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Spatial Illustration of Indicators on the Example of Biomass Potential for Energy Purposes in the Tabi District

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ABSTRACT

This paper is intended to show the importance of spatial accounting, the practicality of mapping and illustration. To this end, biomass potential that can be grown on arable lands and the resulting indicators were studied on the example of the Tabi járás (Tabi district) of Hungary. The processed data was projected onto maps for mapping the absolute potential, but also specific indicators such as values per hectare or per capita. The results are plotted in equal intervals and along with natural fractures classification of the data. The results thus obtained emphasize the heterogeneity caused by spatial unevenness. Taking such information into account can improve the efficiency of state interventions, investments, developments and the decentralization of other decisions.
Keywords: spatial analysis, sustainable energy, environmental indicators, arable land use, thematic map

INTRODUCTION

In accordance with the title, the indicators presented in this article are neither intended to discuss the theoretical sustainability of bioenergy systems, nor specific practices in a particular area. Our task is to provide a spatial illustration of the indicators and to highlight the regional differences. We would like to demonstrate the practicality of the spatial illustration of data. To do this, we use a geographic information system (GIS) toolbar to map the created indexes. Spatial illustration allows us to notice the spatial heterogeneity of data, which may raise a lot of new relationships, questions and problems. The information thus obtained then can be used, for example, in the formation of government policies, plant location decisions or even infrastructure development. In addition, the examples presented can be used in any situation where data is stationary, thereby enabling spatial analysis.

Our chosen region is the Tabi járás (Tabi district) in Somogy county, in the Southern Transdanubian region of Hungary. The reason for this selection can be explained by the knowledge gained from previous project works and the available database. The area is located in Somogy county, consists of 24 settlements, its seat and only town is Tab. The district has an area of 427.24 km², a population of 12 786 people, thus the population density is about one-third of the national average, ~30 people/km². Our indicators are based on biomass, which comes from the agricultural nature of the area and the idea of the local resource-based economic development. Of course, we would have been able to choose data of an economic or social feature, but in the spirit of our solidarity with global natural problems, we have advocated a (limited) renewable resource. We did this despite the fact that our current study will not have a direct practical bearing, but we hope that this work's approach on energy may inspire others.

Although climate change has brought renewable energy into the spotlight all over the world, one of the most controversial of these alternatives is undoubtedly the energetic use of biomass produced on arable land. When discussing the use of arable biomass, the "food versus fuel" debate (*Zhanga et al.*, 2010), the dilemma of carbon (and pollutant) neutrality (*Brack*, 2017), the energy balance of the resource, or the optimal soil utilization and influencing soil supply (*Hutkainé Göndör et al.*, 2013) are often debated areas - just to mention the most exciting ones. Biomass is undoubtedly different from the lifeless and inexhaustible nature of sunshine, wind or tides due to its living matter, but with carefully selected quantitative and utilization criteria it can be a complete component of a sustainable energy system. This is especially true in agricultural or forestry areas where soil or slope conditions are unfavourable, for example.

THEORETICAL BACKGROUND

There are several questions regarding the planting of biomass for energy purposes. Different plants have different advantages and disadvantages as well as environmental needs. What kind of plant we choose to grow is influenced by several environmental, economic, technical or legal factors. Although it is not our intention to consider practical aspects, there are a few ideas that illustrate the complexity of this issue. For the sake of simplicity, we consider three different biomass feedstocks: (i) straw of cereals (primarily wheat) and maize stalk; (ii) energy grass, (iii) energy forest (fuelwood). The yield and energy density of the plants are shown in *Table 1*.

Table 1

Yield and energy density data for plants

	Yield, t/ha	**Energy density, MJ/t**
Straw and maize stalk[1]	9.75 (*Agrárium7*, 2015)[2]	14400 (*Ivanovic and Glavas*, 2013)
Energy grass	16 (*Gyulai*, 2007)	15500 (*Gyulai*, 2007)
Energy forest	20 (*Szajkó et al.*, 2009)	17000 (*Gyulai*, 2007)

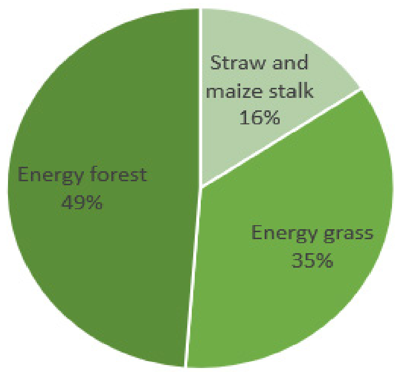
[1]As a simplification, we assume that straw and corn stalks are present in the area in a half-half proportion, so yields and energy densities are averaged.

[2] We did not find data of the current average yields of straw and maize stalks in Hungary in peer-reviewed scientific journals. For the calculation, we worked with the data from the article titled "Szalmafélék és szármaradványok" (Straw and stem residues) in Agrárium7.

Based on the yield (t/ha) and energy density (MJ/t) of plants per unit area (*Table 1*), the total amount of heat which can be „harvested" from a given area can be estimated. Since the ratios of energy contents are constant between the plants, assuming the same needs of the plants, their masses are formed in the same proportion in any area. For the sake of clarity, the ratio of energy content to the whole is illustrated in *Figure 1* based on *Table 1*. It is evident that the energy forest has the highest potential (yield and energy density too), followed by energy grass, followed by straw and maize stalk. However, it is important to bear in mind that this latter raw material is a by-product, so it is natural that its yield is below those of the other two main crops. In other words, if we focus only on volume, the oldest type of biomass used, fuelwood from (energy) forest will „triumph". Leaving aside the environmental, economic, technical, legal circumstances, we can say that if the goal is to derive a specified amount of energy from the smallest possible area, then it is worth to concentrate on wood from the three energy sources.

Figure 1

Distribution of heat potential of crops grown per unit area



Although energy forest is the absolute „winner" of yields and energy potentials, its plantation makes it impossible to grow food and/or feed crops, which can lead to food shortages, thus rising prices as well. The energy forest is followed by energy grass, which can be cultivated under extreme natural conditions (frost, drought, poor soil quality etc.). Through its deep penetrating root system, it prevents erosion and deflation and consequently, after harvesting, replenishes large quantities of organic matter. The cost of planting is well below that of the forest, and in contrast to the latter one, it can be utilized annually (*Gyulai*, 2007).

If we want to align ourselves with EU and national priorities (*Dinya*, 2018), leaving behind direct energy production, we must give preference to the residues of crop production. This latter solution also poses a number of dilemmas. After harvesting, crop residues left on the soil play an important role in the replenishment of soil, as they improve their structure and their chemical composition during decomposition. Thus, biofertilizers although carried can be replaced by fertilizers, this is often produced from fossil fuels (natural gas) under fairly energy-intensive conditions. In addition, we have not taken into account the material and environmental aspects (e.g. greenhouse gas and noise emissions) of the transport of biofertilizer and the transport of fertilizers.

While not all of the arguments for and against different cultures have been listed, it is clear from these few that optimizing installations is far from easy. We have not even considered the decision-making role of spatial heterogeneity. It is a challenge in itself to select and determine the plant to be grown but finding the optimal place to produce a selected plant is not an easier task. The (increasing) popularity of spatial analysis is precisely due to the fact that mapping data can provide additional information that justifies redesigning our ideas created on the „homogeneous plain". With the information we extract, we are more confident in choosing a good geographic location for our activity.

Spatial recognition and illustration are very common in most scientific fields, including energy management. This is mainly due to the uneven geographical distribution of energy sources. There are enormous regional disparities in the case of non-renewable and renewable energy sources if we compare Central Europe with the Middle East or Scandinavia. This question is also important for Hungary, as there are significant differences in the potential of coal, solar energy (*Solargis*, 2020) or geothermal energy (*Mádlné Szőnyi et al.*, 2008) in our different regions.

According to *Turner* (1990), many ecological issues require the study of large regions and an understanding of spatial heterogeneity. Spatial and temporal analyses are becoming increasingly important in ecological studies. In his study, he examined the relationship between landscape patterns and ecological processes with a neutral modelling approach. *Ayotte et al.* (2001) attempted to improve the reliability of wind forecasts with the help of temporal and spatial analysis. By investigating wind speed and direction data from several meteorological towers, he attempted to reduce modelling errors in the context of wind energy calculations. *Ramachandra and Shruthib* (2007) undertook a spatial mapping of energy supply and demand to contribute to the design of a regionally integrated energy system. By understanding the regional characteristics of supply and demand, decision-making processes can be supported, and the dissemination of local and renewable energy technologies can be facilitated. The research by *Arnettea and Zobe* (2011) uses a geographic information system (GIS) to map renewable energy sources with a regionally heterogeneous picture. The model analyzes the potential of wind, solar and biomass in the southern Appalachian region (USA), where electricity generation is highly dependent on coal. Replacing this fossil resource with alternative energy sources would improve the state of the environment. *Zhaoa et al.* (2014) undertook a survey of regional factors influencing the intensity of energy-related carbon dioxide emissions in the analytical region of 30 Chinese provinces. According to their study, the greenhouse gas emissions of energy use strongly depend on the natural and social characteristics of the areas. *Mola-Yudego et al.* (2014) investigated the spread of plants suitable for producing wood pellets using space statistical methods. Their purpose was to identify areas with significant pellet production capacity. The study provides methodological tools for identifying the most important pellet production areas in Europe, which have additional economic and political relevance.

Several spatial analyzes have already been made by Hungarian authors in many different fields. *Bíró et al.* (2002) dealt with the probability of spatial and temporal occurrence of inland waters. The aim of his research is to create category maps whose successive overlaps produce an inland water hazard map. *Tóth* (2007) examined the criminal-geographical status of Hajdú-Bihar county, one of the most problematic areas in Hungary, between 1990 and 2003. *Bálint* (2011) emphasizes the spatial differences in life expectancy at birth between 2005 and 2009 and presents the most important micro-regional characteristics according to the current classification. *Szigeti* (2013) examines macro-level changes in the ecological footprint in time and space. As she puts it, „we want to present a moment where the temporal path that each country traverses and the spatial situation to which they have reached are both visible."

METHODOLOGY

For the analysis, on one hand, we used the public maps of the Open Street Map (*Geofabrik*, 2019) (border map layer and coordinates of the settlements), on the other hand, the European Union CORINE Land Cover database with a scale of 1:50 000 (CLC50-HU) that is extended by the Department of Geodesy, Remote Sensing and Land Offices, under the Government Office of the Capital City Budapest (*Lechner Tudásközpont*, 2020). For calculation of the potentials, we used Microsoft Excel, while for GIS operations we used QGIS 2.18.20.

Table 2 shows our initial data. Population data and territory data of settlements are from the National Spatial Development and Spatial Planning Information System (TEIR), as are "gold crown"[3] (aranykorona, GC) values, which were published by the Central Statistical Bureau of Hungary in the Agricultural Census Survey 2000. The arable areas were calculated in QGIS based on the CORINE spatial database. Fields were selected on the CORINE map and shown in dark in *Figure 2*. It can be seen that most of the area can be used for crop production.

In order to represent spatially the characteristics of the area, we plotted the values of the gold crowns of the settlements and charted the population, the size of the total area and the arable area (*Figure 3*). The gold crown categories are designed to have the same number of settlements in each.

The best fields are typically located in the middle and middle east of the district. The diagrams show a similar proportion of the area of the settlements and the area of their arable land in the whole district. We calculated the correlation coefficient between them, which proved our assumption that the relationship is close: $r = 0.92$.

[3] It is officially a land quality indicator, which is an indicator of the net income of a unit of land, i.e. its fertility, location and cultivability. Its origins date back to 1850.

Table 2

Basic data about the Tabi district

Settlement	Population, head	Settlement area, ha	Arable land area, ha	Gold crown
Andocs	1062	4328.25	2659.10	13.64
Bábonymegyer	796	2191.72	1253.14	12.95
Bedegkér	389	2599.44	1879.27	24.96
Bonnya	228	1458.16	783.98	11.89
Fiad	115	1490.68	517.67	15.76
Kánya	410	1448.81	1150.68	21.67
Kapoly	653	2230.68	1288.11	14.63
Kára	35	537.52	340.01	17.29
Kisbárapáti	348	2871.84	1243.17	13.95
Lulla	187	1038.10	505.32	15.02
Miklósi	200	1047.10	675.36	16.39
Nágocs	685	2227.20	1581.93	16.88
Sérsekszőlős	139	667.41	448.70	16.03
Somogyacsa	166	2446.01	1232.01	12.36
Somogydöröcske	133	1081.80	499.52	15.92
Somogyegres	163	1080.73	934.68	18.2
Somogymeggyes	477	1562.66	1206.24	13.36
Szorosad	94	647.40	326.36	11.33
Tab	4307	2585.45	1331.77	13.55
Tengőd	404	3013.80	1556.23	22.49
Torvaj	244	1141.67	684.18	13.7
Törökkoppány	441	2578.69	1388.49	13.96
Zala	243	921.87	646.21	15.97
Zics	320	1499.90	1249.92	16.97

Source: TEIR, KSH

To estimate the biomass potential, we started from the areas of the municipalities suitable for growing arable crops. The area of arable land was aggregated by settlement, and the lands were weighted with gold crown values, thus taking into account their different quality. Subsequently, the average yields per unit area (different from plant to plant) were plotted on the arable land and the results were also expressed in the estimated heat content (*Table 3*).

Figure 2

Arable lands in the Tabi district

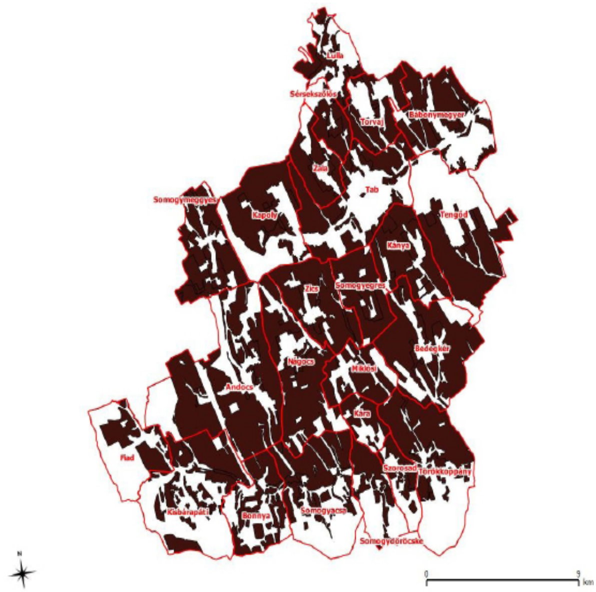


Figure 3

Gold crown categories by settlement and population, total area and arable land values in the chart

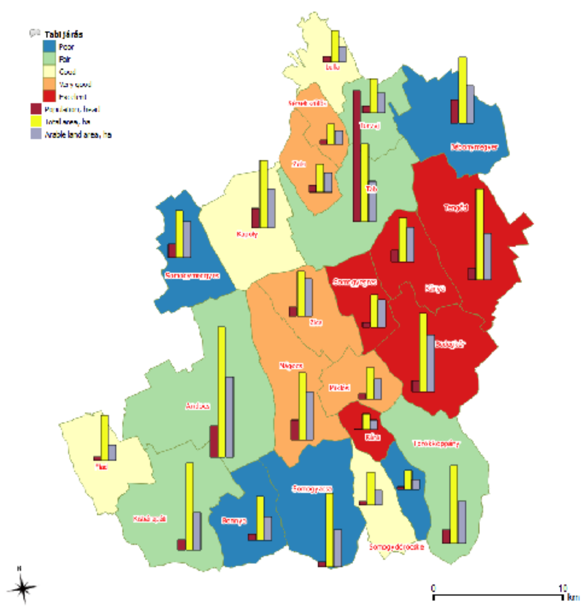


Table 3

Theoretical biomass potential that can be produced in the settlements of the district

Settlement	Energy content of straw and maize stalk, MJ	Energy content of energy grass, MJ	Energy content of energy forest, MJ
Andocs	330705714	749406222	1027411756
Bábonymegyer	154903281	351023516	481241918
Bedegkér	257001643	582386763	798433466
Bonnya	95999988	217543832	298245576
Fiad	65583075	148616618	203748590
Kánya	153218882	347206530	476008953
Kapoly	161594982	366187459	502031194
Kára	43643792	98900407	135589267
Kisbárapáti	155032032	351315277	481641912
Lulla	63608599	144142293	197614434
Miklósi	86025208	194940164	267256677
Nágocs	202349817	458541252	628645265
Sérsekszőlős	56977265	129115147	177012702
Somogyacsa	151495856	343302012	470655985
Somogydöröcske	63370520	143602786	196874788
Somogyegres	120908722	273989063	375630167
Somogymeggyes	149648080	339114802	464915455
Szorosad	39763287	90106863	123533603
Tab	165498094	375032231	514157091
Tengőd	208616811	472742774	648115094
Torvaj	85134376	192921466	264489106
Törökkoppány	173169308	392415830	537989445
Zala	82014991	185852685	254798036
Zics	160004921	362584252	497091313

Although absolute quantities are undoubtedly important, economic science often uses specific indexes derived from them, as they can carry more information. Therefore, the absolute amounts calculated per crop were used to construct indexes. All the energy produced was divided by the area of the settlement and the number of its inhabitants, thus obtaining values per hectare and per capita. While the former one may be the productivity of the settlement, the latter one may represent a kind of energy abundance.

The heat potential data for each area has been categorized into five categories: poor, fair, good, very good, excellent, to make the maps easier to understand. There were two kinds of logic in the classification. On one hand, we divided the minimum and maximum ranges into five equal intervals, and on the other hand, we divided the categories into five groups based on the natural breaks classification method[4] (*Jenks*, 1967). Using the resulting categories, we created a thematic map and, as shown in the legend, marked the thermal potentials using five different colours. For the purpose of illustration, we also prepared a heat map and a symbolic map that can be seen at the end of the study.

SPATIAL ILLUSTRATION OF THE INDEXES

By taking into account the advantages and disadvantages of different raw materials, we can select the raw materials that meet our needs and the environment. Once this is done, there may be an optimization of deployments, which is strongly supported by the regional approach. In order to illustrate spatial unevenness, the heat energy produced from biomass per settlement is shown on a map. *Figure 4* shows the settlements according to the heat energy from the plants. Since the produced energy is always proportional to the yield, and since the yield is always proportional to the size of the arable land per settlement, no matter what kind of plant the energy comes from (assuming the same needs), the ratios between the settlements will remain constant. The colour of the map is therefore the same for all three raw materials.

There are significant differences in the amount of energy that can be produced per settlement, which is particularly visible on the map (*Figure 4*). The largest settlement with absolute potential is Andocs. It is the largest area in terms of both settlement and arable land, so even if it does not have high quality arable land (GC: 13.64), it is only by its size that it can produce most of the raw materials.

Examining natural breaks, the district retains its Andocs priority, but the proportion of good and very good settlements increases. This map clearly shows that the potential of small settlements is small, due to the clear relationship between the area and the potential. In fact, a map of the arable land would have done the same.

Because of the above-mentioned facts, it is more appropriate to examine the specific values. If we plot the area on the basis of the thermal energy potential per hectare per settlement, the result is significantly different from the previous one (*Figure* 5). Based on the potential per hectare, we have four areas with excellent potential: Kánya, Bedegkér, Zics, Somogyegres. These four villages are considered to be the most productive parts of the district. As the relationship between the area of the settlements and the area of their arable land is very strong (r = 0.92), it is not enough to be large, but the quality of the land is also important. The four settlements are part of the areas with the best gold crown values (GC: 16.97 - 24.96). Taking into account natural

[4] It is done by seeking to minimize each class's average deviation from the mean of the class while maximizing each class's deviation from the means of the other groups. Therefore, this method tries to reduce the variance within classes and maximize the variance between classes.

breaks, the „picture" improves, several settlements get better (e.g. Somogymeggyes, Kisbárapáti or Miklósi) and only Fiad stays in the poor category.

Figure 4

Spatial distribution of heat energy potential from field-grown biomass (equal interval on the left, natural breaks on the right)

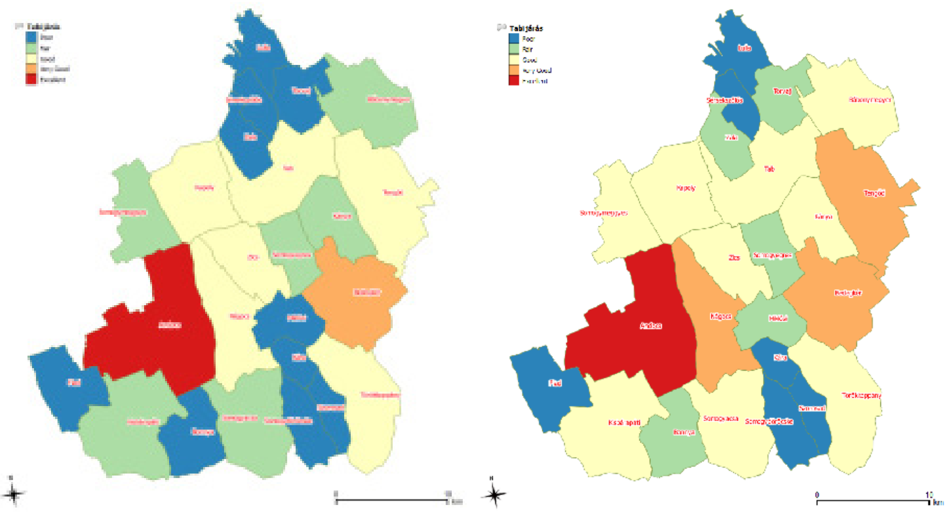
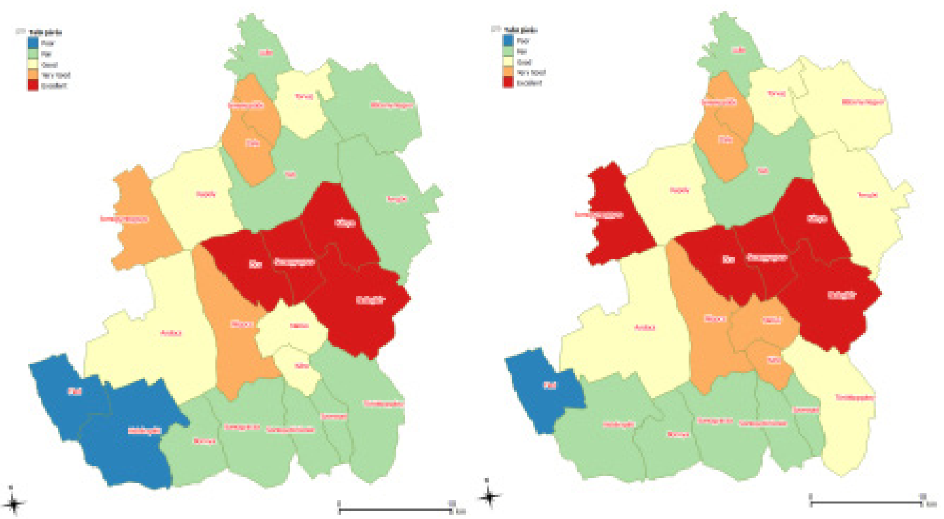


Figure 5

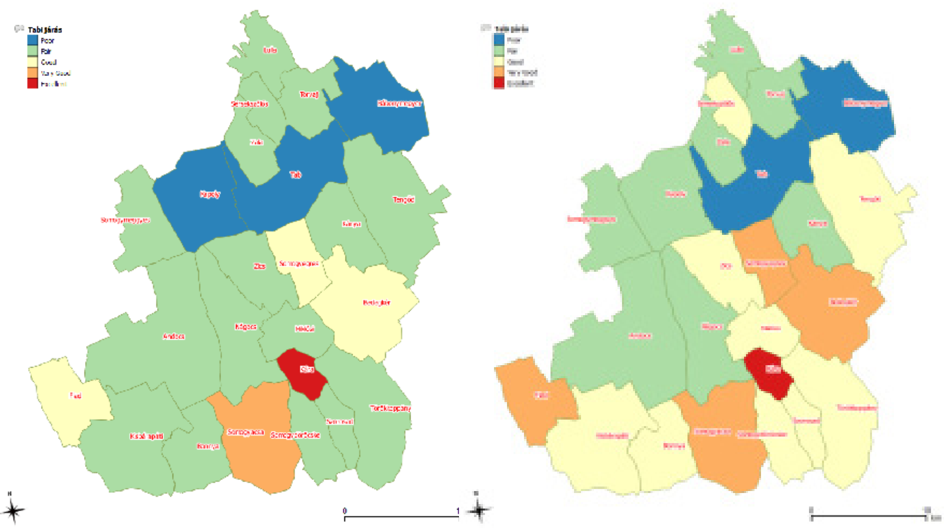
Thermal energy potential per hectare per settlement (equal interval on the left, natural breaks on the right)



The potential can also be projected for the inhabitants of the settlement, so we can depict the area based on the thermal energy potential per capita of the settlement, which can be interpreted as a kind of energy abundance indicator (*Figure 6*). According to this indicator, only Kára is the excellent settlement. This is explained by the fact that only 35 inhabitants live in the least populated settlement of the district, and the village is in the upper-mid dle part of the area according to the ratio of their arable land to the total area. The fact that the quality of the soil is one of the best here in the district also contributes to Kára's excellent position (GC: 17.29).

Figure 6

Thermal energy potential per capita
(equal interval on the left, natural breaks on the right)



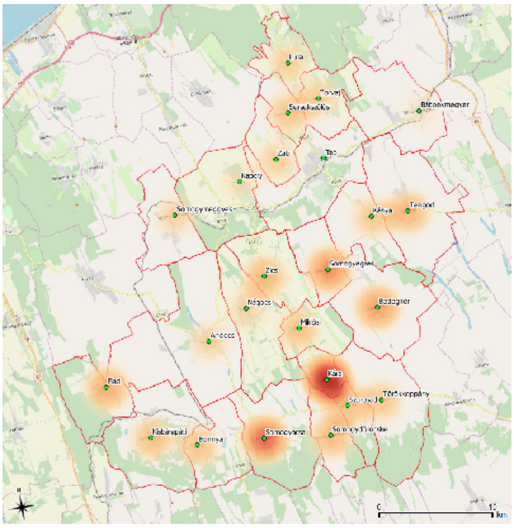
Based on the per capita values, the district has a more or less uniform picture, with most of its settlements falling into the poor and the fair categories. Tab, Bábonymegyer and Kapoly have the smallest potential, these settlements are among the most populous ones in the district.

According to the data depicted along the natural breaks, Kára is still the only settlement with excellent conditions, but besides Somogyacsa several settlements belong to the very good category (Fiad, Bedegkér, Somogyegres). People living in the south-eastern and western parts of the district are most abundant in thermal energy which can be "collected" from the soils. Tab, Bábonymegyer are also the weakest ones in this division.

Perhaps the differences are even more striking when the data is plotted on a heat map (*Figure 7*). This is also a clear indication that the „focal point" of the area is Kára. There is no category for the heat map, it heats up by its absolute value.

Figure 7

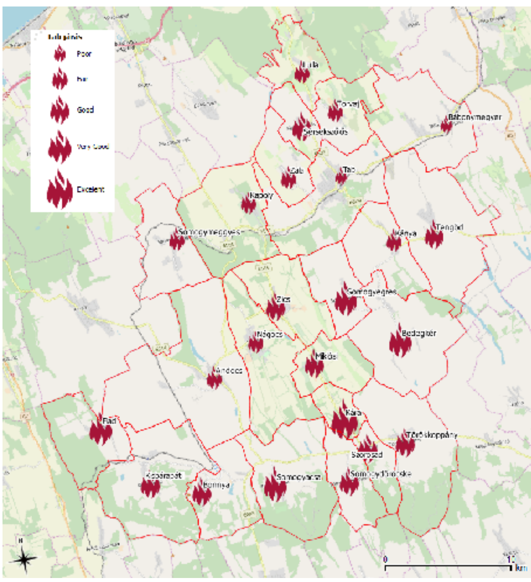
Thermal energy potential per capita per municipality



For example, if you want to present the analysis in a residential forum, you can use some spectacular symbol to illustrate the values. *Figure 8* illustrates the magnitude of the thermal energy potential of a flame of various sizes.

Figure 8

Thermal energy potential per capita on a graduated symbol map



CONLCUSIONS

The article attempted to illustrate the importance and practicality of the spatial illustration of the indicators created for environmental and economic analyzes. By mapping the data, we were able to observe a number of contexts that generate new questions and ideas within us. Settlements with different potentials in different parts of the region and adjacent to each other provide a basis for a number of organizational, transportation or management concerns. The new aspect can help in the decision-making process. As for energy management, in several other disciplines it is worth considering the regionality of the information processed. This will allow the intervention to be developed to be more closely related to the characteristics of the territorial unit under investigation, and regulation, investment or any development will be more in line with the principle of subsidiarity.

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