (1819–1869) - Második katonai felmérés' 1819). However, water still plays a role in the heat management of settlements: in connection with the growth of built-up areas and climate change, the negative effects of heat waves in populated areas are reduced (Somers et al. 2013). By creating smaller reservoirs, we can reduce the negative effects of flash floods ('Csapadék - Általános éghajlati jellemzés - met.hu' 2021). Feasibility is examined through pilot projects within the framework of the EU-supported LIFE-MICACC project ('LIFE-MICCAC projekt' n.d.).

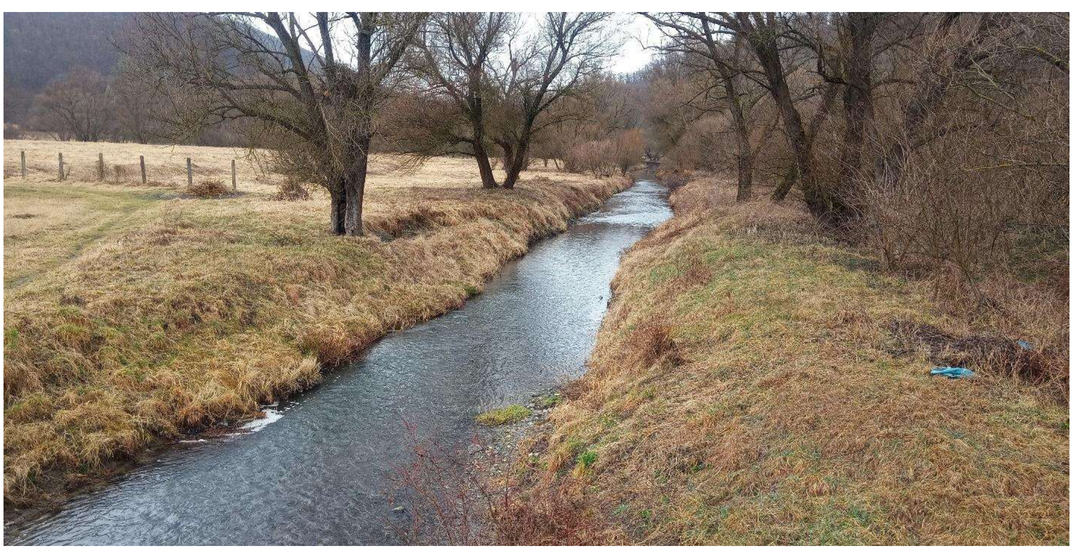


Figure 75. Regulated stream in the sample area.

The settlements belong to the North Bükk and the Uppony Mountains, which are parts of the immense landscape of the North Central Mountains. Most of the western part of the North Bükk comprises Upper Carboniferous limestone shale and sandstone assemblages; the oldest rocks of the Uppony Mountains are the oldest in the country, with more than 450 million years old sea sediments pressed into shale. The water depth has been constantly changing in the area so that these sediments can be varied, such as sandstone, dolomite, limestone and clay. In the Devonian age, volcanic rocks were associated with the previously developed character. (Dövényi 2010) These characteristics determine the mineral resources of the study area and their mining potential.

The study area is located in the brownstone basin of Borsod, where mining began at the end of the 18th century. The mentioned settlements are Parasznya, 25 km away, and Sajókaza, which is 40 km away from the sample area. The sample area is located in the Ózd-Egercsehi lignite basin within the Borsodi lignite basin. A mine was established in the area before 1845 in the Sáta area (György et al. 1998). I found the first trace of the mines on the historical maps in the 1941 military survey, where the geographical names refer to the mining areas. (Fig. 76) The productive area is 165 km2, on which the Borsodi Szénbányák extracted 1.5-2 Mt of lignite annually (György et al. 1998). Traces of deep-pit mining are still preserved in the landscape today (Fig. 77). The landscape still preserves the traces of deep-pit mining (Figure 78).

Figure 76. The microregion ont he Military survey from 1941. ('Magyarország Katonai Felmérése (1941)' 1941)

Figure 77. Trace of mining in the study area.

The mined coal was primarily used by the Ózd Metallurgical Works, which began to be built in 1846, and the trial plant started in 1847. Metallurgy in Ózd also created a prosperous economic environment in the region—the changes of ownership, I. and II. World War II, political upheavals meant a standstill, but the economic history of the sample area was determined by the smelter from the second half of the 19th century (Benyó et al. 1980). After 1990, the ironworks no longer operated at total capacity; its place was taken over by smaller public and private companies (Vorsatz 1996). At the same time, job opportunities also decreased, which caused the complex economic and social problems described earlier. Today, coal as an energy source must be relegated to the background, as it is a significant source of pollution (European Environmental Agency 2014).

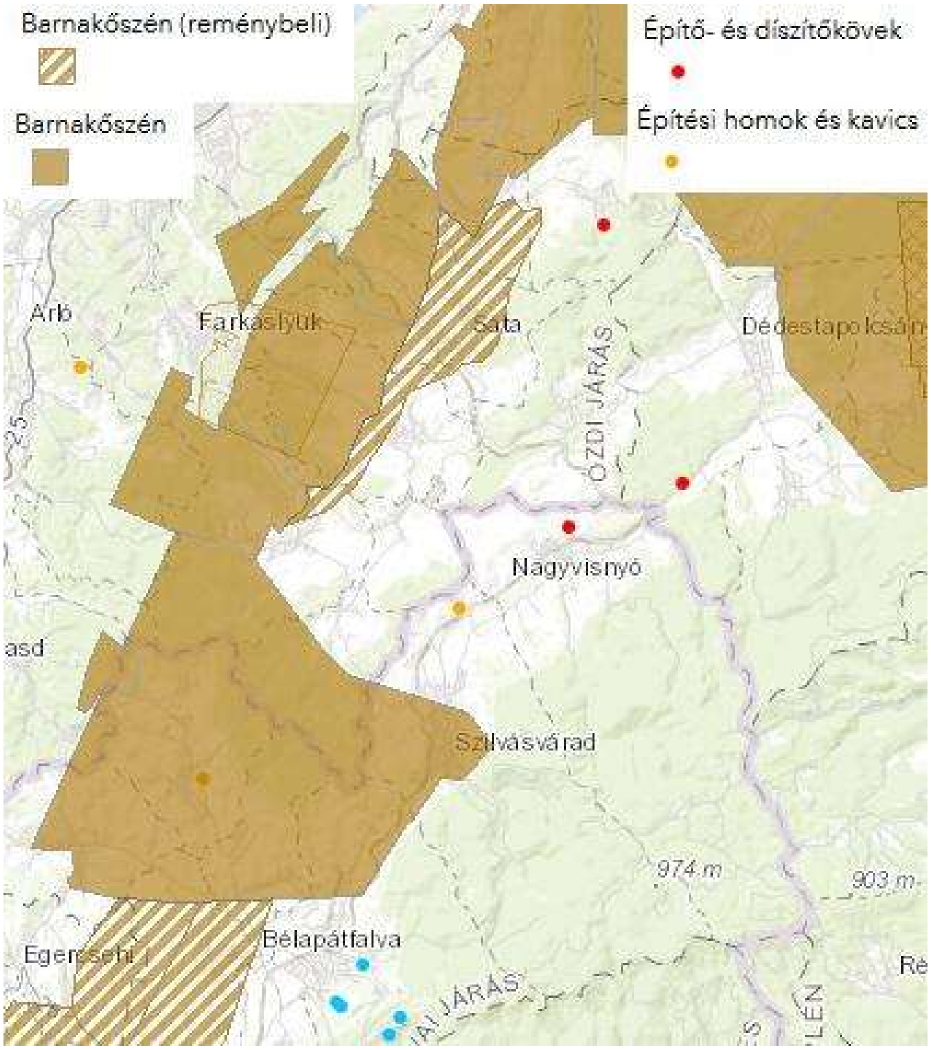


Figure 78. Mineral sources of the study area in Bükk.

The landscape use structure of the Bükki microregion is significantly different from the other sample areas. In this case, the proportion of forested areas is the largest, nearly 57%, the proportion of grassland areas is 28%, and the proportion of built-up areas is 5.9%. The share of agricultural land is tiny; the share of land used for cultivation is only 7.6% (Fig. 79). From the point of view of the energy mix, the question is to what extent the much smaller built-up area and the high proportion of forests affect the energy mix, and to what extent there will be differences with the Kecskemét sample area.

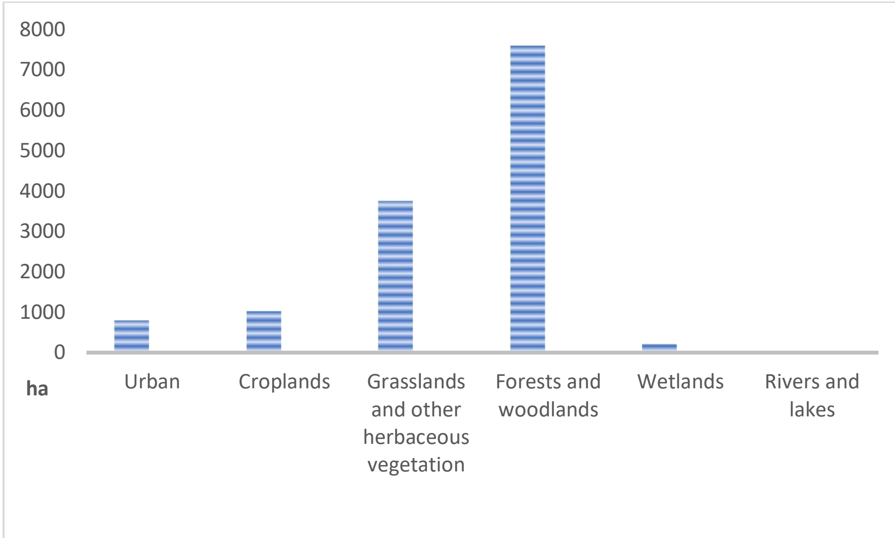


Figure 79. Land use structure of Bükk microregion.

In order to determine the potential of solar energy and biomass production, I first determined the size of the areas related to energy production using the Hungarian Ecosystem Map, using the zonal histogram analysis of the QGIS program on the raster map. In the case of solar energy, I considered the buildings since, in this case, it is not necessary to build a new network, and the energy investment is carried out in a built-up area. To determine the solar energy potential, I took the area of the buildings as a basis and calculated the energy potential for 10, 20 and 30% coverage (Table 30). The settlements' annual irradiation is broken down by month in Appendix M11, and the table on which the area calculations are based can be found in Appendix M12.

	Households	Area (m^2)	Yearly in-plane irradiation (kWh/m2)	Energy potential 10% coverage (kWh)	Energy potential 20% coverage (kWh)	Energy potential 30% coverage (kWh)	Energy potential 10% coverage (MWh)
Lénárddaróc	158	76400	1467,35	2017900	4035799	6053699	2018
Csokvaomány	417	168400	1496,47	4536100	9072200	13608300	4536
Bükkmogyorósd	102	36000	1455,06	942879	1885758	2828637	943
Nekézseny	340	126800	1425,80	3254246	6508492	9762738	3254
Nagyvisnyó	510	171600	1452,90	4487718	8975435	13463153	4488
Csernely	415	156400	1495,41	4209878	8419756	12629635	4210
Sáta	514	181200	1496,14	4879810	9759620	14639431	4880
Sum/Average	**2456**	**916800**	**1469,88**	**24328530**	**48657061**	**72985591**	**24329**

Table 30. Solar energy potential of microregion in Bükk.

Based on the measurement data, the electrical energy produced by a 1 kW solar cell in the settlement differs slightly; the topography influences this since the settlements are adjacent. Based on the results, 24,328,530 kWh of electricity can be produced at 10% coverage, 48,657,061 kWh at 20%, and 72,985,591 kWh at 30%. Examining the relationship between the solar energy potential and the number of households (Fig. 80), it can be established that the energy potential is more significant in the case of more households. However, no statistical correlation can be established due to the small sample.

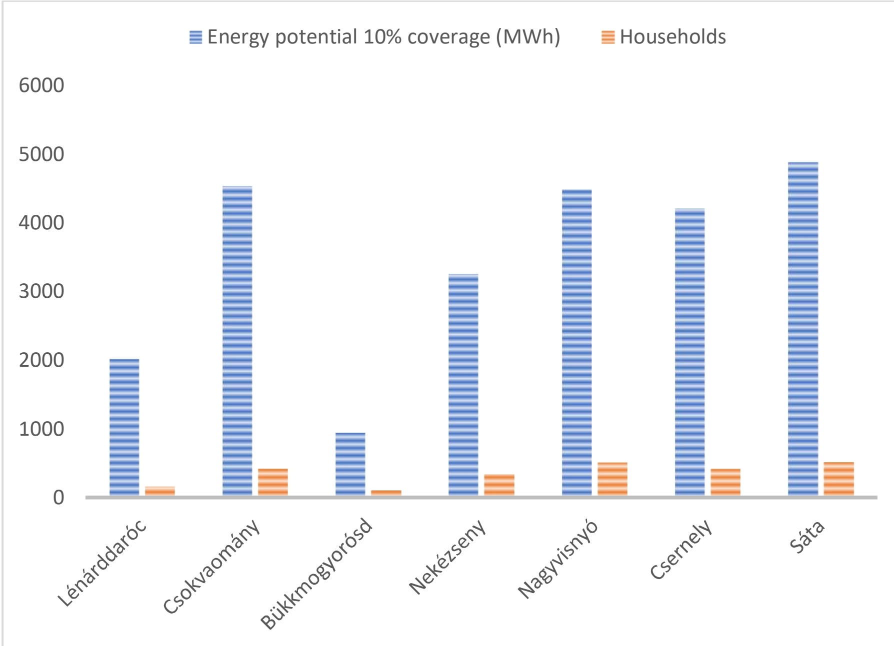


Figure 80. Households and solar energy potential with 10% coverage in Bükk micro-region.

For biomass production, I took wood production as a basis, the averages of which were determined using forestry statistics, the area of each tree species and tree species groups based on the Ecosystem Map of Hungary. The stock of living wood in the settlement (Fig. 81) shows that the native Quercus and other hardwood species are mainly present. In the settlement of Sáta, there are also native Populus species in a small area. The planted tree species is Picea abies (Baráz 2002), the proportion of which is not significant, but from an ecological point of view, it would be worthwhile to replace it with native species in the future.

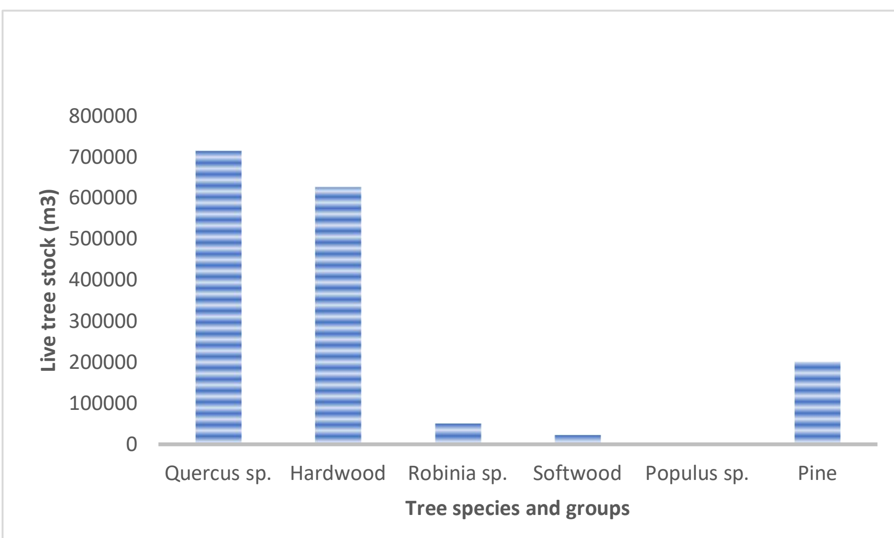


Figure 81. Tree livestock by species and species groups in Bükk micro-region.

From the perspective of settlements (Fig. 82), the Nagyvisnyó settlement has the largest forest areas; here, the species belonging to the hardwood group dominate, while the Quercus species dominate the other settlements. Native Populus species are only found in the settlement of Sáta, and softwood is not typical of the settlements either. The energy potential of the settlements according to tree species groups can be found in the appendix.

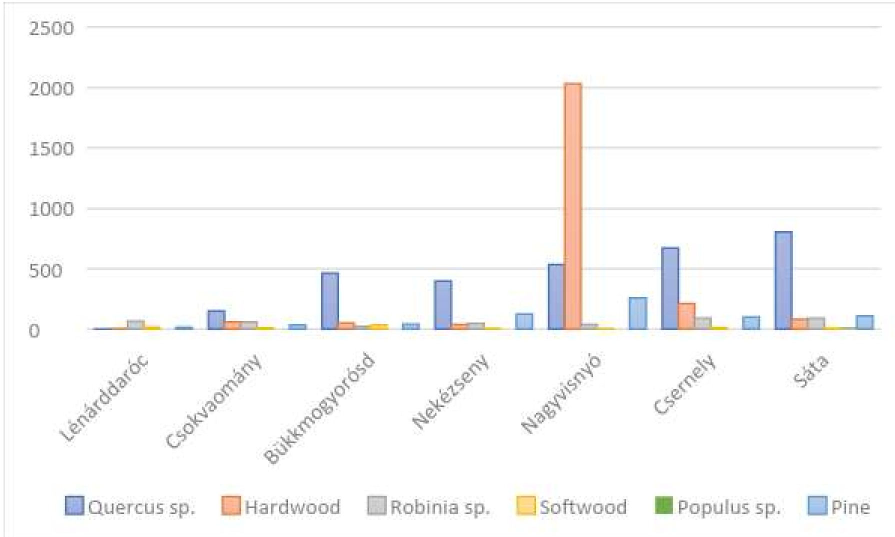


Figure 82. Tree livestock by species and species groups and settlements in Bükk micro-region.

The biomass energy potential of the investigated settlements is 33,035,149 kWh (Table 31), calculating the raw wood stock of each tree species or tree species group and the annual amount extracted from it for energetic use. Biomass can primarily be used for heating. This amount of energy can cover the annual heating energy of 2,509 households, which can cover 102% of the households in the study area. Biomass can also be used to produce electricity, which is 30% efficient. In the case of the sample area, if 100% of the biomass potential is used for electricity production, then 9,910,545 kWh of electricity can be produced, which can supply 148% of the households in the settlement.

Group of species	Area (ha)	Average live tree stock/ha (m3)	Live tree stock (m3)	Annual timber production of firewood (%)	Annual timber production of firewood (m3)	Energy (kWh/m3)	Energy potential (kWh)	Heating (kWh)	Electricity (kWh)
Quercus sp.	3027	236	714381	0,8	5715,05	2940	16802251	8401126	175615
Hardwood	2475	253	626124	1,02	6386,47	1960	12517479	6258740	58874
Robinia sp.	412	121	49891	1,52	758,34	2940	2229516	1114758	1793900
Softwood	85	262	22291	0,64	142,66	2100	299591	149795	153323
Populus sp.	14	141	1912	0,48	9,18	1960	17988	8994	143102
Pine	678	296	200605	0,26	521,57	2240	1168324	584162	306929
Sum	**6691**		**1615205**				**33035149**	**16517575**	**2631742**

Table 31. Biomass energy potential of Bükk microregion.

The biomass potential can be divided into different proportions for heating and electricity use (Fig. 83). Even though the production of electricity entails a significant energy loss, as the average heating energy consumption of a household is 4.8 times the electricity consumption, so with the use of 60% heating and 40% electricity, the heating and electricity consumption of almost the same number of households can be ensured with biomass in the sample area. With the division, approximately 60%-60% of the households are supplied with heating energy and electricity. The table of calculations on which the figure is based can be found in Appendix M13. An essential aspect of both heating and power generation is the consideration of airborne dust pollution, especially in this case, since due to topographic features, pollution can remain in the valleys for a longer time in windless weather in winter (Ferenczi et al. 2020).

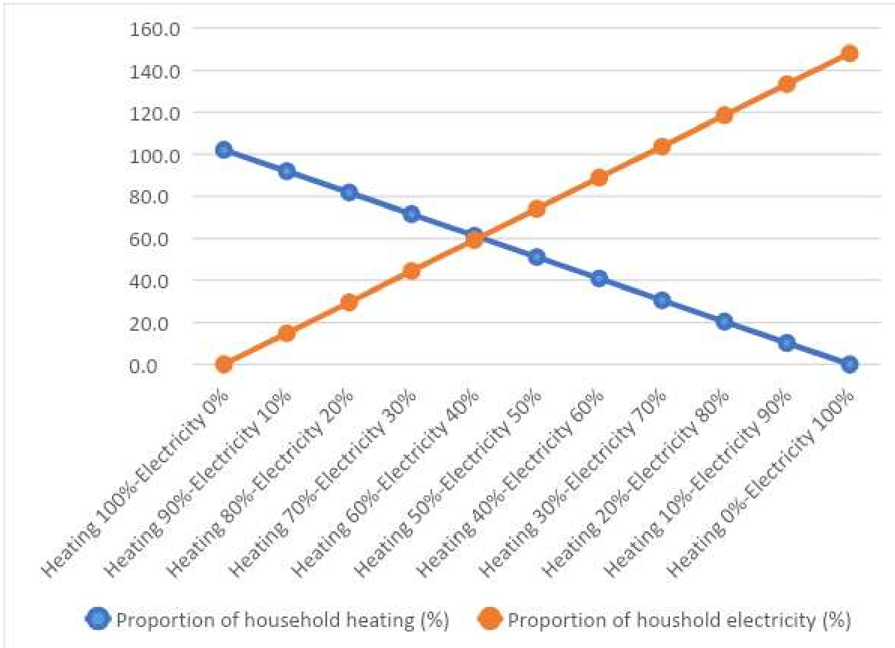


Figure 83. Proportion of heating and electricity potential of biomass in Bükk microregion.

In the case of waste, I calculated the average municipal waste of the settlements of the sample area between 2017 and 2021 based on the data provision of NHKV National Waste Management Coordinating and Asset Management Private Limited Company. Based on the average period between 2017 and 2021, the amount of municipal waste in the investigated settlements is 945,464 tons. Examining the quantity covering five years, the quantity in the case of Nagyvisnyó decreased significantly in 2019, in the case of Csernely in 2018, and in the case of the other settlements, the quantity hardly changed. (Fig. 84). The amount of waste per household is between 300-440 kg, which means a difference of more than 30%, the least in Csokvaomány, the most in Nagyvisnyó (Fig. 85). The biogas that can be produced from waste, which can be used for heating purposes, the results of this I explained it in the following subsection. The table of calculations on which the datasets is based can be found in Appendix M14. Electricity can also be produced in waste incineration plants. In my research, I calculated that electricity is produced from 50% of the waste and biogas from 25%. So, 260 MWh of electricity can be produced from 472,732 t of waste.

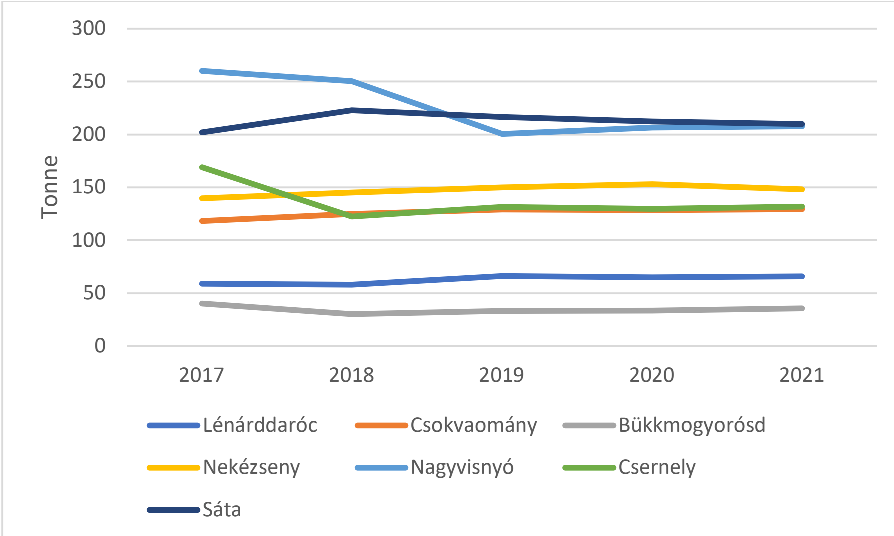


Figure 84. Amount of municipal waste in microregion in Bükk between 2017 and 2021.

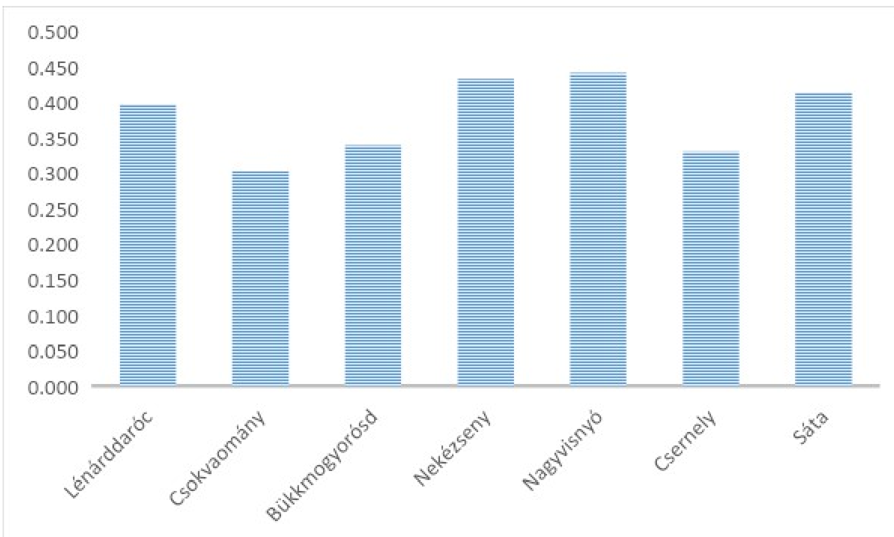


Figure 85. Amount of municipal waste per household in microregion in Bükk between.

In the next step, I determined the biogas potential of the settlement from animal manure and waste. For the number of livestock, I used serial data from the 2020 agricultural census settlement ('Hungarian Central Statistical Office' n.d.). I calculated that biogas is produced from 50% of animal manure. Livestock is not significant in the investigated settlements. In Csokvaomány and Csernely, there is a significant cattle herd, in Bükkmogyorósdon there is a sheep herd, and in addition, the hen herd is the most significant in the settlements (Fig. 86).

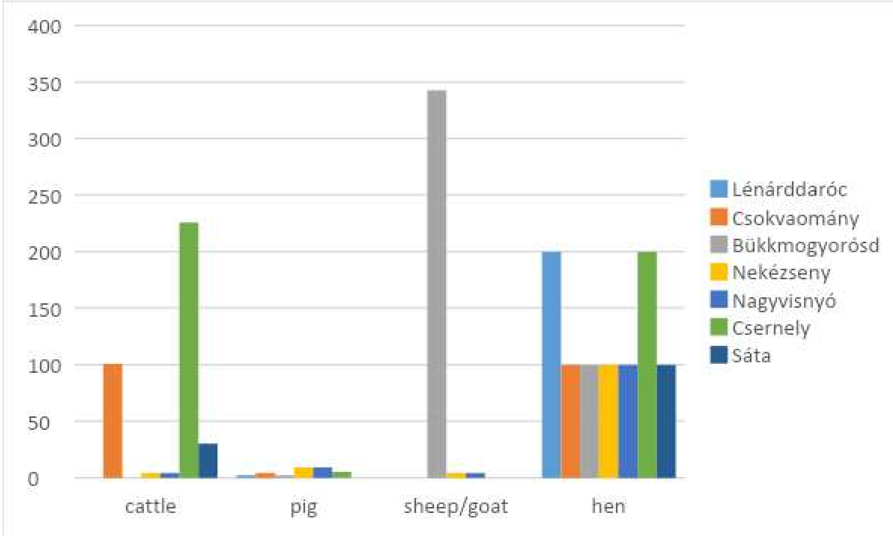


Figure 86. Livestock per settlement in Bükk microregion.

When examining the biogas potential per settlement, the existing cattle stock in the case of Csokvaomány and Csernely determines that the biogas potential is outstanding in these two settlements. There is minimal potential in Bükkmogyorós and Sáta: in the case of the former, due to the sheep population, while in the latter case, the potential is represented by 30 cattle (Fig. 87).

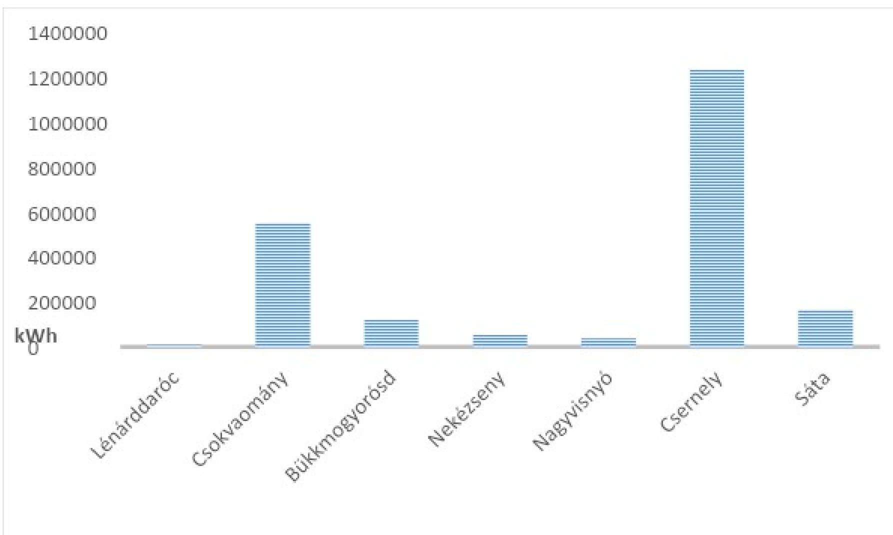


Figure 87. Biogas energy potential per settlement from manure in Bükk micro-region.

In the case of waste, I calculated the amount collected at 25%. This is 236.366 t, which has an energy potential of 9691.01 kWh. Since the efficiency of direct electricity production in the case of waste is much higher, I calculated the total biogas production using it for heating purposes.

Biogas can also be used as heating energy, and electricity can also be produced from it. Similar to biomass, there is a significant difference here, too, if we examine it from the point of view of household energy consumption (Fig. 88). Since electricity can be produced more efficiently from biogas, the scissors open more significantly than in the case of biomass (Fig. 83), when we examine different scenarios in percentage resolution. In the case of biomass, the trend reverses at 60% heating energy and 40% electricity. In the case of biogas at 70%-30%, in this case, it supplies 4.7%

of households with heating energy and 4.6% with electricity. The table of calculations on which the figure is based can be found in Appendix M15.

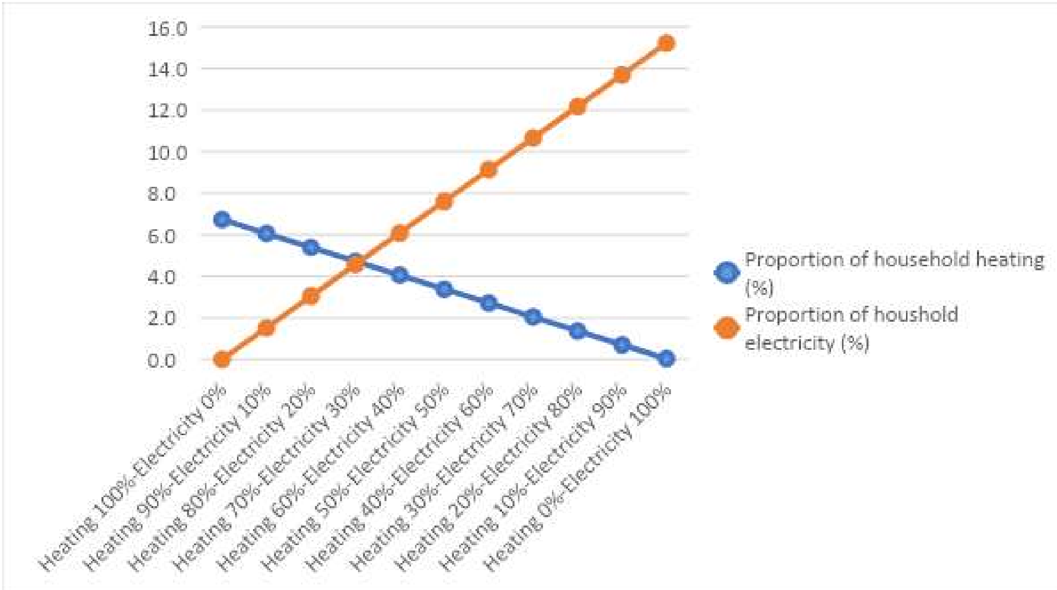


Figure 88. Proportion of heating and electricity potential of biogas in Bükk micro-region.

Before performing the calculations described in the methodology chapter, I looked at wind energy's potential in two databases containing wind speed data. First, I calculated an average based on the PVGIS (CATTANEO 2018) datasets. Based on the data for the period 2005 and 2020, the average wind speed values are 1.6 (Lénárddaróc, Csokvaomány) and 1.76 m/s (Nekézseny) (Table 32), which does not reach the 5-5.5, which represents the efficient use of wind energy m/s value. Although the settlements are adjacent to each other, they still show progress, both in terms of speed and annual distribution.

	Speed (m/s)
Lénárddaróc	1,6
Csokvaomány	1,72
Bükkmogyorósd	1,6
Nekézseny	1,76
Nagyvisnyó	1,75
Csernely	1,7
Sáta	1,72

Table 32. Wind speed in 10 meter heights according to PVGIS.

The Global Wind Atlas ('Global Wind Atlas' n.d.) Contains several data related to altitude; as the altitude increases, the wind speed increases (Fig. 89) and the estimated electrical power per square meter (Fig. 90). Although I excluded tall wind turbines from the study due to the environmental effects on the landscape and soil, it is essential from what height these facilities can be used, since the power projected onto the area can be estimated, similar to biomass and solar energy. In the examined settlements, the wind exceeds the average speed of 5.5 m/s at a height of 150 meters, which reaches the minimum for efficient use. However, with the continuous development of technology, producing wind turbines located at lower altitudes may become more and more economical. In the figures, I have also compared them with the data of Gols settlement, where there is significant wind energy production. Comparing the data series, Bökkmogyorósd, which has the most significant potential, has a potential edge deviation of 259 W at 150 meters and 316

W at 200 meters per square meter. The annual wind speed distribution of the study area can be found in Appendix M16.

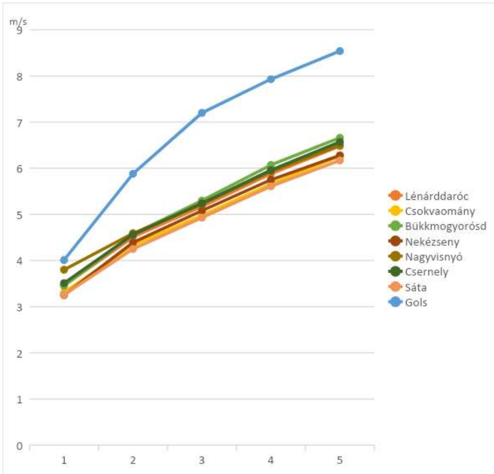


Figure 89. Wind speed in different heights in Bükk microregion.

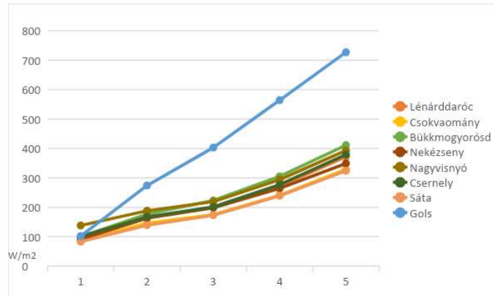


Figure 90. Mean power density in different heights in Bükk microregion.

There were 2,456 households in the study area in 2016 (Központi Statisztikai Hivatal n.d.-a), and the electricity consumption per household was 2,724 kWh/year. I calculated two scenarios: 10 and 20% of households are supplied with electricity by wind energy. In the case of 10%, the annual production is rounded to 669,014.4 kWh; in the case of 20%, it is 1,338,028.8 kWh (Table 33).

Settlement	**Population**	**Wind energy potential 10% (kWh)**	**Wind energy potential 20% (kWh)**
Lénárddaróc	158	43039,2	86078,4
Csokvaomány	417	113590,8	227181,6
Bükkmogyorósd	102	27784,8	55569,6
Nekézseny	340	92616	185232
Nagyvisnyó	510	138924	277848
Csernely	415	113046	226092
Sáta	514	140013,6	280027,2
Sum	**2456**	**669014,4**	**1338028,8**

Table 33. Wind energy potential in Bükk microregion.

First, I prepared a map of the slope category of the study area (Appendix M17), which shows that several watercourse sections are suitable for further investigation. Lénardaróc is the only settlement that I excluded from the further analysis. First, I selected the sections to be examined, and then I examined the slope of the sections. In the case of Csokvaomány, Bükkmogyorósd, Nekézseny and Sáta, I found specific points that could correspond based on the slope angle. In the case of Nagyvisnyó and Csernely, I found five sections. After that, I compared it with the county plans (Borsod-Abaúj-Zemplén Megye Területrendezési Terve 2020; Heves Megyei Önkormányzat Közgyűlése Elnökének 5/2020. (V.7.) önkormányzati rendelete Heves Megye Területrendezési Tervéről 2020) since establishing a hydropower plant may cause a complex ecological impact. Nekézseny (Fig. 95, 96) and Nagyvisnyó (Fig. 97, 98) can be excluded entirely since, in the case of the former, almost the entire settlement area is part of an ecological network or a buffer zone.

In contrast, the examined area of the latter is part of an ecological network. The examined area of Bükkmogyorósd (Fig. 91, 92) and Csokvaomány (Fig. 93, 94) is an ecological buffer zone, so I exclude it. In the case of Csernely (Fig. 99, 100) and Sáta (102, 103), further investigation can be carried out, as the investigated areas border the parts belonging to the ecological zone, so there is a chance that a small-scale hydropower plant can be established. The technological, ecological, water, and economic aspects must be coordinated in the next planning step.

Figure 91. Cross section overview in Bükkmogyorósd.

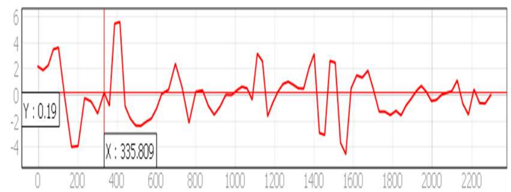


Figure 92. Cross section in Bükkmogyorósd.

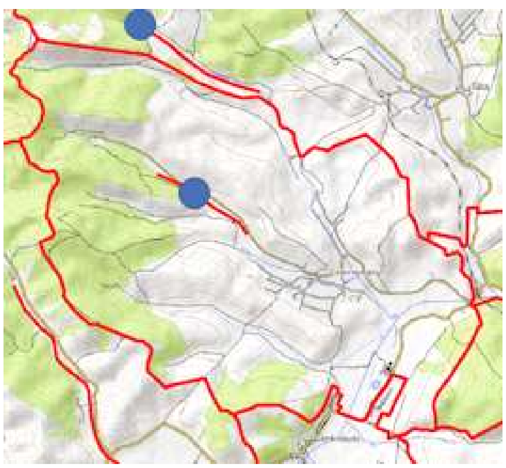


Figure 93. Cross section overview of Csokvaomány.

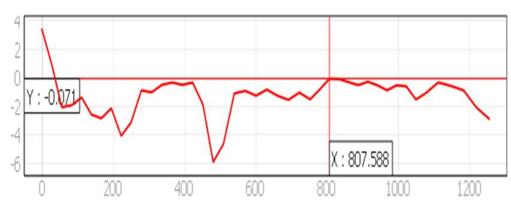
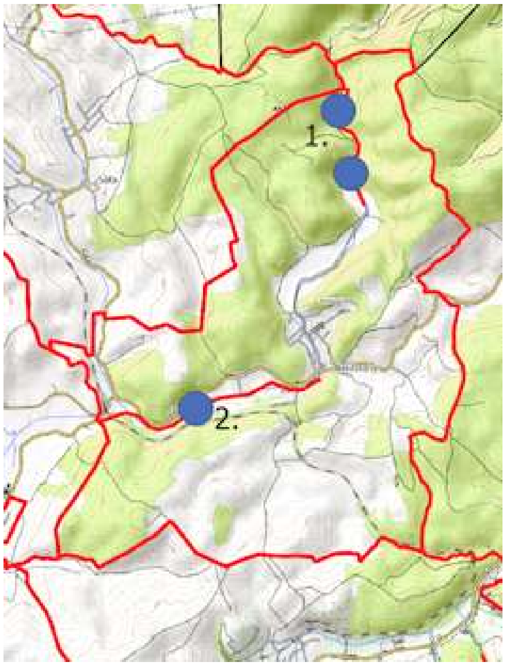


Figure 94. Cross section in Csokvaomány.



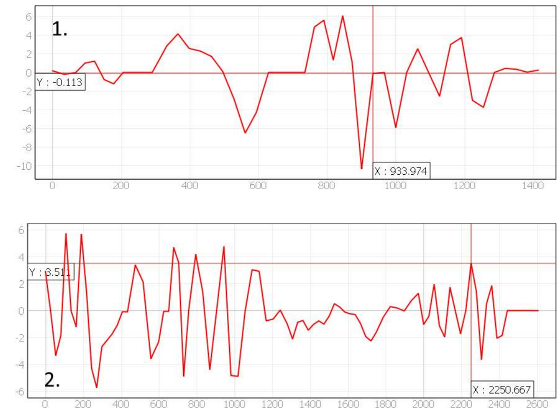


Figure 96. Cross section in Nekézseny.

Figure 95. Cross section overview of Nekézseny.

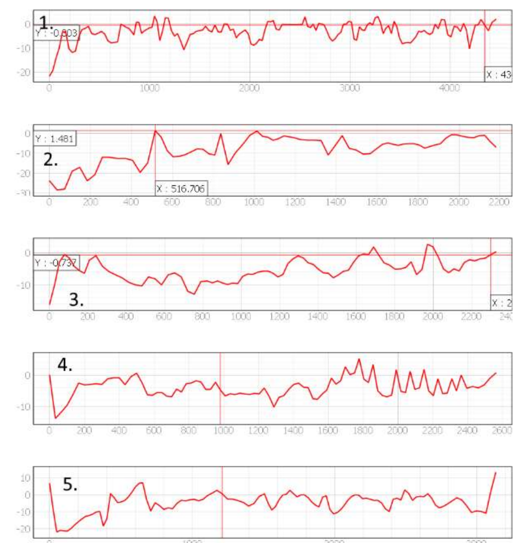


Figure 97. Cross section overview of Nagyvisnyó.

Figure 98. Cross section in Nagyvisnyó.

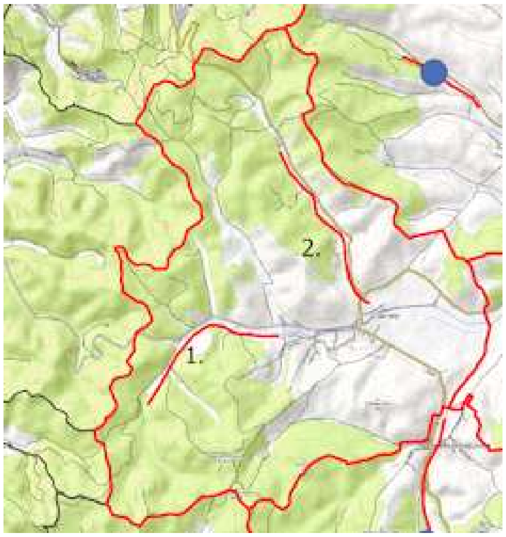


Figure 99. Cross section overview of Csernely.

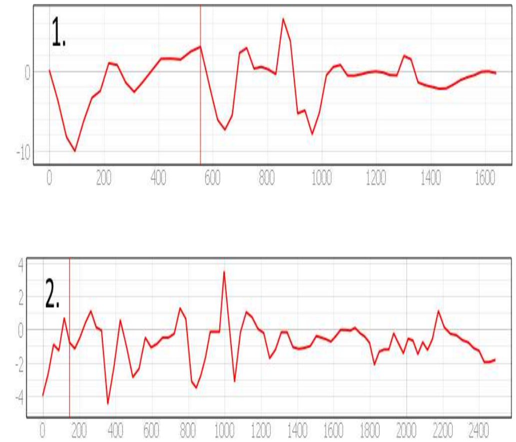


Figure 100. Cross section in Csernely.

Figure 101. Cross section overview of Sáta.

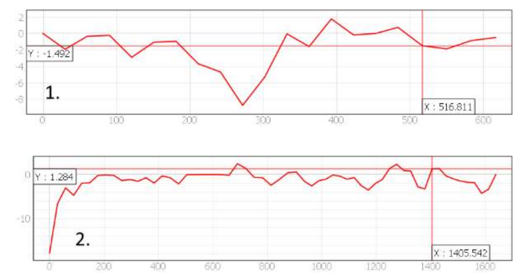
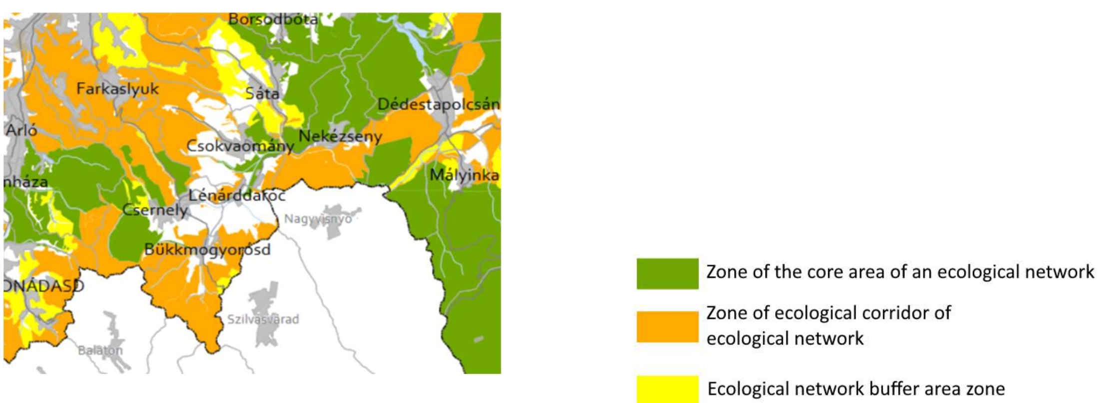
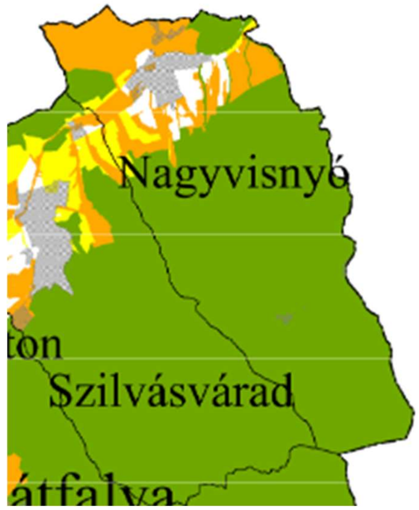


Figure 102. Cross section in Sáta.



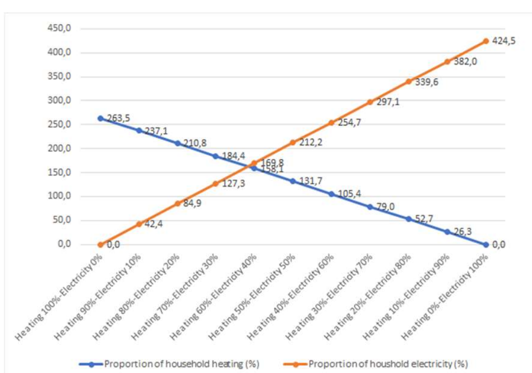
(a)



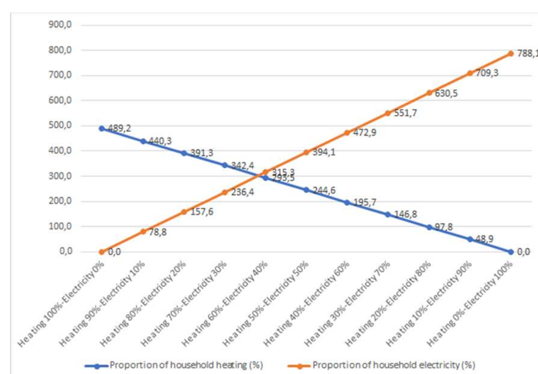
(b)

Figure 103. Ecological network zones in (a) Borsod-Abaúj-Zemplén and in (b) Heves.

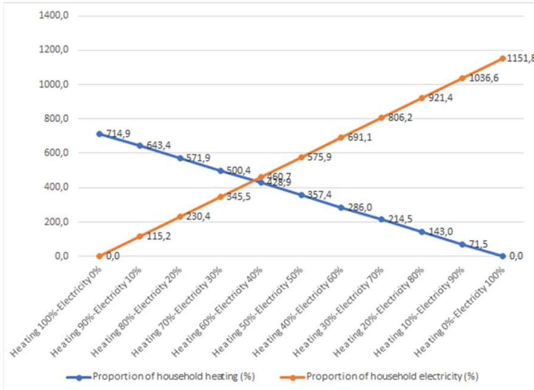
Geothermal energy potential is based on the potential of geothermal energy for heating purposes. This requires the use of electricity. According to the methodology, I calculated four scenarios (Fig. 104 a, b, c, d). Using geothermal energy can significantly increase the heating energy potential of the settlement. Considering the first scenario, which calculates the production of the least amount of electricity (Fig. 104 a), in the case of total use, it can supply 263.5% of households with heating energy. In the case of the most favourable scenario (Fig. 104 d), this ratio is already 721.1%. Since in all cases, I counted on increasing the ratio of wind and solar energy so the environmental impact does not increase significantly, in the case of both energy sources, I calculated that the location of the production is the built-up area, where the electricity production can be directly connected to the already existing networks. In addition to increasing the heating energy efficiency of your residential buildings, the broadest possible inclusion of geothermal energy can reduce harmful emissions. Since it requires significant electricity, developing the electrical network in parallel is important. The table of calculations on which the figure is based can be found in Appendix M18.



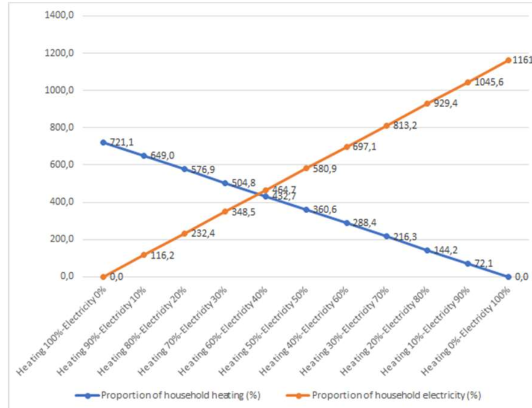
(a)



(b)



(c)



(d)

Figure 104. Ground heat potential of Bükk microregion by propotion of household heating and electricity. (a) Solar panel coverage of buildings 10%, wind energy covers 10% of households (b) Solar panel coverage of buildings 20%, wind energy covers 10% of households (c) Solar panel coverage of buildings 30%, wind energy covers 10% of households (d) Solar panel coverage of buildings 10%, wind energy covers 20% of households.

Examined at the settlement level (Fig. 105), in the case of the first scenario, in the case of the first scenario, 27% of the electricity potential in the settlements covers residential heating energy in the case of Lénárdaróc, while the worst ratio is in Nekézseny, where the ratio is 39%. This ratio is 15 and 21% in the second scenario, respectively. In the case of the third and fourth, there is a minimal difference. In the fourth scenario, the best rate is 10%, and the worst rate is 14% for Nekézseny, Nagyvisnyó and Sáta. The ratios show that geothermal heat can be provided as heating energy with renewable resources.

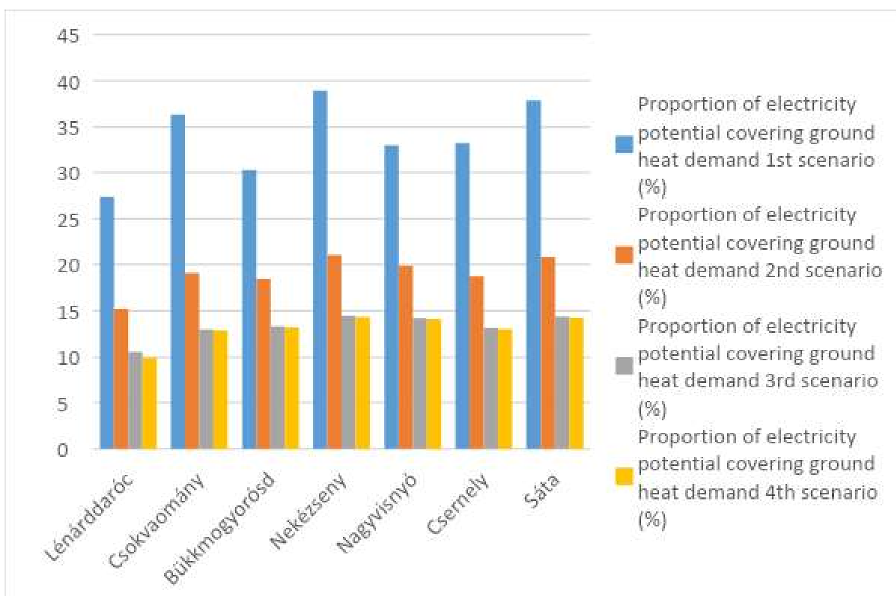


Figure 105. Proportion of electricity potential in different scenarios in Bükk microregion.

4.1.4. Consumption and energy balance in Bükk microregion

After defining the production side, the consumption parameters follow to examine the extent to which the renewable energy potential can cover the consumption. Considering that the examined sample area consists of small settlements, I considered half of the average per household in terms of industrial consumption, commercial and public services. Figure 106 shows the area's energy consumption, which does not include fishing and unspecified energy use, as their proportion is insignificant overall. However, I took it into account during the calculations of the energy balance. In each examined sector, the proportion of electricity consumption is significantly lower and almost insignificant in the case of transport, agriculture and forestry. In the case of households, the unspecified energy consumption is heating, presumably also in the case of services and commerce, heating is the other significant consumption, and in the case of industry, heating and the use of internal combustion engines are also significant. Transport consumption is primarily limited to internal combustion engines. In the case of agriculture/forestry, the detailed data on agriculture (Fig. 107) shows that energy consumption is primarily based on internal combustion engines since the proportion of diesel is more than 50%. Using natural gas is also significant, but in that case, it is a raw material for fertilizer production. The unspecified energy consumption in the microregion is 1,895,942,501 kWh annually (this is 63.8% of the total consumption), the electricity consumption is 465,051,718 kWh (36.2% of the total consumption), which is a total of 2,970,712,206 kWh. When examining the consumption, it is important to consider that electricity is significantly lower in current consumption when compiling the energy mix. However, at the same time, an increase is expected, and how it can be replaced with the examined renewable energy sources.

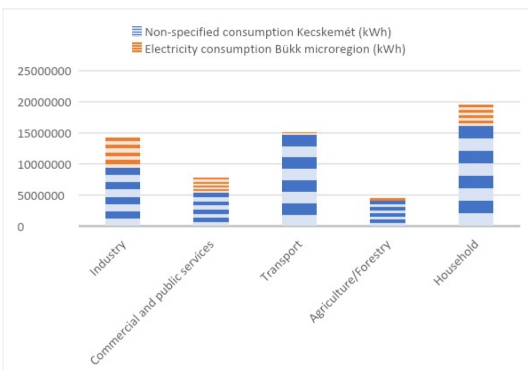


Figure 106. Consumption of Bükk microregion by sectors.

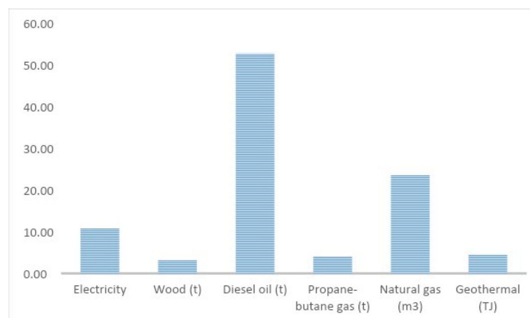


Figure 107. Proportion of energy sources in agriculture in Bükk microregion.

First, I examine the electricity balance of the microregion since consumption can be determined in all sectors. The estimated total electricity consumption of the settlement is 628,944,153 kWh per year, and a significant part of the electricity production based on renewable energy sources examined in four scenarios is solar energy (Fig. 108). In the case of the first scenario, the system can provide 244.4% of the estimated electricity consumption of the settlement. In the case of the second scenario, production already exceeds consumption by more than four and a half times (453.8%). In the third scenario, the ratio is 663.1%, while in the fourth, it is 668.9%. Since there is significant overproduction in the case of all four scenarios, it is worth examining the proportions of total consumption. In the case of all four scenarios, the source of the electric current potential is primarily solar energy; even with 10% coverage of the buildings, it is 85.7%. So, the potential of electric current is primarily an uncontrollable source of energy.

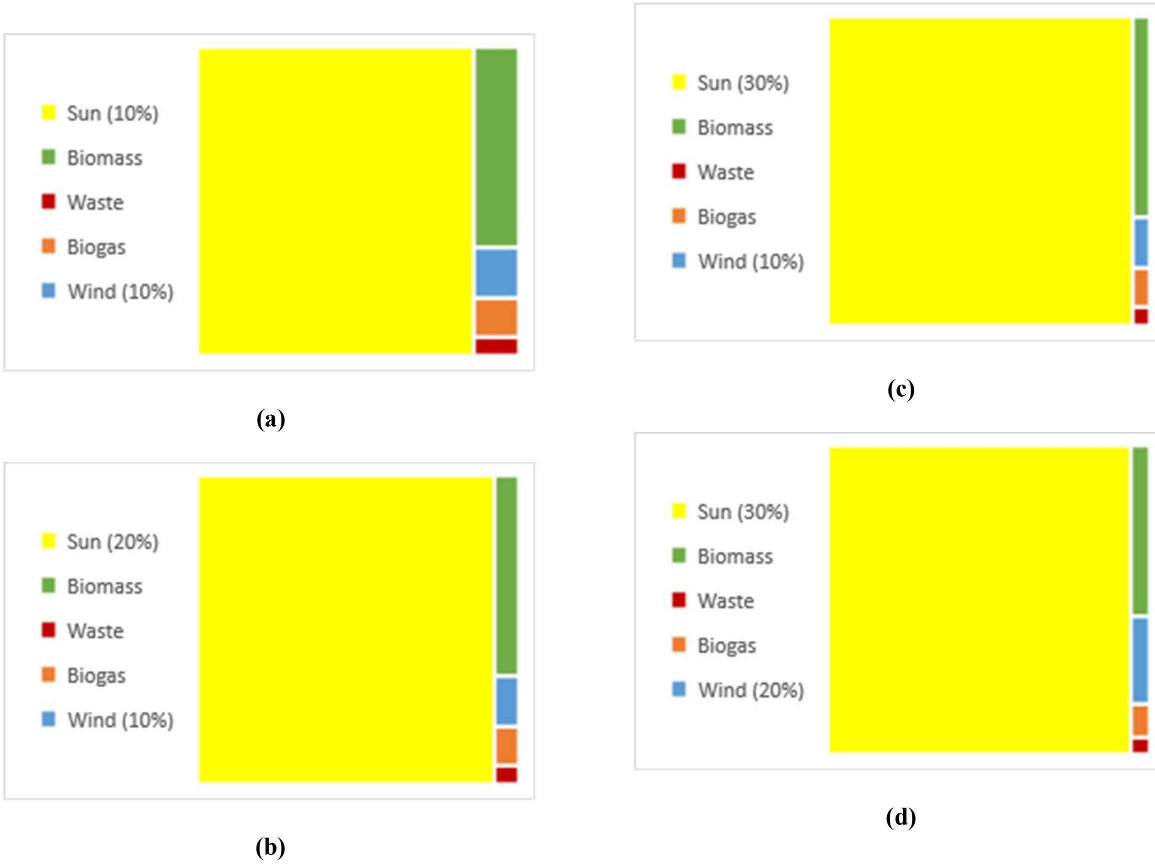


Figure 108. Electricity potential of Bükk microregion (a) Solar panel coverage of buildings 10%, wind energy covers 10% of households (b) Solar panel coverage of buildings 20%, wind energy covers 10% of households (c) Solar panel coverage of buildings 30%, wind 10% (d) Solar panel coverage of buildings 30%, wind 20%.

After that, it is necessary to examine how the surplus sources of electricity from renewable energy sources and other energy sources can cover the unspecified part of the consumption. In this case, I calculate to what extent the heating in these settlements can be solved with geothermal heat in the case of residential and trade and services. There are two reasons for this: the use of firewood can cause health problems due to the dust in the valleys, and the energy sources for heating are quickly sorted (firewood, manure) or are collected regionally like garbage. The consumption of non-electrical consumption by households and services and trade is 21,464,992 kWh per year, 8% of which is provided by existing electricity consumption; I deducted this from the electricity consumption of households. Unlike Kecskemét, I examined all four scenarios here. I summarized the results of the four scenarios in Table 34. In all cases, the electricity surplus is significant: 34.38% in the first scenario, 64.9% in the second scenario, 75.98% in the third scenario, and 76.19% in the fourth scenario. However, there is a significant deficit, at 60.52%, regarding the use of other energy. Electricity production can partly cover the shortfall, such as the electric transport transition. Therefore, not all energy sources examined can replace the currently used energy sources, such as the internal combustion engines of agricultural machines. To improve the ratio, it is essential to modernize the buildings (Lucon et al. 2015), similar to the Kecskemét sample area. The consumption data at the settlement level can be found in the appendix M19; since the energy sources I presented above show a slight difference in households, I did not examine them in summary.

		Sum consumption (kWh)	Ground heat consumption (kWh)	Sum production (kWh)	Energy balance (kWh)	Energy surplus (%)
First scenario	Electricity	11352435	7154997	28398480	9891048	34,83
	Non-specified	28269105		17610653	-10658452	-60,52
Second scenario	Electricity	11352435	7154997	52727011	34219579	64,90
	Non-specified	28269105		17610653	-10658452	-60,52
Third scenario	Electricity	11352435	7154997	77055541	58548109	75,98
	Non-specified	28269105		17610653	-10658452	-60,52
Fourth scenario	Electricity	11352435	7154997	77724556	59217124	76,19
	Non-specified	28269105		17610653	-10658452	-60,52

Table 34. Estimated consumption and energy balance based on renewable energy in Bükk microregion.

When examining the energy network, I used the utility map. It is characteristic of all winter settlements that electricity and natural gas networks are available in populated areas. (Fig. 109). This means that the excess electricity production is connected to the network, but possible network development is necessary due to the excess load. At the regional level, the settlements are connected to the north Ózd substation and Szilvásvárad in the south (Fig. 110).

a. Lénárddaróc

b. Csokvaomány

c. Bükkmogyorósd

d. Nekézseny

e. Nagyvisnyó

f. Csernely

g. Sáta

Figure 109. Energy network of the settlements in Bükk microregion.

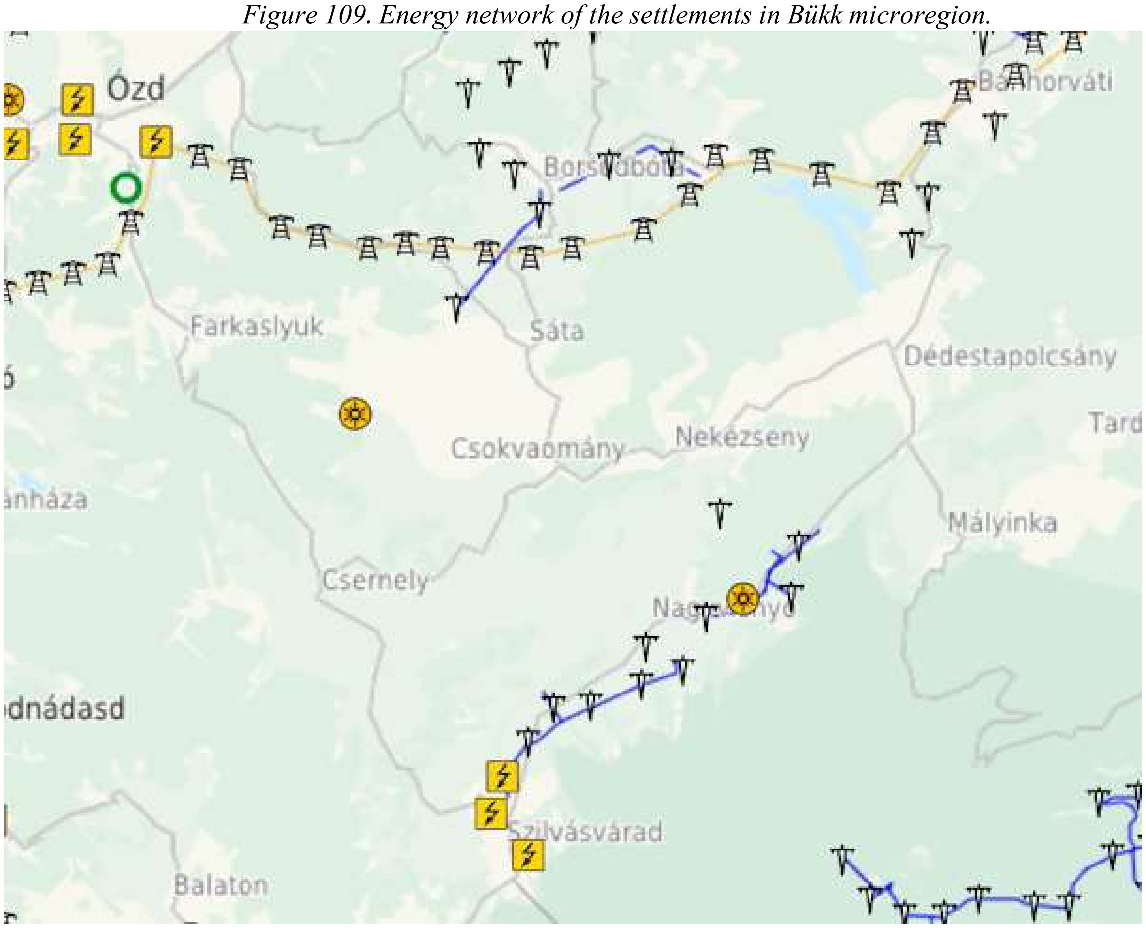


Figure 110. Energy network in regional scale include Bükk microregion. (123map GmbH & Co.KG n.d.)

4.2. Summary of the results of energy potential and energy balance in the sample areas

In the case of both study areas, I estimated the renewable energy potential as described in the methodological section and compiled the energy mix based on this. I drew the following conclusions from the results of the two sample areas:

- In the case of both sample areas, the electricity potential of solar energy is the most significant in all examined scenarios.

- When examining the energy mix, the share of biomass is not much more significant in the Bükki sample area, even though the proportion of forest areas is 57%. In comparison, the Kecskemét sample area barely exceeds 22%.

- Due to landscape and environmental effects, I limited wind energy production to built-up areas and small-scale wind turbines; it is not significant at this level in the energy mix. This energy potential can be increased with large-scale turbines and the involvement of other land uses, which must first be analysed in terms of technological and economic potential.

- In the case of Kecskemét, there was a surplus of electricity in the third and fourth scenarios, for which at least 30% of the buildings must be covered with solar panels.

- There was a surplus of electricity in all scenarios in the Bükki sample area, which means smaller settlements can have a positive energy balance covering the consumption of other areas.

- Examining the energy balance, in terms of energy potential, the transition to renewable energy sources primarily means non-electricity use. Examining the consumption, electricity consumption is a fraction of the use for other purposes. The question is in which cases other uses can be replaced with electricity and how well the energy system can handle this.

- In the case of wind and solar energy, the energy potential data differ on a micro-regional scale; therefore, due to the reliability of the data, the energy potential of the two energy sources must be examined on a settlement basis.

When examining the energy potential of the sample areas, the solar energy potential is the most significant in both cases. In addition, wind can be a significant energy potential, which has been limited by considering landscape and environmental effects. These two energy sources cannot be controlled. Among the controllable energy sources, the energy potential of biomass, biogas and waste is due to the limited amount of raw materials available. Depending on the use, a significant environmental impact can be expected in each case since establishing an industrial facility must be considered in the case of electricity production. In the case of direct use, biomass air pollution, and the case of biogas, primary effects on the soil due to the construction of a network must be expected. The question beyond landscape architecture is whether these energy sources can balance uncontrollable energy sources on a systemic level. The production of electric current influences the geothermal potential; here, the degree of the potential depends on the other energy sources. This knowledge contributes to rethinking the limitations of energy production; I fit the limitations of landscape architecture into the model. The landscape potential of different energy sources is different: In some cases, even when landscape and environmental aspects are taken into account, the potential exceeds the technological and economic potential (e.g. solar), while in other cases, it narrows the limits (e.g. biomass) (Fig. 111).

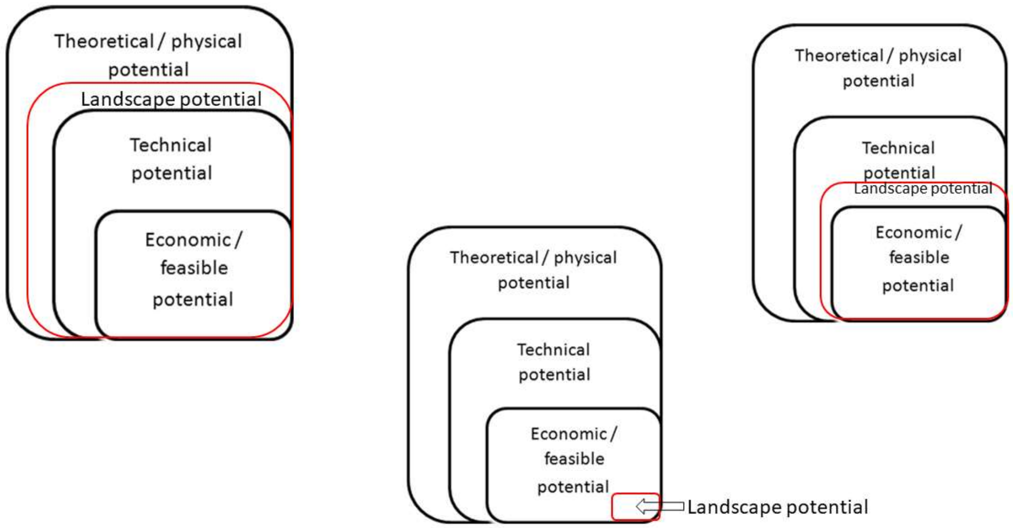


Figure 111. Types of energy potential considering landscape.

Another summary statement is the steps in the planning of energy systems. In the case of the sun, wind, biomass, biogas, and geothermal energy, I estimated the energy potential with landscape architecture tools, considering the landscape and environmental effects. In the case of both study areas, I estimated renewable energy. By summarizing the methods, I found that only sun and wind production can be limited due to landscape effects at the settlement level. In other cases, the economic and technological aspects must be examined at the object level with the environmental effects. Thus, the first step in the ideal planning process of the energy system is the determination of the energy potential of the landscape, the second step is the determination of the technological potential considering the network load, and the third is the determination of the economic potential. There is always a connection between the individual steps; the other two constantly check the changes in some steps (Fig. 112).

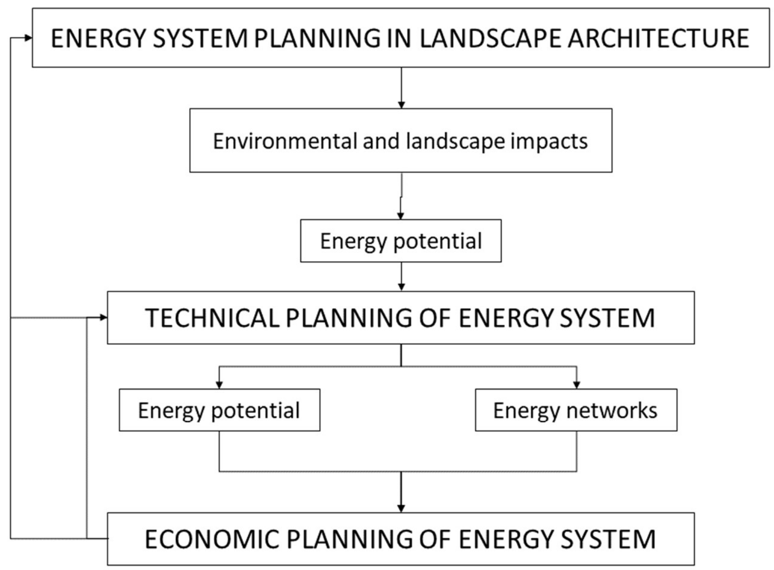


Figure 112. Ideal process of energy system planning in the perspective of landscape architecture.

5. NEW SCIENTIFIC RESULT

In this chapter, I presented the results of my research, which I carried out by examining the questions and hypotheses formulated in the objectives. Based on this, I formulate the new scientific results in theses.

My hypotheses can be classified into two groups: on the one hand, to interpret the concept of energy transition in landscape architecture, which examines the theoretical background of the research area; on the other hand, the implementation of the related landscape architecture tasks of the energy system into practice. The structure of the dissertation also maps these two extremes: on the one hand, the literature research examines the theoretical background of the topic, and on the other hand, I present the practical application through case studies in the results. The link between the two is represented by the material and the method, which partially integrates the knowledge of literature research into practical application. According to my research results, the chapters Anag and Method and the Results reflect on each other, while I concluded the literature review, which appeared during the methodological investigation. I illustrate the structure of the dissertation and the relationship of the hypotheses and theses to the thesis in Figure 113. In the following, I present the results of the hypotheses based on my research, with the theses formulated because of the conclusions drawn from it.

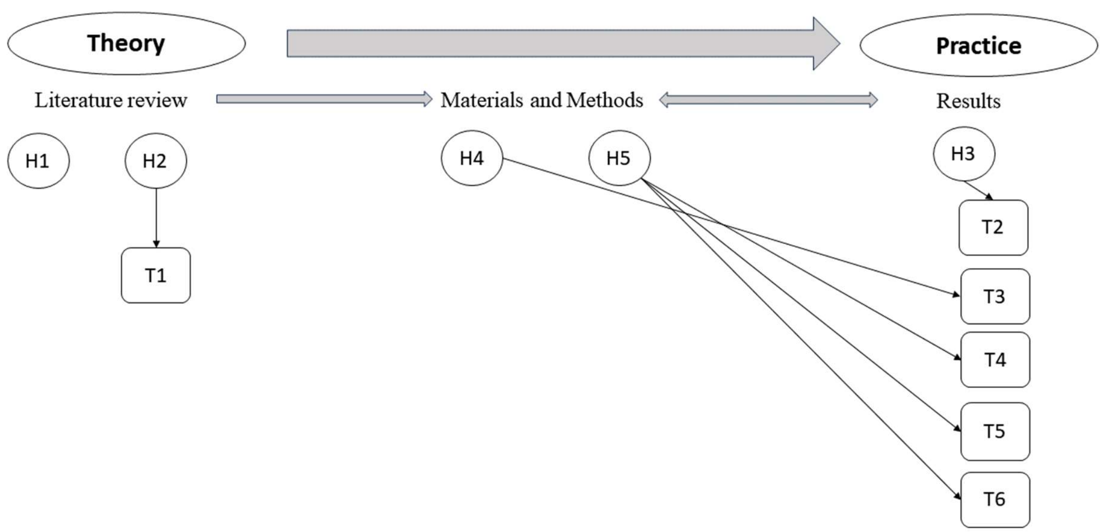


Figure 113. Relation between the hypotheses, theses and parts of the dissertation.

H1: The definition defining the spatial and temporal changes of the energy system includes changes in energy production and consumption in an environmental, economic, social, and cultural sense; this can be interpreted in the context of landscape architecture.

I examined the hypothesis from several angles since physics, environmental science, and the economic-social system can describe the energy change. In the physical sense, energy means some change, which presumably has the dimensions of time and space. I also analysed the environmental science background of the hypothesis: environmental systems can always be characterized from the point of view of matter and energy. Landscape architecture deals with closed and open systems, where, in each case, there is a process of energy change with elements outside the system. As in physics, energy describes a process, so it has the dimensions of space and time. In addition, I presented the theoretical models of the economy in the literature research; the current goal is the circular economic model, the foundations laid by industrial ecology. In this model, too, energy can be linked to the change in pressure. From the literature research, I concluded that the energy system changes in space and time; physics describes it as a fundamental science and other disciplines adopt this interpretation. I analysed the changes in the energy system of the landscape by analysing historical maps in the results section, where I identified the objects on the historical maps that are evidence of changes in the energy system.

The hypothesis is true, and previous landscape architecture research has already been confirmed; it is not possible to formulate a new scientific result.

H2: The energy transition reinterprets some tools and frameworks of landscape architecture, and new tasks and tools are integrated into the planning processes.

To verify the hypothesis, I reviewed the previous research related to the energy system of landscape architecture. Both international and Hungarian books on the practical application of landscape architecture, published in the 1980s, deal with the energy system of nature and the built environment. In most disciplines, due to the oil crisis of the 1970s, science also drew attention to the fact that planning the energy system requires thorough research. Based on the international literature, I found that landscape architecture design impacts the energy management of environmental elements and systems; this can be landscaping, material use, and orientation. These tools should be considered both as an object and on a larger scale. Based on the Hungarian literature, I found a connection between the energy system and the landscape structure. Reviewing the cultural system, he concluded that environmental education affects energy use. By examining the legislative background and environmental science foundations and reviewing recent landscape architecture research, I found that landscape architecture deals with the landscape and environmental effects of energy system facilities. From the past decade and a half, I highlighted two doctoral research, based on which I determined that the new challenges of landscape architecture are the examination of the landscape and its energy potential, and the examination of the landscape and environmental effects is directly related to it.

I verified the hypothesis; I summarized this in the following thesis:

T1: Based on the literature research, I divided the tasks of landscape architecture related to the energy transition into two parts: on the one hand, the tools used in current design practice (these influence the energy balance of environmental elements and systems), which can help with energy efficiency, environmental education and the preparation of environmental impact studies; on the other hand, it can be interpreted as a new task to determine the energy potential of a given area, taking into account the landscape and environmental effects.

H3. The planning of the energy system can be incorporated into the practice of landscape planning and territorial planning.

I verified the hypothesis; I summarized this in the following thesis:

In the material and method chapter, I connected the definition of renewable energy potential and the landscape and environmental effects. I determined the renewable energy sources according to end use and the energy potential I could determine with the available statistical data and technological descriptions. Solar and wind energy are electrical, and in the case of biomass and biogas, I numerically determined the electric current and the heating potential. Based on the electric current potential determined previously, I also quantified the geothermal potential in a derived manner. In some cases, I could not determine the energy potential, on the one hand, due to the complexity of energy production beyond landscape architecture (use of solar energy for heating, use of waste for district heating, hydropower, geothermal energy, electricity and district heat). I also examined the energy mix of the energy potentials that can be determined with landscape architecture tools in several scenarios. I compared them with the estimated energy consumption of the study area. From the point of view of the reliability of the currently available data, I designated the settlement scale as the smallest unit of planning, and from the point of view of the data, the unit that gives the most relevant results from the point of view of landscape architecture planning. By determining the energy potential, I made the renewable energy sources of a given area partially assessable since some renewable energy sources' landscape and environmental effects are different. Different environmental effects must be expected for end uses, so I made it assessable in advance. I have also added a check of the available network system. This can help plan the specific energy system territorial planning.

T2: With landscape architecture tools, I can determine the electricity potential of solar energy and wind energy at the settlement level, partly the potential of biomass, biogas, thermal energy, and electricity produced from waste; in addition, I can designate places that are potentially suitable for the use of hydropower, based on the electricity potential of the renewable energy sources I have determined, geothermal potential. I visually analysed the existing energy networks, examining the possibility of integrating the energy sources into the system. I assessed each renewable energy source's possible landscape and environmental effects according to end-use. By connecting the two tests, the designability of the energy system can be helped, and certain environmental costs that affect energy production can be internalized.

H4: Renewable energy sources and their landscape and environmental effects are directly related, thus influencing the energy potential.

In the material and methodology chapter, I examined the possibilities of determining the energy potential of each renewable energy source separately, and I summarized their landscape and environmental effects with a life cycle approach. Based on this, I was able to directly connect the potential of wind and solar energy and limit the production at the settlement level from a landscape architecture point of view. In both cases, energy production objects appear as secondary land use on the one hand in built-up areas and on the other hand in agricultural areas. In other cases, energy production is tied to objects, and at the settlement level, the effects cannot be directly linked to the potential.

I partially verified the hypothesis and formulated it in the following thesis:

T3: In the material and method chapter, based on the examination of the potential and environmental effects of each renewable energy source, I formulated the correlations of solar and wind energy in a generally applicable thesis: During landscape planning, the amount of energy potential of the sun and wind can be directly linked to the landscape and environmental effects, from the nature of the production therefore, they can be directly linked to land use and to limit the potential by taking landscape and environmental effects into account. In the case of biomass, biogas, waste and geothermal energy, the environmental effects can be formulated generally at the settlement and micro-regional level, depending on the end use. However, the production must also be examined at the object scale for decision-making.

H5: The physical characteristics of renewable energy sources can be interpreted on a landscape scale; they must be considered when planning the energy system.

I examined the hypothesis through the case studies, on the one hand, by comparing the energy mix of each sample area and, on the other hand, the results of the two sample areas. The theses belonging to the hypothesis are labelled T4, T5, and T6; I formulated the justification separately. All statements made in the thesis can be linked to weather-dependent, uncontrollable energy sources,

therefore, I verified the hypothesis partially.

In the case of both sample areas, I summarized the potential of the energy sources that can be determined in landscape planning in an energy mix, based on which I formulated the relevant thesis. Since the solar energy potential dominates the energy mix, and the energy source cannot be controlled, production from the network's point of view is technologically limited in producing electricity.

T4: Based on the energy mix of the examined sample areas, I found that even with the area restriction, the solar energy potential dominated the energy mix in all cases, so the area use restriction can be justified from technological and economic aspects.

When using wind for energy, I examined the two scales regarding landscape and environmental effects. On the one hand, turbines can be used in households based on slow wind movement, suitable for large-scale, significant electricity production. I limited the latter's production, considering the landscape and environmental effects. However, this is a significant potential for energy system planning. The distribution of the annual production potential of solar and wind shows that wind can partially supplement production at the system level. The systemic examination goes beyond the framework of landscape architecture.

T5: I limited the wind energy production to built-up areas considering landscape effects. This energy potential is insignificant in the energy mix, and this ratio can be increased by including large-scale turbines and other land uses.

During the case studies, I examined the energy sources' potential separately and compared the settlements at the micro-regional level. Based on this, I determined that the geographical features, even at the settlement level, influence the production of energy sources linked to weather phenomena.

T6: When determining the energy potential, I observed that in the case of the sun and wind, even on a small scale, the geographical features influence the potential, so the settlement level is the most miniature scale for determining the energy potential.

6. CONCLUSIONS AND RECOMMENDATIONS

Doctoral research raises at least as many new questions as it closes. In the chapter, I draw the general conclusions of the research, based on which they can be transferred into planning practice. In addition, I formulate the questions that can lead to new research for more efficient energy system operation.

Based on the literature research, it can be established that landscape planning has taken the energy system into account in various planning tools for a long time. External factors (climate change, Russian-Ukrainian war) give these tools a new focus. On the other hand, new tasks must be integrated into the planning practice, as the energy system is highly complicated today, and we have such new knowledge. In my research, this theoretical foundation marked the path by which I was able to develop methods that could be incorporated into design practice, and I was able to analyse the relationship between the energy system and landscape planning.

Based on the currently available statistical data, these renewable energy sources, which may represent the energy potential of the given area in the future, can not only be designated in a general way for the development of settlements and areas but, based on my research, some data can be used to quantify these energy sources. The area's potential can be assessed through the sun, wind, biomass, waste and biogas, and geothermal heat. This knowledge can contribute to increasing the efficiency of regional development.

From the point of view of planning, the current legal framework is twofold: the vision of the future was defined in decentralization; on the other hand, decision-making is centralized. Part of the reason for this is that there are only a few projects on a scale smaller than the national scale which would examine the issues of the energy system numerically by examining several energy sources. Using the methodology that I know, data on the numerical potential of specific renewable energy sources can already be partially included in regional development documents starting at the settlement level.

Based on the research, I recommend creating a legal cross-system of spatial planning to calculate the energy potential. Based on the material and method and the results chapter, I showed that the energy potential of the sun, wind, biomass, biogas, and indirectly of geothermal energy can be quantified in whole or in part at the settlement and regional level. Based on this, I recommend that the renewable energy potential of the given area and its environmental effects be quantitatively assessed in the settlement and territorial plans. In addition to these, it is essential not only to analyze the energy potential but also the energy network. This way, the energy system becomes more plannable and can be assigned to economic developments. The transfer can also help implement the circular economic system into the legal framework since, in this way, the energy surplus and energy deficit can be assessed in smaller regional systems.

Through the Bükk microregion, I presented a breakaway region. In these cases, preparing energy plans at the settlement level can contribute to rural development and reduce energy poverty, to which they are particularly exposed. Since I analysed the landscape and environmental effects as well, the overall environmental condition of the settlement can also improve. This can contribute to a more efficient use of EU cohesion funds.

It is also characteristic of energy system planning that the environmental effects are almost the last to be considered, whether we are talking about global climate change or the environmental condition of a settlement. The ideal would be first to assess the environmental effects of energy sources, the principles of life cycle analysis should apply, and in addition to the energy sources, the characteristics of the network; this is followed by a technological assessment, then economic planning, the different areas reflect on each other. The examination of the energy potential of the sun clearly showed that there are energy sources whose potential can be unlimited from a technological or economic point of view, so the principles of landscape and environmental effects could be applied as a first step.

My second proposal, which concerns a legal framework, concerns solar energy. Based on the results, the solar energy potential dominates the energy potential even if I limit it to the roof structure of the buildings. This is how I recommend limiting solar energy investments to urban areas. At the settlement level, the protection of the built environment must be considered. In the case of potentially protected buildings, the possibility of installing solar panels must be investigated separately.

When estimating the energy potential of biogas and biomass, I examined the efficiency of end-use. Further complex research is required for those energy sources where multi-purpose energy use is possible. On the one hand, the environmental effects are different in the case of use. However, it is also essential to consider that the amount of useful energy decreases during energy conversion.

From an ecological point of view, the most essential issue beyond my doctoral research is the role of water. Through the case studies, I showed that there may be potential places where even a small-scale hydropower plant can be investigated. First, I examined the topography and excluded the areas under ecological protection. Aquatic and water-related ecosystems are incredibly fragile, so that any change can cause severe environmental damage. Climate change causes significant changes in the water cycle, so it is not easy to detect how this affects the production of hydropower plants. Why bother with this? From the point of view of the energy mix, an element whose production can be controlled can be included in the energy mix, and according to our current knowledge, the most efficient way to store electricity is the pumped hydropower plant. In the latter case, it is also essential to plan on a small scale, with which the adverse environmental effects can be reduced. Another critical issue is that water is not only involved in production but is a cooling medium in thermal power plants and is necessary for energy production.

In conclusion, I return to the classic landscape engineering toolbox. Although I examined the new tasks thoroughly in my research, in the literature review, there were many examples of how landscape planning can be made more efficient by influencing environmental elements and systems. This toolbox must be consciously integrated into practice, using it appropriately when it is necessary to "heat" and when it is necessary to "cool".

7. SUMMARY

In my doctoral dissertation, I examined a topical issue on a landscape scale. Energy determines all our activities since no natural or human activity can be imagined without energy. The research broadly covered the landscape and environmental effects of renewable energy sources and the potential of some energy sources.

Why is this research necessary? During the transformation of the energy system, we not only reduce the effects of climate change and eliminate its cause. What is the role of landscape architecture in the energy transition? It is general design experience that our engineering field only examines the influences of the energy system and can reduce the adverse impacts with its design tools. In order to reduce the negative effects on the environment and landscape, the role of landscape architecture in planning the energy system must be reconsidered.

In my research, in the literature review, I presented in detail the scientific foundations of the energy system, the energy flows characteristic of environmental elements and systems, the economic system's relevant aspects and the cultural system's tasks. After that, I analysed the Hungarian legal framework. I introduced the tools of landscape architecture that influence the energy system and the latest research that leads the possibilities of landscape architecture and energy system research in a new direction. Based on these, I defined the tasks of landscape architecture that affect energy transition. These primarily apply to devices already used in planning practice that affect the energy balance of environmental elements and systems. Determining the regional energy potential with landscape architecture tools appeared as a new task, during which the characteristics of the landscape and the environment can be considered.

In the methodology, I defined the practices that can be used to determine the potential of specific renewable energy sources. I explained the landscape and environmental effects of the given energy source depending on the use or production. In some cases, I took them into account when determining the potential. I examined the method in two sample areas at two scales: urban and small-town micro-regional levels. In both cases, I also examined the consumption side, and based on the potential and consumption, I examined the energy balance of the areas.

Based on the conclusions, I formulated the new research results. There are area-based, generally applicable calculations of the potential of individual energy sources. On the other hand, results affect the general relationship between the energy system and landscape planning: I have determined the place of the energy potential of the landscape between the physical, technological, and economic potential, the ideal course of the planning of the energy budget from a landscape point of view, the tasks of landscape architecture in the energy transition.

My research explored the possibilities of analysing the energy system on a landscape scale. The results can help the optimal development of spatial and energy system planning. The energy transition can become more efficient by analysing the energy balance on a regional basis. By reconsidering the role of the landscape approach, some of the future unquantifiable adverse environmental effects can be reduced.

8. ÖSSZEGZÉS

Doktori disszertációmban egy aktuális téma táji léptékű kérdést vizsgáltam meg. Az energia minden tevékenységünket meghatározza, hiszen az energia nélkül nem elképzelhető el semmilyen természeti, és semmilyen emberi tevékenység sem. A kutatás széles körűre kiterjedt a megújuló energiaforrások táji, környezeti hatásaira és egyes energiaforrások potenciáljára.

Miért is fontos ez a kutatás? Az energiarendszer átalakítása során nemcsak csökkentjük a klímaváltozás hatásait, hanem annak okát szüntetjük meg. Mi a tájépítészet szerepe az energia átmenetben? Általános tervezői tapasztalat, hogy mérnöki területünk csak az energia rendszere hatásait vizsgálja, tervezési eszközeivel csökkentheti a negatív hatásokat. A környezeti és táji negatív hatások csökkentése érdekében újra kell gondolni a tájépítészet szerepét az energa rendszer tervezésében.

Kutatásomban az irodalmi áttekintésben részletesen bemutattam az energia rendszer természettudományos alapjait, a környezeti elemekre és rendszerekre jellemző energia áramlásokat, a gazdasági rendszer vonatkozó aspektusait és a kulturális rendszer feladatait. Ezt követően elemeztem a magyar jogi keretrendszert. Ismertettem a tájépítészet azon eszközeit, amelyek befolyásolják az energiarendszert, illetve a legújabb kutatásokat, amelyek új irányba terelik a tájépítészet és az energiarendszer kutatásának lehetőségeit. Ezek alapján meghatáoztam a tájépítészet energia átmenetre hatást gyakorló feladatait. Ezek egyrészt elsősorban az környezeti elemek és rendszerek enegriaháztartását befolyásoló, a tervezési gyakorlatban már használt eszközökre vonatkozik. Új feladataként megjelent a területi energiapotenciál meghatáozása tájépítészeti eszközökkel, amely folyamat során figyelembe vehetőek a táj és a környezet adottságai.

A módszertanban meghatároztam azokat a gyakorlatokat, amelyekkel meghatározhatóak egyes megújuló energiaforrások potenciálja. Ismertettem az adott energiaforrás felhasználástól vagy termeléstől függő táji és környezeti hatásait, és egyes esetekben figyelembe vettem a potenciál meghatározása során. A módszer két mintaterületen, két léptékben vizsgáltam meg: városi és kistelepülések mikrorégiós szintjén. Mindkét esetben megvizsgáltam a fogyasztási oldalt is, és a potenciál és fogyasztás alapján megvizsgáltam a területek energia mérlegét.

A következtetések alapján megfogalmaztam az új kutatási eredményeket. Egyek egyrészt az egyes energiaforrások potenciáljának terület alapú általánosan alkalmazható számításai. Másrészt az energiarendszert és a táji tervezés általános kapcsolatát befolyásoló eredmények: Meghatároztam a táj energiapotenciáljának helye a fizikai, technológiai és gazdasági potenciál között, az energiaháztartás tervezésének táji szempontú tervezésének ideális menete, a tájépítészet feladatai az energia átmenetben.

Kutatásomban az energiarendszer táji léptékű elemzésének lehetőségeit kutattam. Az eredmények segíthetik a területi tervezés és az energiarendszer tervezésének optimális fejlesztését. Az energiaháztartás területi alapú elemzésével hatékonyabbá válhat az energia átmenet. A táji szemlélet szerepének újragondolásával csökkenthetőek a jövőbeni, meg nem határozható negatív környezeti hatások egy része.

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KÖSZÖNETNYILVÁNÍTÁS

Egy doktori kutatás sok munkával lemondással jár nemcsak a doktorjelölt, hanem a környezete számára is. Elsősorban szeretném megköszöni Anyukámnak és Apukámnak, hogy mindig támogattak, nemcsak engem, de a testvéreimet is, hogy tanulhassunk. Anyukámnak szeretném megköszönni, hogy mindig gondolt arra, hogy az anyagi feltételeket biztosítsa a tanuláshoz. Apukámnak pedig azt, hogy mindig igyekezett azokat a technikai feltételeket megteremteni, hogy fejlődhessünk.

Szeretném megköszöni témavezetőmnek, Sallay Ágnesnek a hosszú éveken át tartó támogatást a kutatás során, a rossz és jó periódusokban egyaránt.

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A műhelyvitán résztvevőket is fontosnak tartom megemlíteni. A műhelyvita bizottsága: Bozó László, a két opponens Gergely Erzsébet és Illyés Zsuzsanna segítségét a disszertáció fejlesztéséhez. Szintén köszönettel tartozom Szilágyi Kingának és Jombach Sándornak, akik a műhelyvita során tanácsokkal láttak el.

Köszönettel tartozom Erdélyi Reginának, Nagy Boglárkának, Prohászka Violának, Guifang Wangnak és Bérczi Szabolcsnak a közös cikkekért. És persze a többi hallgatónak, akikkel bár nem írtunk közös cikket ((de ki tudja mit hoz a jövő), mégis örömtelivé tették az elmúlt éveket.

És végül, de nem útolsó sorban szeretném megköszöni a férjemnek, aki a maga módján a legtöbb támogatást nyújtotta az elmúlt években, és aki nélkül nem fejlődtem volna ennyit. És, hogy milyen az élet egy doktorandusszal? Egy idézet tőle, amit talán a legtöbbet hallottam, ha doktori kutatással kapcsolatban: "Tönkre tetted az életemet a doktorival!"

APPENDICES

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296/2015. (X. 13.) Korm. rendelet a földgáz végső menedékes szolgáltatásról és a földgázkereskedő működésének lehetetlenülése esetén a felhasználók földgázellátását veszélyeztető helyzet fennállása következtében alkalmazandó eljárásról
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1995. évi LIII. törvény a környezet védelmének általános szabályairól
2006. évi XXVI. törvény a földgáz biztonsági készletezéséről
2007. évi LXXXVI. törvény a villamos energiáról
2008. évi LXX. törvény a villamos energiával összefüggő egyes kérdésekről
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DATASETS

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M2 National forestry data for the calculation of firewood for energy purposes

The national data based on the National Forestry Dataset. (Nemzeti Földügyi Központ 2022)

Live wood stock averages

	2019			2020			2021			Average
	Area (ha)	Live tree stock (m3)	m3/ha	Area (ha)	Live tree stock (m3)	m3/ha	Area (ha)	Live tree stock (m3)	m3/ha	m3/ha
Quercus robur	174640	37300632	214	175795	38013118	216	177158	38745912	219	216
Quercus petraea	177766	47080167	265	176949	47200015	267	175917	47545388	270	267
Other Quercus sp.	36980	7375943	199	36719	7574398	206	37851	7800527	206	204
Quercus cerris	213359	49211158	231	215668	50180514	233	216454	50862731	235	233
Quercus sp. Sum.	**602745**	**140967900**	**234**	**605131**	**142968045**	**236**	**607380**	**144954558**	**239**	**236**
Fagus sp.	112791	40926923	363	112861	41310302	366	113611	41640584	367	365
Carpinus sp.	97094	17918059	185	96732	18080434	187	97231	18277668	188	186
Acer sp.	27862	5077179	182	29171	5311601	182	30247	5520773	183	182
Ulmus sp.	5338	876153	164	5490	907889	165	5529	953907	173	167
Fraxinus sp.	62970	13843721	220	63557	14099509	222	63671	14142331	222	221
Other hardwood	24408	4523168	185	25020	4713907	188	25377	4844870	191	188
Other hardwood Sum.	**330463**	**83165203**	**252**	**332831**	**84423642**	**254**	**335666**	**85380133**	**254**	**253**
Robinia sp.	**454531**	**54663853**	**120**	**456632**	**55447007**	**121**	**459135**	**56252838**	**123**	**121**
Plopii hibrizi	105695	17277877	163	105059	17424307	166	102629	17493719	170	167
Native Populus sp.	91904	18637586	203	94237	19450944	206	95892	20410943	213	207
Populus sp. Sum	**652130**	**90579316**	**139**	**655928**	**92322258**	**141**	**657656**	**94157500**	**143**	**141**
Salix sp.	18894	5078753	269	18645	5088026	273	17936	5002814	279	274
Alnus sp.	47814	11001792	230	47974	11095019	231	47796	11205413	234	232
Tilia sp.	23296	7507273	322	23551	7635904	324	23705	7638696	322	323
Other softwood	6997	1562183	223	6800	1606091	236	6778	1640067	242	234
Other Softwood Sum	**97001**	**25150001**	**259**	**96970**	**25425040**	**262**	**96215**	**25486990**	**265**	**262**
Pinus sylvestris	109434	35375500	323	108137	35444435	328	106308	35606309	335	329
Pinus nigra	58763	12068735	205	58006	12227492	211	57627	12351268	214	210
Picea abies	11197	4439891	397	10495	4269070	407	9800	4102548	419	407
Larix decidua	3556	1447698	407	3078	1474068	479	3076	1499358	487	458
Other pine species	2269	418884	185	2200	425677	193	2200	448287	204	194
Pine species Sum.	**185219**	**53750708**	**290**	**181916**	**53840742**	**296**	**179011**	**54007770**	**302**	**296**

Timber production averages

	2019			2020			2021			Average		
	Livestock (m3)	Harvested firewood (m3)	Harvested firewood (%)	Livestock (m3)	Harvested firewood (m3)	Harvested firewood (%)	Livestock (m3)	Harvested firewood (m3)	Harvested firewood (%)	Livestock (m3)	Harvested firewood (m3)	Harvested firewood (%)
Quercus sp.		491760			655339			529700				
Quercus cerris		619322			532202			619684				
Quercus sum.	**1,41E+08**	**1111082**	**0,79**	**142968045**	**1187541**	**0,83**	**144954556**	**1149384**	**0,79**	**142963500**	**1149336**	**0,80**
Fagus sp.		336110			290257			310069				
Carpinus sp.		143686			124117			156481				
other hardwood		337184			362177			526905				
Hardwood sum.	**83165203**	**816980**	**0,98**	**84423642**	**776551**	**0,92**	**85380133**	**993455**	**1,16**	**84322993**	**862329**	**1,02**
Robinia sp.	**54663853**	**972559**	**1,78**	**55447007**	**599555**	**1,08**	**56252838**	**962341**	**1,71**	**55454566**	**844818**	**1,52**
Plopii hibrizi		54399			118277			57108				
Native Populu sp.		41870			44911			57239				
Populus sp. Sum	**90579316**	**96269**	**0,11**	**92322258**	**163188**	**0,18**	**94157500**	**1076688**	**1,14**	**92353025**	**445382**	**0,48**
Salix sp.		10323			12294			8938				
Other softwood		150388			159130			146036				
Softwood sum	**25150001**	**160711**	**0,64**	**25425040**	**171424**	**0,67**	**25486990**	**154974**	**0,61**	**25354010**	**162370**	**0,64**
Pine species	**53750708**	**124639**	**0,23**	**53840742**	**177441**	**0,33**	**54007770**	**122372**	**0,23**	**53866407**	**141484**	**0,26**

Kecskemét (Cattaneo 2018)

European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

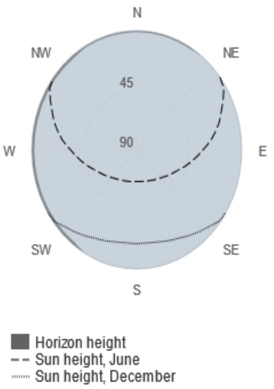
Provided inputs:

Latitude/Longitude:	46.908,19.693
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

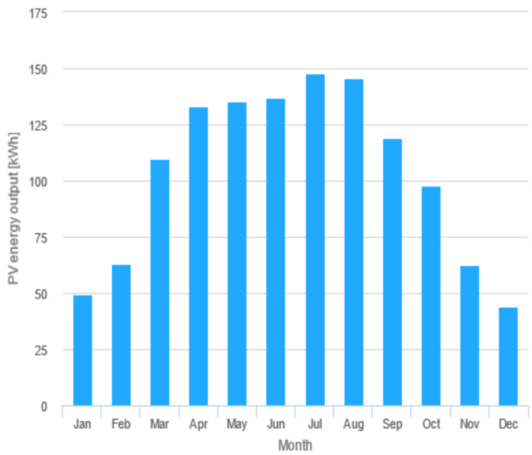
Simulation outputs

Slope angle:	35 °
Azimuth angle:	0 °
Yearly PV energy production:	1245.17 kWh
Yearly in-plane irradiation:	1578.61 kWh/m²
Year-to-year variability:	59.62 kWh
Changes in output due to:	
Angle of incidence:	-2.83 %
Spectral effects:	1.35 %
Temperature and low irradiance:	-6.87 %
Total loss:	-21.12 %

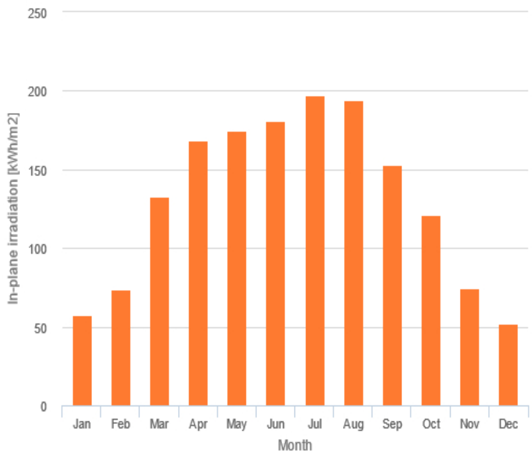
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	49.5	57.5	11.9
February	62.8	74.0	20.9
March	109.9	133.0	21.5
April	133.2	168.4	17.4
May	135.4	174.5	14.6
June	137.2	180.6	8.9
July	148.1	197.3	10.1
August	145.8	193.8	14.8
September	118.8	152.6	14.8
October	98.0	121.0	16.1
November	62.4	74.2	10.5
December	43.9	51.8	11.5

E_m: Average monthly electricity production from the defined system [kWh].
H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].
SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Joint Research Centre

Report generated on 2023/08/20

M4 Territorial data of Kecskemét based on Ecosystem Map of Hungary.
(Agrárminisztérium 2019)

	Landuse	Area (pixel)	Area (m2)
Urban	Low buildings	27019	10807600
	High buildings	3165	1266000
	Paved roads	26429	10571600
	Dirt roads	4980	1992000
	Railways	2677	1070800
	Other paved or non-paved artificial areas	10890	4356000
	Green urban areas with trees	27658	11063200
	Green urban areas without trees	86303	34521200
Croplands	Arable land	277969	111187600
	Vineyards	5842	2336800
	Fruit and berry, and other plantations	25807	10322800
	Energy crops	5	2000
	Complex cultivation patterns with scattered buildings	14315	5726000
	Complex cultivation patterns without buildings	9465	3786000
Grasslands and other herbaceous vegetation	Open sand steppes	48774	19509600
	Closed sand steppes	18197	7278800
	Salt steppes and meadows (grasslands affected by salinisation included)	2814	1125600
	Closed grasslands in hills and mountains or on cohesive soil	8533	3413200
	Other herbaceous vegetation	17185	6874000
Forests and woodlands	Turkey oak forests	68	27200
	Native poplar dominated forests	26393	10557200
	Pioneer forests of hilly and mountainous regions	56	22400
	Pedunculate oak forests, monospecific or mixed with ash	569	227600
	Other mixed deciduous forests	1371	548400
	Alder forests	57	22800
	Poplar woods outside the floodplain	320	128000
	Conifer-dominated plantations	29674	11869600
	Black locust-dominated mixed plantations	55293	22117200
	Plantations dominated by non-native poplar and willow species	11596	4638400
	Plantations of other non-native tree species	6881	2752400
	Clearcut	3382	1352800
	Forest stand under regeneration	623	249200
	Other ligneous vegetation, woodlands	40662	16264800
Wetlands	Tall-herb vegetation of marshes and fens standing in water	664	265600
	Fens and mesotrophic wet meadows, grasslands with periodic water effect	685	274000
Rivers and lakes	Water bodies	1881	752400
	Water courses	13	5200

M5 Biomass potential of Kecskemét by end use

	Heating (kWh)	Electricity (kWh)	Number of household heating	Number of household electricity	Proportion of household heating (%)	Proportion of houshold electricity (%)
Heating 100%-Electricity 0%	18606783	0	1413	0	2,8	0,0
Heating 90%-Electricity 10%	16746104,7	558203,49	1272	205	2,5	0,4
Heating 80%-Electricity 20%	14885426,4	1116406,98	1131	410	2,2	0,8
Heating 70%-Electricity 30%	13024748,1	1674610,47	989	615	2,0	1,2
Heating 60%-Electricity 40%	11164069,8	2232813,96	848	820	1,7	1,6
Heating 50%-Electricity 50%	9303391,5	2791017,45	707	1025	1,4	2,0
Heating 40%-Electricity 60%	7442713,2	3349220,94	565	1230	1,1	2,4
Heating 30%-Electricity 70%	5582034,9	3907424,43	424	1434	0,8	2,8
Heating 20%-Electricity 80%	3721356,6	4465627,92	283	1639	0,6	3,3
Heating 10%-Electricity 90%	1860678,3	5023831,41	141	1844	0,3	3,7
Heating 0%-Electricity 100%	0	5582035	0	2049	0,0	4,1

M6 Dataset of waste of Kecskemét.

(Kecskemét Megyei Jogú Város Önkormányzata 2019)

Year	Waste (t)
2010	34011
2011	30101
2012	27380
2013	26423
2014	25306
2015	19816
2016	18660
2017	20042
2018	54439
2019	31910,5

M7 Biogas potential of Kecskemét by end use

	Heating (kWh)	Electricity (kWh)	Number of household heating	Number of household electricity	Proportion of household heating (%)	Proportion of houshold electricity (%)
Heating 100%-Electricity 0%	22919712	0	1741	0	3,5	0,0
Heating 90%-Electricity 10%	20992470	3757348	1594	1379	3,2	2,7
Heating 80%-Electricity 20%	19065228	4820696	1448	1770	2,9	3,5
Heating 70%-Electricity 30%	17137986	5884043	1302	2160	2,6	4,3
Heating 60%-Electricity 40%	15210744	6947391	1155	2550	2,3	5,1
Heating 50%-Electricity 50%	13283502	8010739	1009	2941	2,0	5,8
Heating 40%-Electricity 60%	11356259	9074087	863	3331	1,7	6,6
Heating 30%-Electricity 70%	9429017	10137435	716	3722	1,4	7,4
Heating 20%-Electricity 80%	7501775	11200782	570	4112	1,1	8,2
Heating 10%-Electricity 90%	5574533	12264130	423	4502	0,8	8,9
Heating 0%-Electricity 100%	3647291	13327478	277	4893	0,6	9,7

M8 Wind speed and mean power density of Kecskemét

('Global Wind Atlas' n.d.)

	Kecskemét		Gols	
Height	**Speed (m/s)**	**Mean power density (W/m^2)**	**Speed (m/s)**	**Mean power density (W/m^2)**
10	3,01	43	4,01	102
50	4,76	141	5,88	274
100	5,98	230	7,2	403
150	6,99	381	7,93	564
200	7,55	519	8,54	727

M9 Geothermal potential of Kecskemét in different scenarios

Scenario 1

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (10%)	343071000	1029213000
Biomass	2791018	8373054
Waste	7922000	23766000
Biogas	4521732	13565196
Wind (10%)	13713000	41139000
Sum.	**372018750**	**1116056250**

Scenario 2

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (20%)	686142000	2058426000
Biomass	2791018	8373054
Waste	7922000	23766000
Biogas	4521732	13565196
Wind (10%)	13713000	41139000
Sum.	**715089750**	**2145269250**

Scenario 3

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (30%)	1029213000	3087639000
Biomass	2791018	8373054
Waste	7922000	23766000
Biogas	4521732	13565196
Wind (10%)	13713000	41139000
Sum.	**1058160750**	**3174482250**

Scenario 4

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (30%)	1029213000	3087639000
Biomass	2791018	8373054
Waste	7922000	23766000
Biogas	4521732	13565196
Wind (20%)	27422000	82266000
Sum.	**1071869750**	**3215609250**

M10 Energy consumption of Kecskemét

The original data is based on the dataset of the International Energy Agency (IEA n.d.)

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Kecskemét (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Kecskemét (kWh)	Consumption of Kecskemét (kWh)
Industry	168557	57607	110950	30819469100	7664	771571959	16001957246	3979	400612401	1172184359
Commercial and public services	91409	28962	62447	17346402766	4314	434270880	8045006436	2001	201408446	635679326
Transport	177661	4237	173424	48173371872	11980	603015302	1176945386	293	14732539	617747840
Agriculture/Forestry	26982	3190	23792	6608894176	1643	82727535	886111820	220	11091999	93819534
Non-specified	1471	266	1205	334722490	83	4189924	73888948	18	924913	5114837
Fishing	98	50	48	13333344	3	166902	13888900	3	173856	340757
Non-energy use	80174	-	-	-	-					
Household					13166	609717987		2724	137117988	746835975
Sum	**546352**	**94312**	**371866**		**25687**	**1895942501**	**26197798736**		**766062141**	**3271722629**

M11 Solar radiation potential of Bükk microregion (Cattaneo 2018)

Lénárddaróc

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

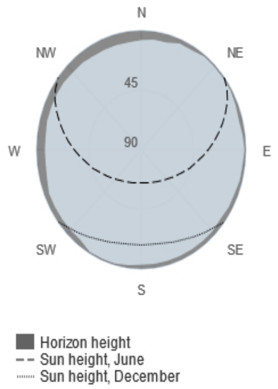
Provided inputs:

Latitude/Longitude:	48.149,20.372
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

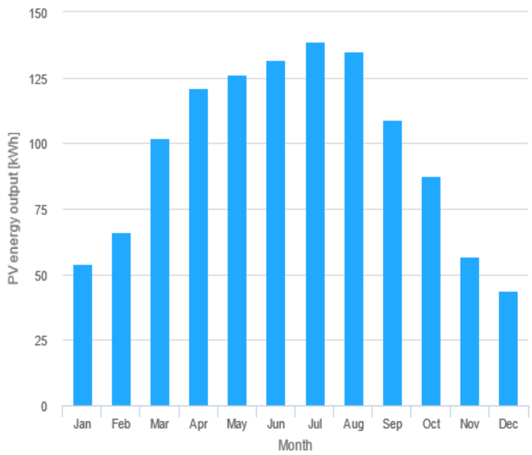
Simulation outputs

Slope angle:	35 °
Azimuth angle:	0 °
Yearly PV energy production:	1172.5 kWh
Yearly in-plane irradiation:	1467.35 kWh/m²
Year-to-year variability:	62.31 kWh
Changes in output due to:	
Angle of incidence:	-2.93 %
Spectral effects:	1.5 %
Temperature and low irradiance:	-5.7 %
Total loss:	-20.09 %

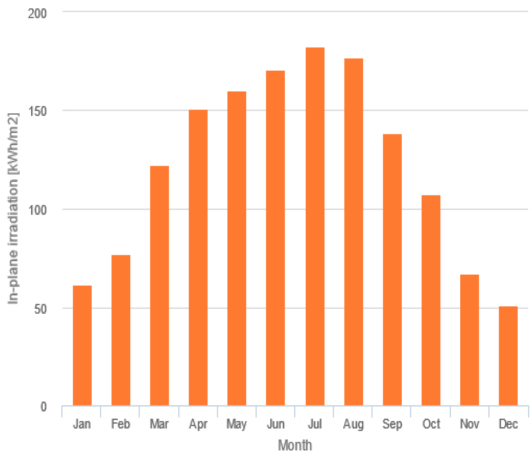
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	54.0	61.7	13.0
February	66.0	76.8	16.9
March	102.3	122.4	19.2
April	120.9	151.2	18.6
May	126.4	160.4	16.3
June	131.7	170.9	10.6
July	138.7	182.3	13.3
August	135.1	177.2	13.8
September	109.2	138.7	15.0
October	87.6	107.5	16.6
November	56.8	67.2	11.9
December	43.9	51.1	9.1

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Report generated on 2023/07/15

M12 Territorial data of Bükk microregion based on Ecosystem Map of Hungary

(Agrárminisztérium 2019)

		Lénárddaróc		Csokvaomány		Bükkmogyorósd	
	Landuse	Area (pixel)	Area (m2)	Area (pixel)	Area (m2)	Area (pixel)	Area (m2)
Urban	Low buildings	191	76400	421	168400	90	36000
	High buildings	0	0	0	0	0	0
	Paved roads	121	48400	525	210000	176	70400
	Dirt roads	37	14800	130	52000	34	13600
	Railways	0	0	0	0	0	0
	Other paved or non-paved artificial areas	3	1200	14	5600	3	1200
	Green urban areas with trees	103	41200	357	142800	322	128800
	Green urban areas without trees	663	265200	1734	693600	606	242400
Croplands	Arable land	2777	1110800	8575	3430000	0	0
	Vineyards	0	0	0	0	0	0
	Fruit and berry, and other plantations	0	0	11	4400	0	0
	Complex cultivation patterns with scattered buildings	1	400	36	14400	0	0
	Complex cultivation patterns without buildings	40	16000	22	8800	2	800
Grasslands and other herbaceous vegetation	Calcareous open rocky grasslands	120	48000	0	0	127	50800
	Siliceous open rocky grasslands	0	0	72	28800	0	0
	Closed grasslands in hills and mountains or on cohesive soil	3798	1519200	12685	5074000	4583	1833200
	Other herbaceous vegetation	313	125200	360	144000	333	133200
Forests and woodlands	Beech forests	0	0	820	328000	0	0
	Sessile oak-hornbeam forests	0	0	1180	472000	2429	971600
	Turkey oak forests	1	400	2580	1032000	9177	3670800
	Downy oak forests	0	0	0	0	0	0
	Native poplar dominated forests	0	0	0	0	0	0
	Pioneer forests of hilly and mountainous regions	189	75600	249	99600	105	42000
	Pedunculate oak-hornbeam forests	0	0	0	0	0	0
	Forests dominated by other native tree species (without excess water)	72	28800	515	206000	482	192800
	Other mixed deciduous forests	0	0	79	31600	267	106800
	Alder forests	0	0	47	18800	471	188400
	Willow woods outside the floodplain	0	0	0	0	0	0
	Poplar woods outside the floodplain	0	0	0	0	0	0
	Forests dominated by other native tree species with excess water	0	0	0	0	0	0
	Conifer-dominated plantations	36	14400	822	328800	1014	405600
	Black locust-dominated mixed plantations	1638	655200	1479	591600	552	220800
	Plantations dominated by non-native poplar and willow species	191	76400	1	400	0	0
	Plantations of other non-native tree species	0	0	0	0	760	304000
	Clearcut	0	0	0	0	55	22000
	Forest stand under regeneration	323	129200	969	387600	1140	456000
	Other ligneous vegetation, woodlands	1456	582400	2510	1004000	1747	698800
Wetlands	Tall-herb vegetation of marshes and fens standing in water	810	324000	1199	479600	278	111200
	Fens and mesotrophic wet meadows, grasslands with periodic water effect	10	4000	93	37200	19	7600
Rivers and lakes	Water bodies	0	0	0	0	0	0
	Water courses	0	0	0	0	0	0

	Landuse	Nekézseny Area (pixel)	Nekézseny Area (m2)	Nagyvisnyó Area (pixel)	Nagyvisnyó Area (m2)	Csernely Area (pixel)	Csernely Area (m2)
Urban	Low buildings	316	126400	428	171200	389	155600
	High buildings	1	400	1	400	2	800
	Paved roads	373	149200	819	327600	674	269600
	Dirt roads	71	28400	149	59600	51	20400
	Railways	92	36800	58	23200	0	0
	Other paved or non-paved artificial areas	20	8000	23	9200	20	8000
	Green urban areas with trees	308	123200	716	286400	326	130400
	Green urban areas without trees	1416	566400	1788	715200	2603	1041200
Croplands	Arable land	3106	1242400	4060	1624000	4091	1636400
	Vineyards	276	110400	0	0	0	0
	Fruit and berry, and other plantations	72	28800	2	800	0	0
	Complex cultivation patterns with scattered buildings	10	4000	19	7600	5	2000
	Complex cultivation patterns without buildings	180	72000	307	122800	0	0
Grasslands and other herbaceous vegetation	Calcareous open rocky grasslands	2	800	40	16000	142	56800
	Siliceous open rocky grasslands	1	400	459	183600	0	0
	Closed grasslands in hills and mountains or on cohesive soil	7296	2918400	12878	5151200	10468	4187200
	Other herbaceous vegetation	655	262000	1023	409200	454	181600
Forests and woodlands	Beech forests	48	19200	48125	1,9E+07	3465	1386000
	Sessile oak-hornbeam forests	2669	1067600	10335	4134000	4200	1680000
	Turkey oak forests	7203	2881200	2960	1184000	12594	5037600
	Downy oak forests	82	32800	67	26800	0	0
	Native poplar dominated forests	0	0	0	0	0	0
	Pioneer forests of hilly and mountainous regions	3	1200	64	25600	255	102000
	Pedunculate oak-hornbeam forests	0	0	0	0	219	87600
	Forests dominated by other native tree species (without excess water)	491	196400	1299	519600	629	251600
	Other mixed deciduous forests	424	169600	461	184400	780	312000
	Alder forests	0	0	964	385600	177	70800
	Willow woods outside the floodplain	11	4400	14	5600	0	0
	Poplar woods outside the floodplain	0	0	0	0	0	0
	Forests dominated by other native tree species with excess water	64	25600	0	0	0	0
	Conifer-dominated plantations	3092	1236800	6456	2582400	2502	1000800
	Black locust-dominated mixed plantations	1182	472800	943	377200	2267	906800
	Plantations dominated by non-native poplar and willow species	0	0	0	0	0	0
	Plantations of other non-native tree species	35	14000	0	0	52	20800
	Clearcut	0	0	33	13200	172	68800
	Forest stand under regeneration	808	323200	5051	2020400	915	366000
	Other ligneous vegetation, woodlands	4422	1768800	7376	2950400	3367	1346800
Wetlands	Tall-herb vegetation of marshes and fens standing in water	463	185200	481	192400	740	296000
	Fens and mesotrophic wet meadows, grasslands with periodic water effect	11	4400	49	19600	3	1200
Rivers and lakes	Water bodies	0	0	37	14800	0	0
	Water courses	50	20000	48	19200	0	0

	Landuse	Sáta	
		Area (pixel)	Area (m2)
Urban	Low buildings	450	180000
	High buildings	3	1200
	Paved roads	563	225200
	Dirt roads	40	16000
	Railways	104	41600
	Other paved or non-paved artificial areas	12	4800
	Green urban areas with trees	278	111200
	Green urban areas without trees	2240	896000
Croplands	Arable land	1889	755600
	Vineyards	0	0
	Fruit and berry, and other plantations	1	400
	Complex cultivation patterns with scattered buildings	28	11200
	Complex cultivation patterns without buildings	37	14800
Grasslands and other herbaceous vegetation	Calcareous open rocky grasslands	0	0
	Siliceous open rocky grasslands	0	0
	Closed grasslands in hills and mountains or on cohesive soil	13754	5501600
	Other herbaceous vegetation	654	261600
Forests and woodlands	Beech forests	1050	420000
	Sessile oak-hornbeam forests	421	168400
	Turkey oak forests	7237	2894800
	Downy oak forests	41	16400
	Native poplar dominated forests	32	12800
	Pioneer forests of hilly and mountainous regions	68	27200
	Pedunculate oak-hornbeam forests	0	0
	Forests dominated by other native tree species (without excess water)	401	160400
	Other mixed deciduous forests	584	233600
	Alder forests	0	0
	Willow woods outside the floodplain	0	0
	Poplar woods outside the floodplain	307	122800
	Forests dominated by other native tree species with excess water	23	9200
	Conifer-dominated plantations	2697	1078800
	Black locust-dominated mixed plantations	2247	898800
	Plantations dominated by non-native poplar and willow species	0	0
	Plantations of other non-native tree species	43	17200
	Clearcut	0	0
	Forest stand under regeneration	1137	454800
	Other ligneous vegetation, woodlands	3796	1518400
Wetlands	Tall-herb vegetation of marshes and fens standing in water	984	393600
	Fens and mesotrophic wet meadows, grasslands with periodic water effect	29	11600
Rivers and lakes	Water bodies	0	0
	Water courses	0	0

M13 Biomass potential of Bükk microregion by end use

	Heating (kWh)	Electricity (kWh)	Number of household heating	Number of household electricity	Proportion of household heating (%)	Proportion of household electricity (%)
Heating 100%-Electricity 0%	33035149	0	2509	0	102,2	0,0
Heating 90%-Electricity 10%	29731634,1	991054,47	2258	364	91,9	14,8
Heating 80%-Electricity 20%	26428119,2	1982108,94	2007	728	81,7	29,6
Heating 70%-Electricity 30%	23124604,3	2973163,41	1756	1091	71,5	44,4
Heating 60%-Electricity 40%	19821089,4	3964217,88	1505	1455	61,3	59,3
Heating 50%-Electricity 50%	16517574,5	4955272,35	1255	1819	51,1	74,1
Heating 40%-Electricity 60%	13214059,6	5946326,82	1004	2183	40,9	88,9
Heating 30%-Electricity 70%	9910544,7	6937381,29	753	2547	30,6	103,7
Heating 20%-Electricity 80%	6607029,8	7928435,76	502	2911	20,4	118,5
Heating 10%-Electricity 90%	3303514,9	8919490,23	251	3274	10,2	133,3
Heating 0%-Electricity 100%	0	9910544,7	0	3638	0,0	148,1

M14 Dataset of waste of Bükk microregion

Based on the data provision of NHKV National Waste Management Coordinating and Asset Management Private Limited Company

Year	**Lénárddaróc (t)**	**Csokvaomány (t)**	**Bükkmogyorósd (t)**	**Nekézseny (t)**	**Nagyvisnyó (t)**	**Csernely (t)**	**Sáta (t)**	**Sum (t)**
2017	59,135	118,308	40,123	139,854	260,05	169,171	202,032	988,673
2018	58,003	124,851	30,211	145,147	250,25	122,63	222,914	954,006
2019	66,215	129,295	33,171	149,889	200,46	131,536	216,441	927,007
2020	64,981	128,542	33,78	152,989	206,62	129,835	212,169	928,916
2021	65,738	129,511	35,716	148,407	207,69	131,735	209,922	928,719
Average	**62,8144**	**126,1014**	**34,6002**	**147,2572**	**225,014**	**136,9814**	**212,696**	**945,4642**
Household	**0,398**	**0,302**	**0,339**	**0,433**	**0,441**	**0,330**	**0,414**	**0,385**

M15 Biogas potential of Bükk microregion by end use

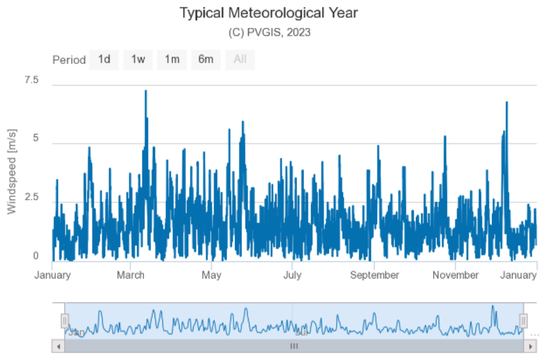
	Heating (kWh)	Electricity (kWh)	Number of household heating	Number of household electricity	Proportion of household heating (%)	Proportion of houshold electricity (%)
Heating 100%-Electricity 0%	2176464	0	165	0	6,7	0,0
Heating 90%-Electricity 10%	1959787	101838	149	37	6,1	1,5
Heating 80%-Electricity 20%	1743109	203677	132	75	5,4	3,0
Heating 70%-Electricity 30%	1526432	305515	116	112	4,7	4,6
Heating 60%-Electricity 40%	1309755	407353	99	150	4,1	6,1
Heating 50%-Electricity 50%	1093078	509192	83	187	3,4	7,6
Heating 40%-Electricity 60%	876400	611030	67	224	2,7	9,1
Heating 30%-Electricity 70%	659723	712868	50	262	2,0	10,7
Heating 20%-Electricity 80%	443046	814707	34	299	1,4	12,2
Heating 10%-Electricity 90%	226368	916545	17	336	0,7	13,7
Heating 0%-Electricity 100%	9691	1018383	1	374	0,0	15,2

M16 Wind energy potential, wind speed and mean power density of Bükk microregion
Wind speed and mean power density based on Global Wind Atlas('Global Wind Atlas' n.d.)

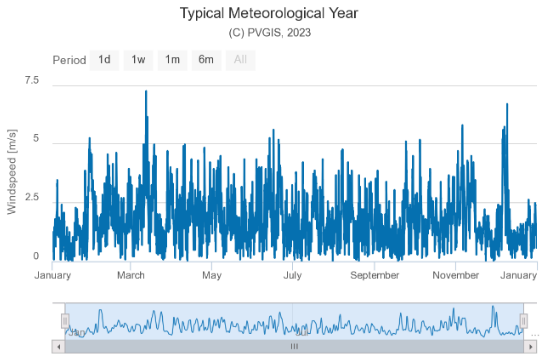
Settlement	Population	Wind energy potential 10% (kWh)	Wind energy potential 20% (kWh)
Lénárddaróc	158	43039,2	86078,4
Csokvaomány	417	113590,8	227181,6
Bükkmogyorósd	102	27784,8	55569,6
Nekézseny	340	92616	185232
Nagyvisnyó	510	138924	277848
Csernely	415	113046	226092
Sáta	514	140013,6	280027,2
Sum	**2456**	**669014,4**	**1338028,8**

		Height (m)				
		10	50	100	150	200
Lénárddaróc	Speed (m/s)	3,46	4,51	5,17	5,88	6,48
	Mean power density (W/m^2)	99	166	200	271	372
Csokvaomány	Speed (m/s)	3,31	4,33	4,98	5,66	6,26
	Mean power density (W/m^2)	85	146	175	241	329
Bükkmogyorósd	Speed (m/s)	3,45	4,57	5,3	6,07	6,66
	Mean power density (W/m^2)	100	177	223	305	411
Nekézseny	Speed (m/s)	3,25	4,39	5,08	5,75	6,28
	Mean power density (W/m^2)	91	163	198	264	349
Nagyvisnyó	Speed (m/s)	3,8	4,59	5,22	5,93	6,5
	Mean power density (W/m^2)	138	188	219	294	393
Csernely	Speed (m/s)	3,51	4,56	5,24	5,96	6,57
	Mean power density (W/m^2)	101	167	201	277	379
Sáta	Speed (m/s)	3,26	4,25	4,93	5,61	6,17
	Mean power density (W/m^2)	83	139	173	239	324
Gols	Speed (m/s)	4,01	5,88	7,2	7,93	8,54
	Mean power density (W/m^2)	102	274	403	564	727

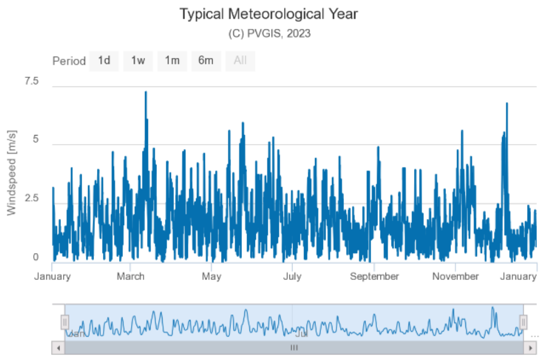
M16 Wind speed in typical meterological year in Bükk microregion (Cattaneo 2018)



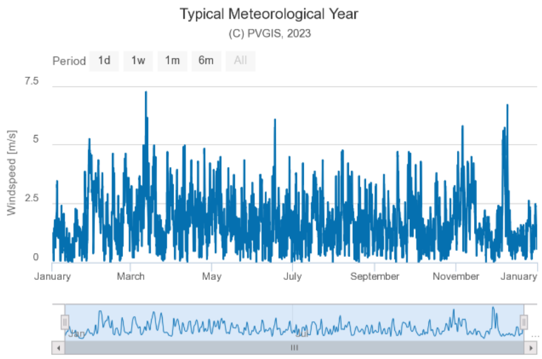
(a) Lénárddaróc



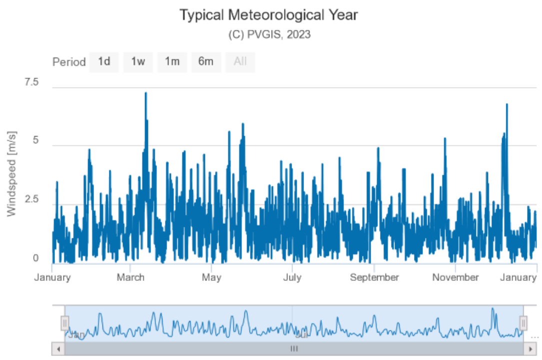
(d) Nekézseny



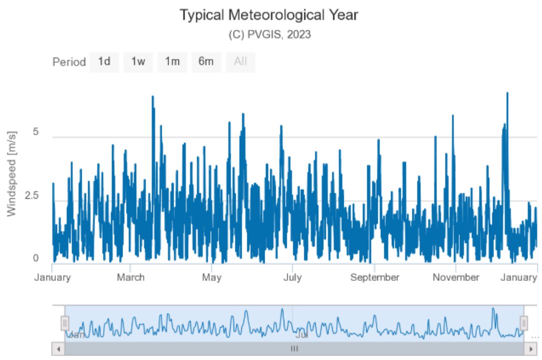
(b) Csokvaomány



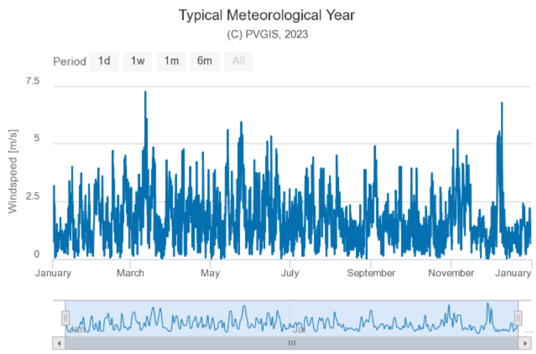
(e) Nagyvisnyó



(c) Bükkmogyorósd

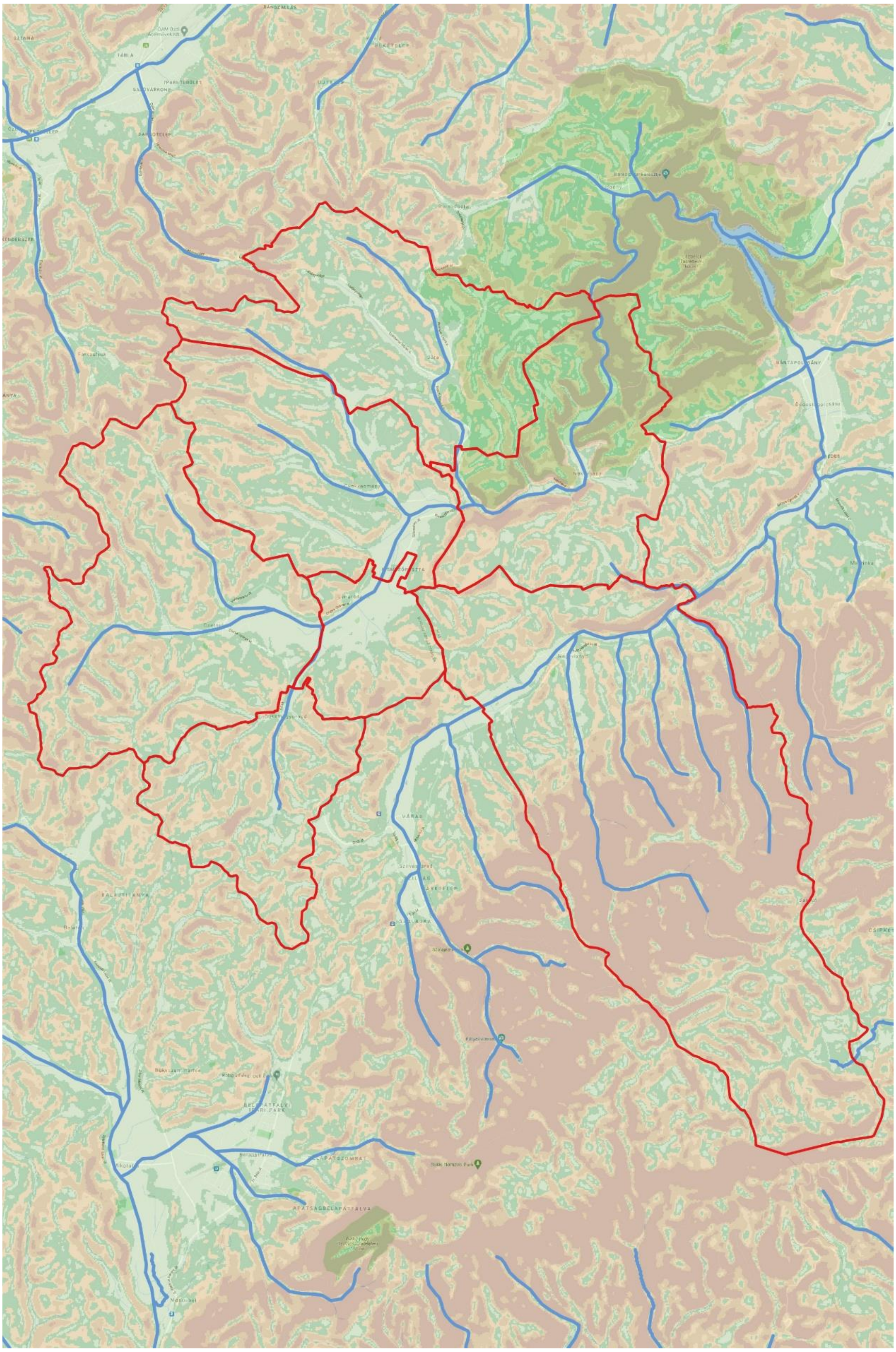


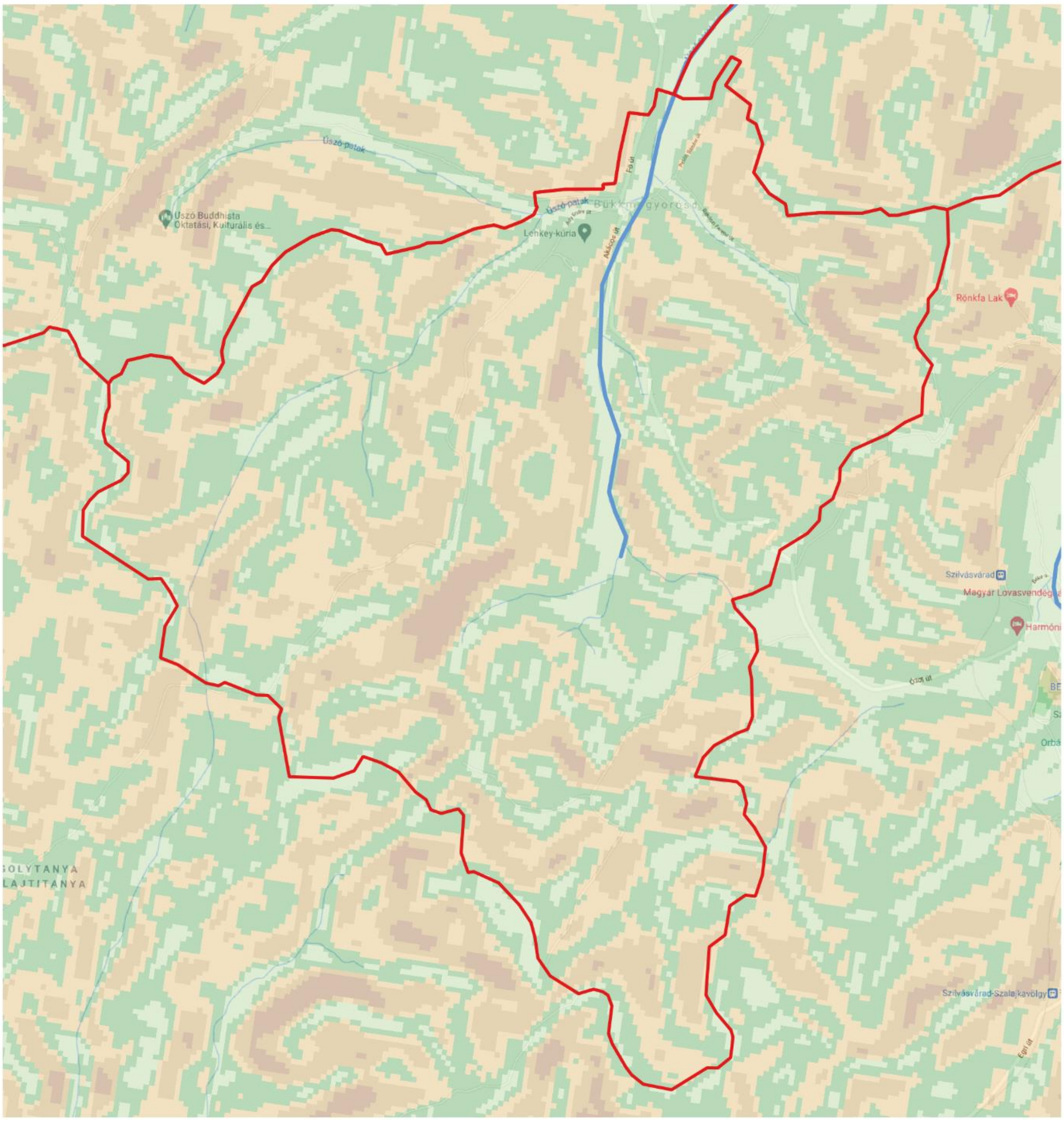
(f) Csernely



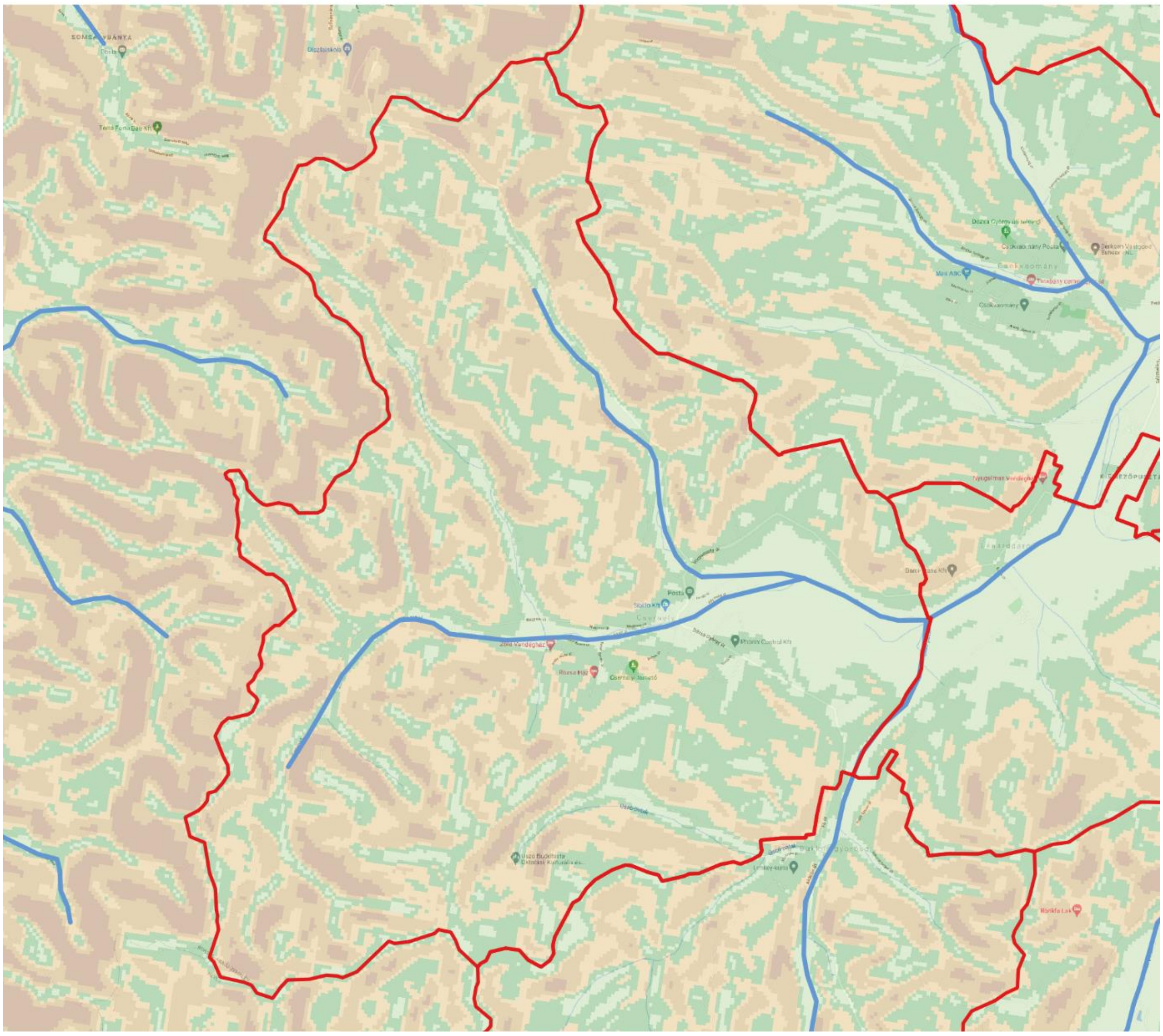
(g) Sáta

M17 Slope category map of Bükk microregion based on EU-DEM (‘EU-DEM — Copernicus Land Monitoring Service’ n.d.) and EU-Hydro (‘EU-Hydro - River Network Database — Copernicus Land Monitoring Service’ n.d.)

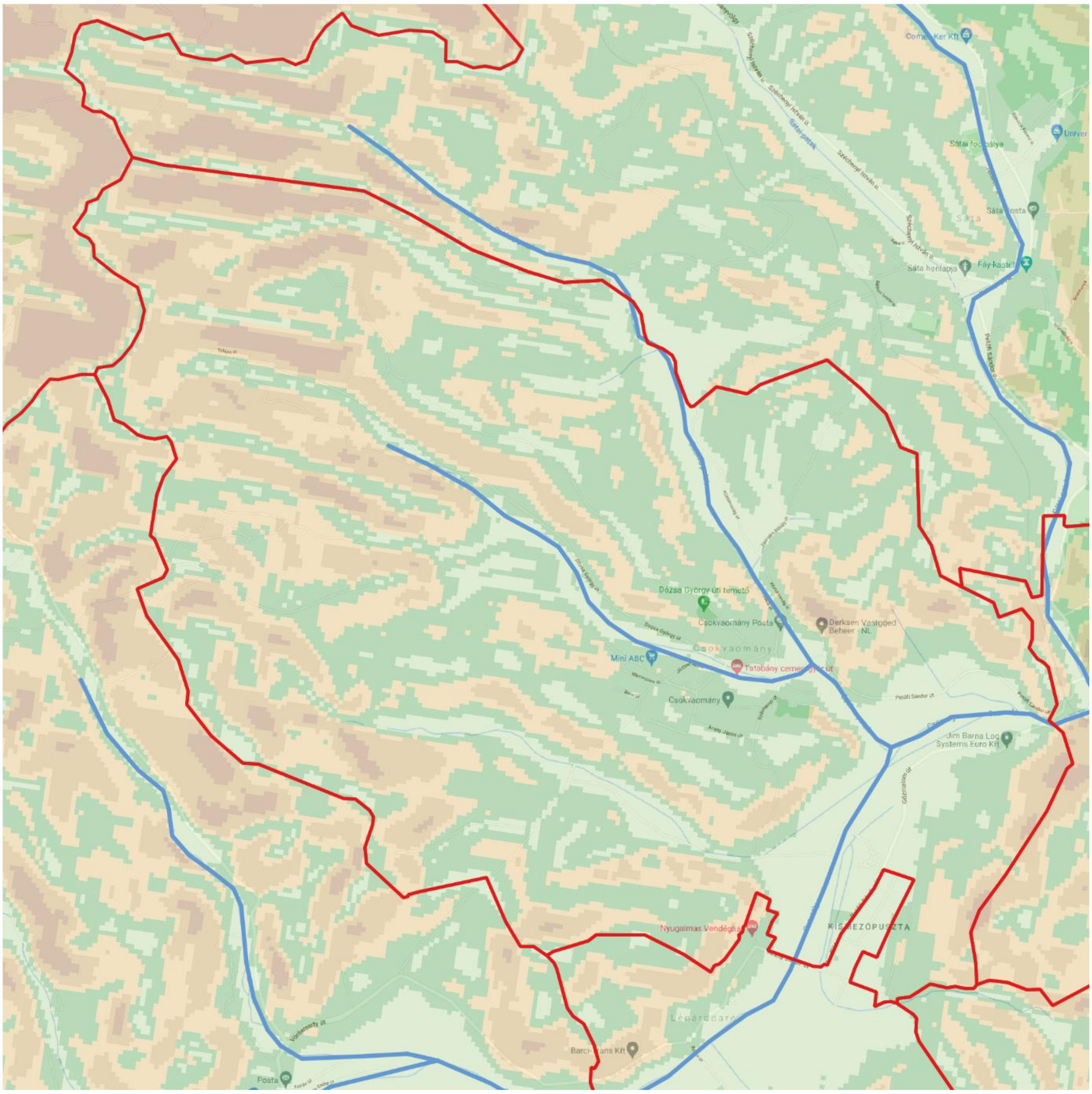




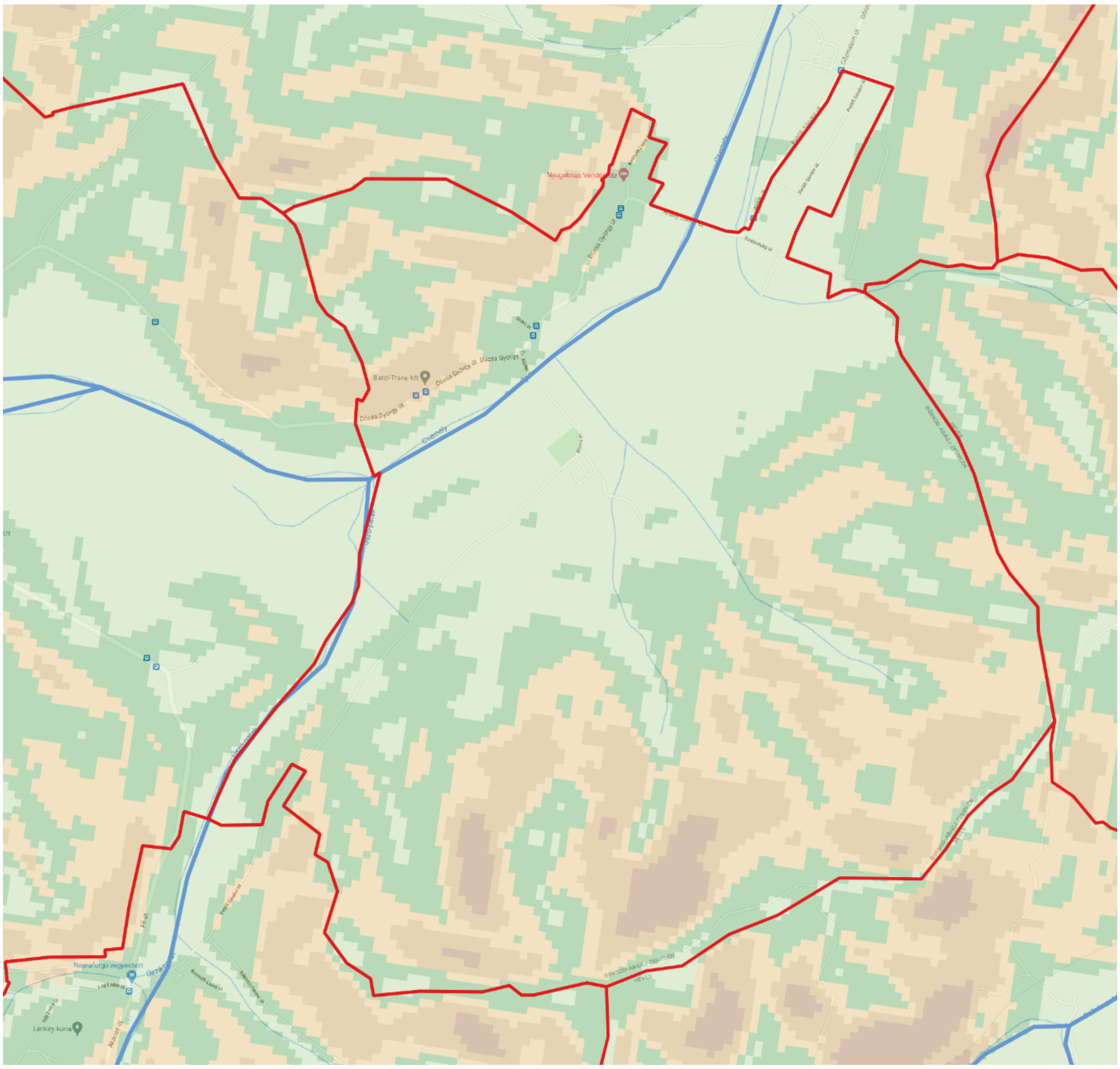
Slope category map of Bükkmogyorósd



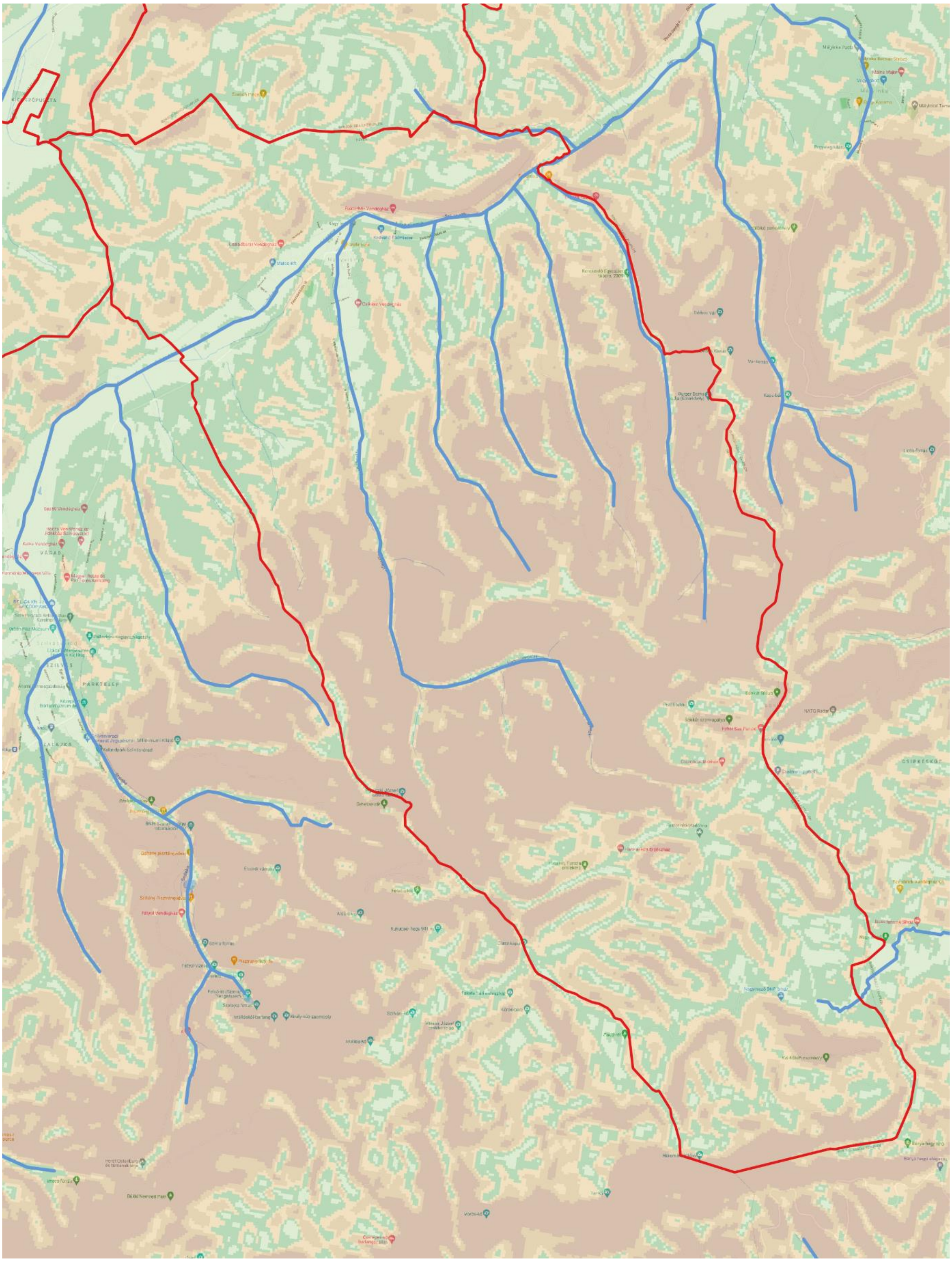
Slope category map of Csernely



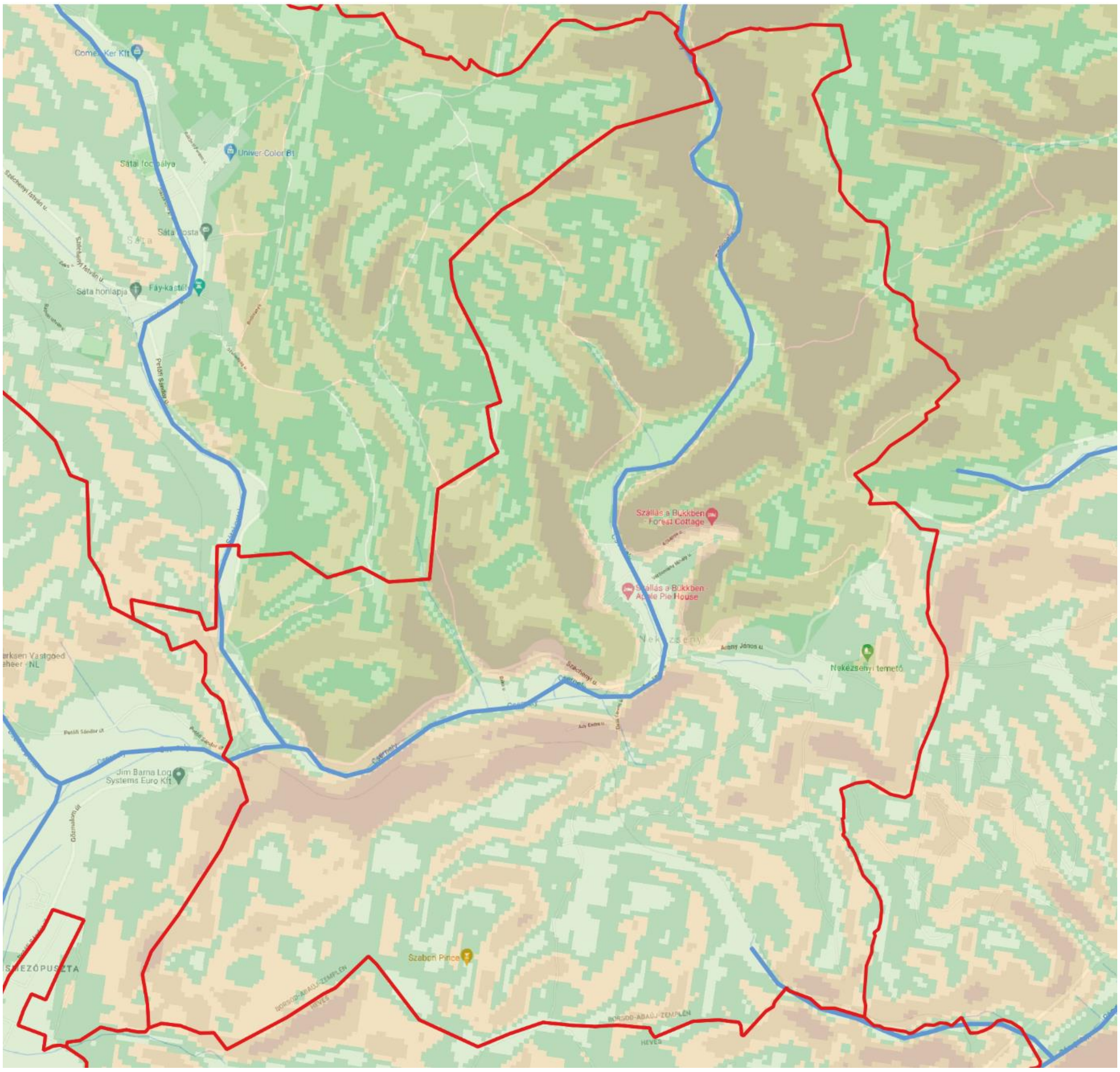
Slope category map of Csokvaomány



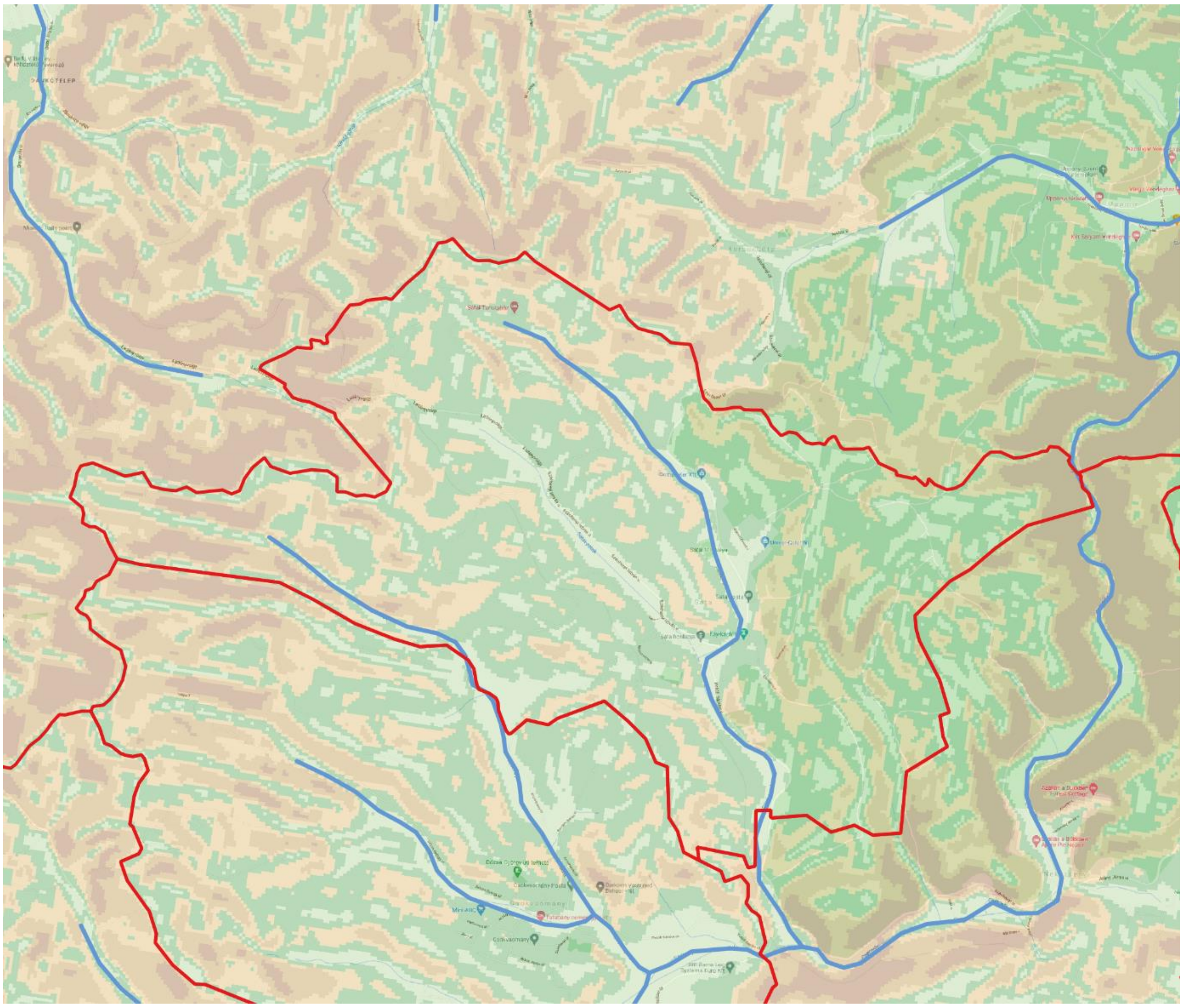
Slope category map of Lénárddaróc



Slope category map of Nagyvisnyó



Slope category map of Nekézseny



Slope category map of Sáta

M18 Geothermal potential of Bükk microregion in different scenarios

Scenario 1

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (10%)	24328530	72985590
Biomass	2631742	7895226
Waste	260002	780006
Biogas	509192	1527576
Wind (10%)	669014	2007043
Sum.	**28398480**	**85195441**

Scenario 2

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (20%)	48657061	145971183
Biomass	2631742	7895226
Waste	260002	780006
Biogas	509192	1527576
Wind (10%)	669014	2007043
Sum.	**52727011**	**158181034**

Scenario 3

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (30%)	72985591	218956773
Biomass	2631742	7895226
Waste	260002	780006
Biogas	509192	1527576
Wind (10%)	669014	2007043
Sum.	**77055541**	**231166624**

Scenario 4

Energy source	Electricity potential (kWh)	Ground heat potential (kWh)
Sun (30%)	72985591	218956773
Biomass	2631742	7895226
Waste	260002	780006
Biogas	509192	1527576
Wind (20%)	1338029	4014086
Sum.	**77724556**	**233173667**

M19 Energy consumption of Bükk microregion

The national data is based on dataset of International Energy Agency. (IEA n.d.)

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Bükk microregion (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Bükk microregion (kWh)	Consumption of Bükk microregion (kWh)
Industry	168557	57607	110950	30819469100	7664	9411470	16001957246	3979	4886585	14298055
Commercial and public services	91409	28962	62447	17346402766	4314	5297144	8045006436	2001	2456737	7753881
Transport	177661	4237	173424	48173371872	11980	14710904	1176945386	293	359409	15070313
Agriculture/Forestry	26982	3190	23792	6608894176	1643	4036371	886111820	220	541191	4577563
Non-specified	1471	266	1205	334722490	83	102216	73888948	18	22564	124779
Fishing	98	50	48	13333344	3	8143	13888900	3	8483	16626
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	16167848		2724	3345072	19512920
Sum	**546352**	**94312**	**371866**		**25687**	**49734097**	**26197798736**		**11620041**	**61354137**

Lénárddaróc

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Lénarddaróc (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Lénarddaróc (kWh)	Consumption of Lénárddaróc (kWh)
Industry	168557	57607	110950	30819469100	7664	605461	16001957246	3979	314365	919826
Commercial and public services	91409	28962	62447	17346402766	4314	340777	8045006436	2001	158047	498825
Transport	177661	4237	173424	48173371872	11980	946386	1176945386	293	23122	969507
Agriculture/Forestry	26982	3190	23792	6608894176	1643	259669	886111820	220	34816	294485
Non-specified	1471	266	1205	334722490	83	6576	73888948	18	1452	8027
Fishing	98	50	48	13333344	3	524	13888900	3	546	1070
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	1040114		2724	215196	1255310
Sum	**546352**	**94312**	**371866**		**25687**	**3199506**	**26197798736**		**747543**	**3947050**

Csokvaomány

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Csokvaomány (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Csokvaomány (kWh)	Consumption of Csokvaomány (kWh)
Industry	168557	57607	110950	30819469100	7664	1597957	16001957246	3979	829685	2427642
Commercial and public services	91409	28962	62447	17346402766	4314	899393	8045006436	2001	417125	1316518
Transport	177661	4237	173424	48173371872	11980	2497739	1176945386	293	61023	2558762
Agriculture/Forestry	26982	3190	23792	6608894176	1643	685329	886111820	220	91888	777216
Non-specified	1471	266	1205	334722490	83	17355	73888948	18	3831	21186
Fishing	98	50	48	13333344	3	1383	13888900	3	1440	2823
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	2745111		2724	567954	3313065
Sum	**546352**	**94312**	**371866**		**25687**	**8444266**	**26197798736**		**1972947**	**10417213**

Bükkmogyorósd

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Bükkmogyorósd (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Bükkmogyorósd (kWh)	Consumption of Bükkmogyorósd (kWh)
Industry	168557	57607	110950	30819469100	7664	390867	16001957246	3979	202944	593812
Commercial and public services	91409	28962	62447	17346402766	4314	219995	8045006436	2001	102031	322026
Transport	177661	4237	173424	48173371872	11980	610958	1176945386	293	14927	625884
Agriculture/Forestry	26982	3190	23792	6608894176	1643	167634	886111820	220	22476	190111
Non-specified	1471	266	1205	334722490	83	4245	73888948	18	937	5182
Fishing	98	50	48	13333344	3	338	13888900	3	352	690
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	671466		2724	138924	810390
Sum	**546352**	**94312**	**371866**		**25687**	**2065504**	**26197798736**		**482591**	**2548095**

Nekézseny

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Nekézseny (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Nekézseny (kWh)	Consumption of Nekézseny (kWh)
Industry	168557	57607	110950	30819469100	7664	1302891	16001957246	3979	676482	1979372
Commercial and public services	91409	28962	62447	17346402766	4314	733318	8045006436	2001	340102	1073420
Transport	177661	4237	173424	48173371872	11980	2036526	1176945386	293	49755	2086281
Agriculture/Forestry	26982	3190	23792	6608894176	1643	558781	886111820	220	74921	633702
Non-specified	1471	266	1205	334722490	83	14150	73888948	18	3124	17274
Fishing	98	50	48	13333344	3	1127	13888900	3	1174	2302
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	2238220		2724	463080	2701300
Sum	**546352**	**94312**	**371866**		**25687**	**6885013**	**26197798736**		**1608638**	**8493651**

Nagyvisnyó

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Nagyvisnyó (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Nagyvisnyó (kWh)	Consumption of Nagyvisnyó (kWh)
Industry	168557	57607	110950	30819469100	7664	1954336	16001957246	3979	1014722	2969059
Commercial and public services	91409	28962	62447	17346402766	4314	1099977	8045006436	2001	510153	1610130
Transport	177661	4237	173424	48173371872	11980	3054789	1176945386	293	74633	3129422
Agriculture/Forestry	26982	3190	23792	6608894176	1643	838172	886111820	220	112381	950553
Non-specified	1471	266	1205	334722490	83	21226	73888948	18	4685	25911
Fishing	98	50	48	13333344	3	1691	13888900	3	1761	3452
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	3357330		2724	694620	4051950
Sum	**546352**	**94312**	**371866**		**25687**	**10327520**	**26197798736**		**2412956**	**12740476**

Cselnely

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Csernely (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Csernely (kWh)	Consumption of Csernely (kWh)
Industry	168557	57607	110950	30819469100	7664	1590293	16001957246	3979	825705	2415999
Commercial and public services	91409	28962	62447	17346402766	4314	895079	8045006436	2001	415125	1310204
Transport	177661	4237	173424	48173371872	11980	2485759	1176945386	293	60731	2546490
Agriculture/Forestry	26982	3190	23792	6608894176	1643	682042	886111820	220	91447	773489
Non-specified	1471	266	1205	334722490	83	17272	73888948	18	3813	21084
Fishing	98	50	48	13333344	3	1376	13888900	3	1433	2809
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	2731945		2724	565230	3297175
Sum	**546352**	**94312**	**371866**		**25687**	**8403766**	**26197798736**		**1963484**	**37220376**

Sáta

	Energy consumption (TJ)	Electricity consumption (TJ)	Consumption (TJ)	Non-specified consumption (kWh)	Non-specified consumption/household (kWh)	Non-specified consumption Sáta (kWh)	Electricity consumption (kWh)	Electricity consumption/household (kWh)	Electricity consumption Sáta (kWh)	Consumption of Sáta (kWh)
Industry	168557	57607	110950	30819469100	7664	1969664	16001957246	3979	1022681	2992345
Commercial and public services	91409	28962	62447	17346402766	4314	1108604	8045006436	2001	514154	1622758
Transport	177661	4237	173424	48173371872	11980	3078748	1176945386	293	75218	3153966
Agriculture/Forestry	26982	3190	23792	6608894176	1643	844745	886111820	220	113262	958008
Non-specified	1471	266	1205	334722490	83	21392	73888948	18	4722	26114
Fishing	98	50	48	13333344	3	1704	13888900	3	1775	3480
Non-energy use	80174	-	-	-	-	-			0	
Household					13166	3383662		2724	700068	4083730
Sum	**546352**	**94312**	**371866**		**25687**	**10408520**	**26197798736**		**2431881**	**12840402**

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