Optimization of Wind Farm Location Planning with GIS Methods Based on a Hungarian Case Study Area (Csongrád County)

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Abstract: In Hungary the utilization of renewable energy sources lags behind the EU average. Only about 1% of the energy produced in the country comes from wind power. GIS can turn out to be an excellent toolkit for regional planning professionals when designing the optimal placement of wind farms based on digital map databases. The aim of our work is to present a methodology for locate those areas that are perfectly or moderately suitable for building wind. The presented methodology can be adapted to other areas by helping the placement of wind farms during the optimization of regional planning. On the basis of the Second Military Survey we created a map showing wind mill density, which in turn was used for describing the wind power potential of the area. Average annual wind speed was calculated from the collected meteorological wind speed time series and we calculated at the height of 100 meter wind speed data using the Hellman exponential function. Based on this map it can be stated that the average annual wind speed calculated at the height of 100 m is about 4.5–5.5 m/s, which means that wind turbines would probably operate profitably. Lastly, by overlaying the wind potential map and the thematic maps limiting the establishment of wind farms, we were able to locate those areas that are unfit, not entirely or highly suitable for the installation of wind turbines. Relying upon our maps we done detailed wind potential calculations were estimated annual amount of electricity can be produced in the study area. Calculated on the basis of 2 MW turbines, 25 % of actual performance and a space of 360x630 meters per turbine, 872 MW of energy could be generated annually if we placed wind turbines in every suitable or perfectly suitable area.

Keywords: wind power; wind energy; renewable energy source; wind turbine

1. Introduction

Nowadays the importance of the use of renewable energy sources is researched more and more from the spatial planning point of view. The growing use of hydro power, wind power, solar power, biomass electricity, biomass heating, photovoltaic and geothermal electricity, geothermal heating, biodiesel and bioethanol creates a new challenge and new tasks for regional planners. For the development of renewable energy sources there is a need for a very detailed, GIS-based spatial analysis of the energy potentials (such as wind energy potential) and the limiting factors (such as protected areas, built-up areas etc.). Out of renewable energy sources, wind energy has the second largest energy potential in Hungary (Imre 2006).

The aim of the study is to use GIS methods for the spatial optimisation of wind turbines. Our goal is to elaborate a methodology which can be used for the spatial planning of wind farms in other areas (regions, countries), and can be expanded by new databases (e.g. aesthetic evaluation). The administrative unit of the county was chosen as the study area, as although the suitable areas for wind farm installation are delineated in the regional plans of Hungarian counties as "areas that can be taken into consideration for wind turbine placement", we need a more detailed spatial delineation based on the geographical characteristics of the study area (Fig 1). The second reason why we have chosen the county level as the study area is that our digital database has a scale limitation.

2. Materials and Methods

2.1. The used databases

For our spatial analyses, we used the following 1:100,000 scale digital databases: the CORINE 2006 Land Cover Map and the digital road and electricity network map. Based on the Hungarian Digital Information System of Protected Areas, we used the 1:100,000 scale NATURA 2000 map of Csongrád county. The synoptic meteorological (especially wind speed) databases of the Hungarian Meteorological Service were also used for wind energy mapping.

2.2. GIS analysis of the limiting land use factors for wind turbine installation

Based on the international literature and the Hungarian legal restrictions, it is possible to identify the limiting factors which exclude the possibility of the use of lands for wind farms in the study area. By assigning the limiting factors to multiple buffer zones, we were able to develop land use scenarios to determine the suitability of each area for wind farm placement.

In our study the following limiting factors were spatially analysed with GIS methods: spatial pattern of protected areas (NATURA 2000 areas), forests, lakes, built-up areas, transport and energy networks. Hungarian and international laws prohibit new wind farm building within the NATURA 2000 protected areas, forests, lakes and built-up areas. Surrounding the built-up areas, the NATURA 2000 areas and the line infrastructures (road and energy networks), we created different buffer zones, within which we precluded the establishment of wind farms.

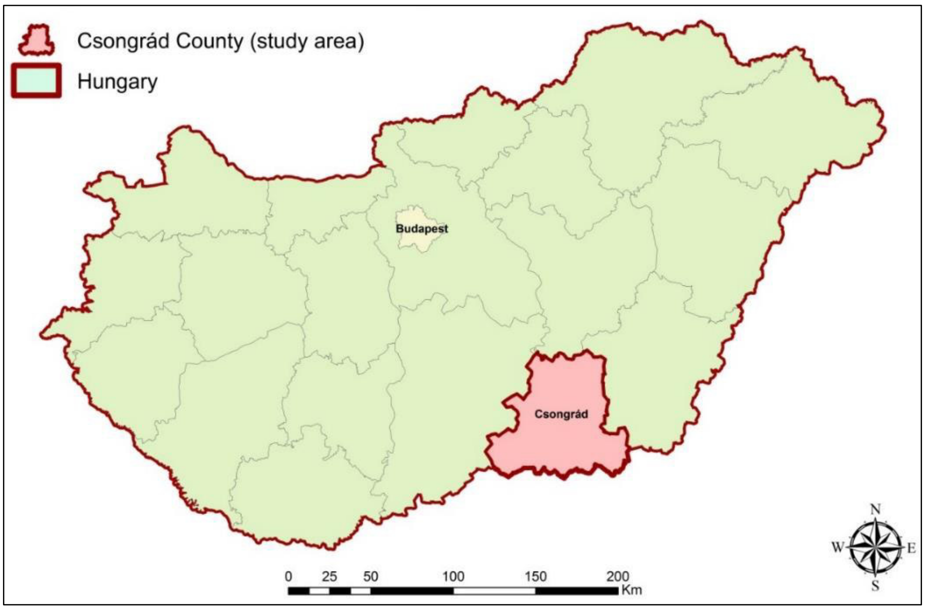

Figure 1. Geographical location of study area

2.2.1 Protected areas as limiting factors for wind power installation

Inside the protected areas, the following regulations have to be considered for the installation of wind turbines.

Natura 2000 sites include two kinds of protected areas: Special Protection Areas for birds and Special Areas of Conservation. The establishment of wind farms is prohibited under the relevant EU legislation in these areas. According to the recommendation of Hungarian Environmental Authorities, an 800–1000 meter buffer zone should be established around Natura 2000 sites and protected areas so that the animals inside these buffer zones would only be exposed to a minimal disturbance by the wind farms (KvVM, 2005). In our evaluation two kinds of scenarios were used and we delineated the 800 and the 1000 meter buffer zones where it is not allowed to build new wind farms.

Based on the Hungarian Digital Information System of Protected Areas, we selected the polygons of Natura 2000 sites and then we created an 800 and 1000 meter buffer zone around the polygons in the ArcGis 10 software. The created buffer zones were defined as unsuitable areas for wind farm installation.

2.2.2 Forests and water land use units as limiting factors for wind power installation

According to Munkácsy (2011), the creation of a 250 meter buffer zone is recommended around the forest areas where it is not allowed to build new wind power infrastructure due to animal protection reasons.

Inside and nearby permanent water bodies it is not possible to install any kind of wind power facilities due to conservation reasons and the fact that the soil structure is not stable enough for a wind turbine basement. We recommended 800 and 1000 meter buffer zones instead of 250 meter buffer zones surrounding the surface water bodies. In our opinion buffer zones need to be extended because the lakes and other water surfaces often have high ecological value and considerable significance for natural conservation purposes.

From the 1:100,000 scale CORINE 2006 Land Cover Map of Hungary the land cover polygons of “water bodies” and “forests and semi-natural areas” have been selected and then we created 250, 800 and 1000 meter buffer zones around the polygons. The created buffer zones were defined as unsuitable areas for wind farm installation.

2.2.3 Built-up areas as limiting factors for wind power installation

According to the Hungarian Environmental Authorities, the creation of a 500 meter buffer zone is recommended in the case of settlements because the wind turbines’ noise disturbs local inhabitants. For our analyses the recommended 500 m buffer zones were used around residential areas (Urban fabric CORINE land cover units).

Using the dromstorre.dk sound calculator software, we were able to verify the buffer zone parameters with our quantitative results. A 2 MW turbine’s sound level is 105 dB in its immediate vicinity, 40 dB 500 meters away while it decreases to 35.9 dB in an 800 meter distance. The results obtained correspond to the above mentioned limits. In such a distance, the resulting noise and vibration would not disturb the local inhabitants.

In our opinion the holiday resort areas must be distinguished from the residential areas because their noise sensitivity is higher. We used 800 meter buffer zones around these land cover polygons, which we selected from the “urban fabric” CORINE land cover units based on visual interpretation. Wind turbine installation also has a strong visual impact, so it would diminish the visual values of the landscapes surrounding the holiday resort areas. From the 1:100,000 scale CORINE 2006 Land Cover Map of Hungary we selected the polygons of urban-fabric areas and then we created 500 and 800 meter buffer zones around these polygons. The created buffer zones were defined as unsuitable areas for wind farm installation.

2.2.4 Road and energy networks as limiting factors for wind power installation

We have taken into consideration and digitized the 120 kV and 400 kV electrical networks and the main international and Hungarian hydrocarbon networks (Tóta 2009). The created 250 meter buffer zones were defined as unsuitable areas for wind farm installation because of the accident risk (Fig 2).

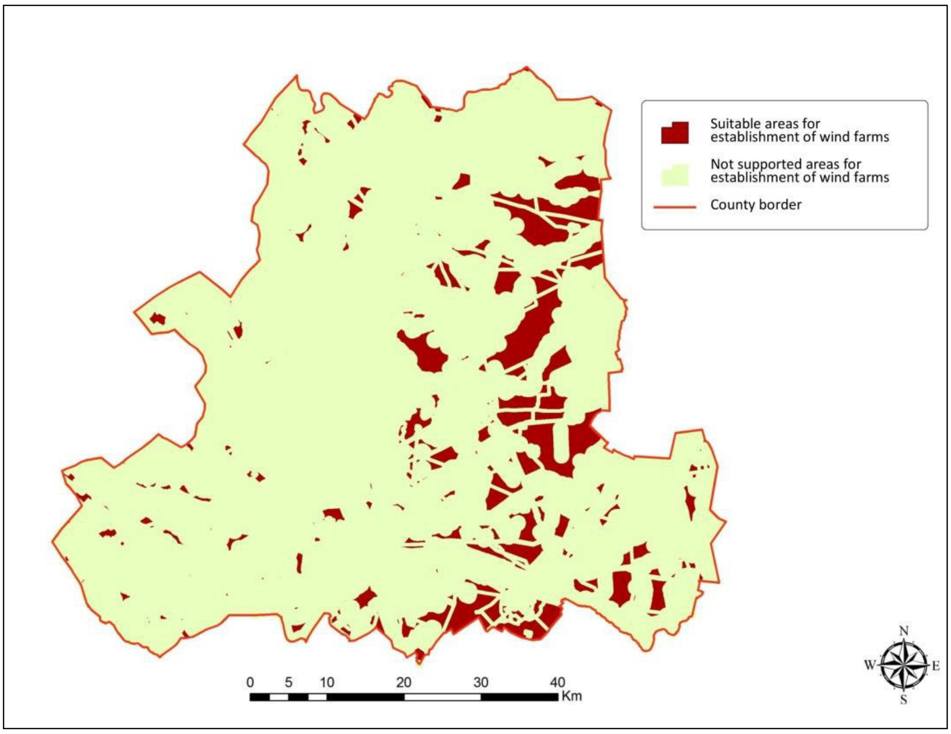

Figure 2. The limiting land use factors for wind turbine installation with buffer zones of the study area

2.3. GIS analysis of *supporting* aspects of wind power installation

The supporting aspects include the paved road network and the electrical networks in case of multiple turbines because both of them can reduce investment costs. In the case of the 120 and 400 kV high voltage networks, the produced energy is transported by electrical cables 1.5 meter deep in the ground. As environmental impact assessment is only required if the underground cable is longer than 15 km, it is practical to develop wind farms within this distance (buffer zones).

A paved road network is also very important for the installation and maintenance of wind turbines. It significantly reduces costs if there is no need for creating new paved ways for service cars. Therefore in our opinion the road network is a supporting factor for wind turbine installation. We digitized the 120 and 400 kV high voltage network in Csongrád County and then we created 250 meter buffer zones surrounding the road network, and 15 km buffer zones surrounding the electricity network. We merged these two buffer zones and used the resulting map to delineate those areas that are highly suitable for the installation of wind turbines (Horváth 2005).

After the road and electricity network analyses we used historical military maps and a wind energy potential map based on synoptic meteorological data to delineate the most suitable areas for wind farms in the study area (Fig 3).

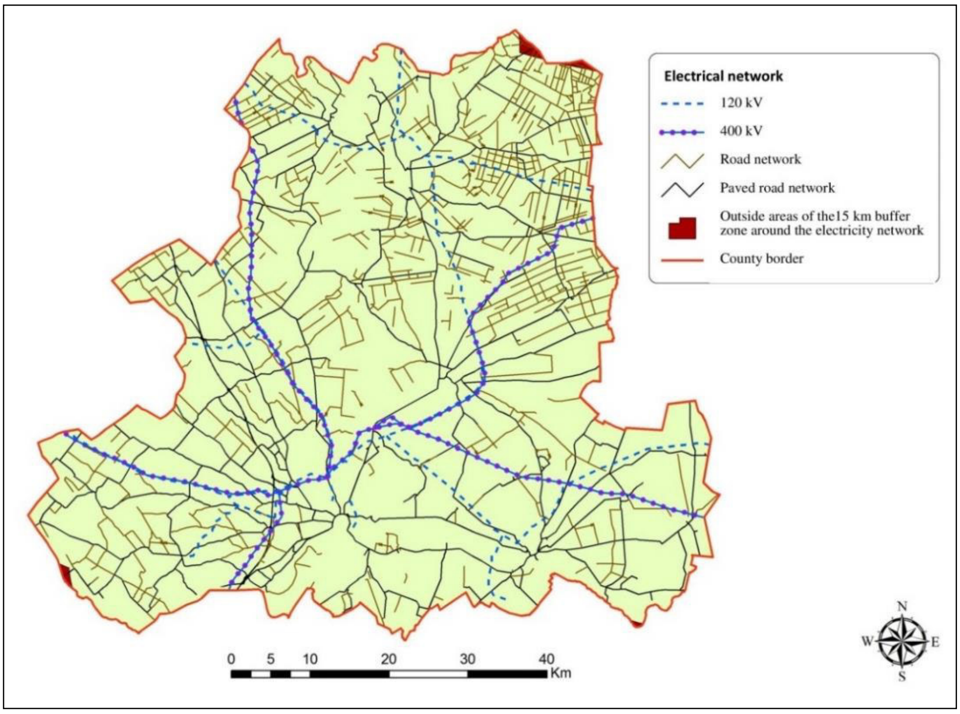

Figure 3. Supporting aspects of wind power installation of the study area

2.3.1 Historical windmills as indicators of the wind energy potential

In her publication, Keveiné Bárány I. (1991) underlined that wind energy potential was first utilized by windmills. She called attention to the fact that the spatial analysis of windmills would be a suitable tool for estimating wind energy potential. Keveiné also demonstrated the spatial distribution of the windmills of the great Hungarian

Plain with the help of a map. During our research, we created a windmill density map that could be an important historical dataset for the wind potential prediction of our study area (Csongrád County).

We used the DVD of the historical military maps of the II. Military Survey georeferenced by Arcanum Ltd. (Arcanum, 2006). The county was divided into equal areas during the digitization and we identified all the windmills by examining them one by one through visual interpretation. Based on the military map sheets created in the indicated period, 96 windmills were identified and digitalized in the study area.

We created a windmill density map from the digitized windmill points with the following method: for every digitalized windmill point data a 3 km buffer zone was drawn in ArcGis 10. By counting the points in the buffer zone and assigning this value to the points, we generated a density map (Fig 4).

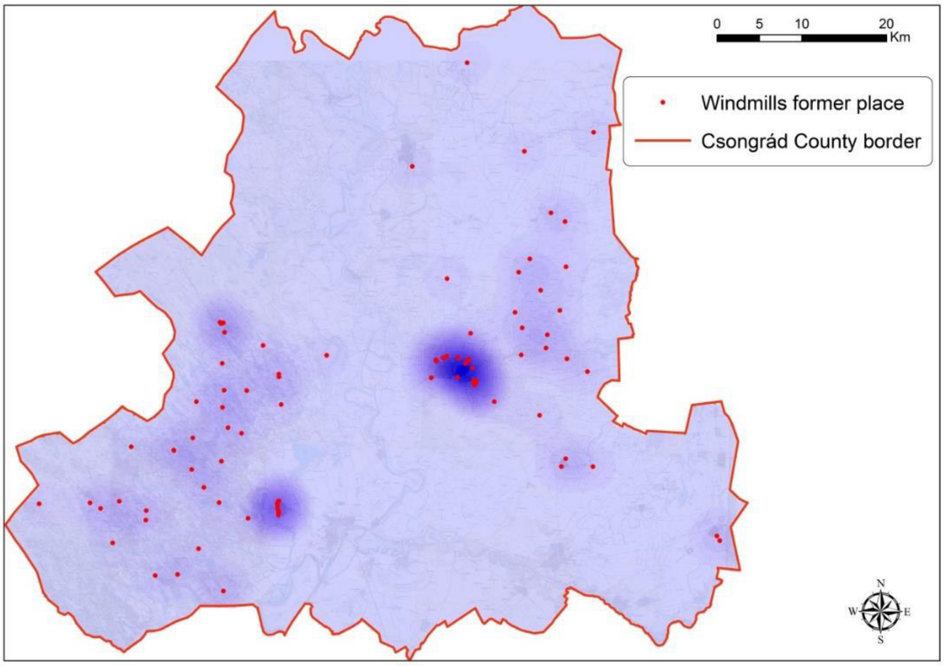

Figure 4. Windmill density map of the study area based on II. Military Survey (1870)

2.4. Creating a wind potential map of the study area using GIS methods

For the installation of wind turbines, it is essential to know the average wind speed data of the study area. In 2005, The Hungarian Meteorological Service produced a wind speed map for the whole country, which was made in a resolution of 2 x 2 km rasters. For our county level analysis, we needed more detailed, higher-resolution annual wind speed averages from a more dense station network. We received the long-time averages of 4 synoptic meteorological stations from the Hungarian Meteorological Service. We also got monthly average wind speed datasets from 3 stations found in the database of the Időkép.hu website. Regarding the M43 motorway and the Csongrád county section of the M5 motorway we also got wind speed datasets from the Motorway Service Companies (AKA Zrt.). Within the study area, 15 meteorological stations' monthly average wind speed data set was available. However, the used interpolation methods require wind speed data that comes from outside the study area. The wind speed datasets of Arad, Baja, Békéscsaba, Kecskemét, Kikinda, Újvidék (Novi Sad), Palics, Szolnok and Zombor were used for this purpose from the ogimet.com website.

For the interpolation of the wind speed data the ArcGis 10 software and the Inverse Distance Weighted (IDW) interpolation method were used. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name inverse distance weighted. The points are not even located far away from each other, which could affect the accuracy of the interpolation.

The synoptic stations represented the station data which has been measured 2m above the surface, therefore we calculated the wind speed at 70 m, 100 m and 120 m using the following formula (Tóth et al. 2006).

Hellman exponential function:

$$v_W(h) = v_{10} * \left(\frac{h}{h_{10}}\right)^{\alpha}$$

Where: $v_w(h)$= velocity of the wind at height [m/s], h=turbine height [m/s]
v_{10}= velocity of the wind at height, h_{10} = 10 meters [m/s]
α= Hellmann exponent

We determined the Hellman exponent under Davenport's classification. We used the 0.25 “Rough” class for most calculations: cultivated or natural area with high crops or crops of varying height, and scattered obstacles at relative distances of 12 to 15 obstacle heights for porous objects (e.g. shelterbelts) or 8 to 12 obstacle heights for low solid objects (e.g. buildings). The 0.5 „Very rough” class was applied for intensively cultivated landscape with many rather large obstacle groups (large farms, clumps of forest) separated by open spaces of about 8 obstacle heights and for low densely-planted major vegetation like bush land, orchards, young forest. It was also used for areas moderately covered by low buildings with interspaces of 3 to 7 building heights and no high trees (Jon W. 1992). We calculated the data measured near the surface for 70 m, 100 m and 120 m heights using the Microsoft Excel software. Based on the studies made by Kircsi A. (2004), surface roughness does not cause significant interference in Hungary in regions higher than 60 m. We created the wind energy potential map with values calculated at 100 m using IDW interpolation, since according to Szalai et al. (2010) it is the recommended height for county level wind speed calculation in Hungary (Fig 5).

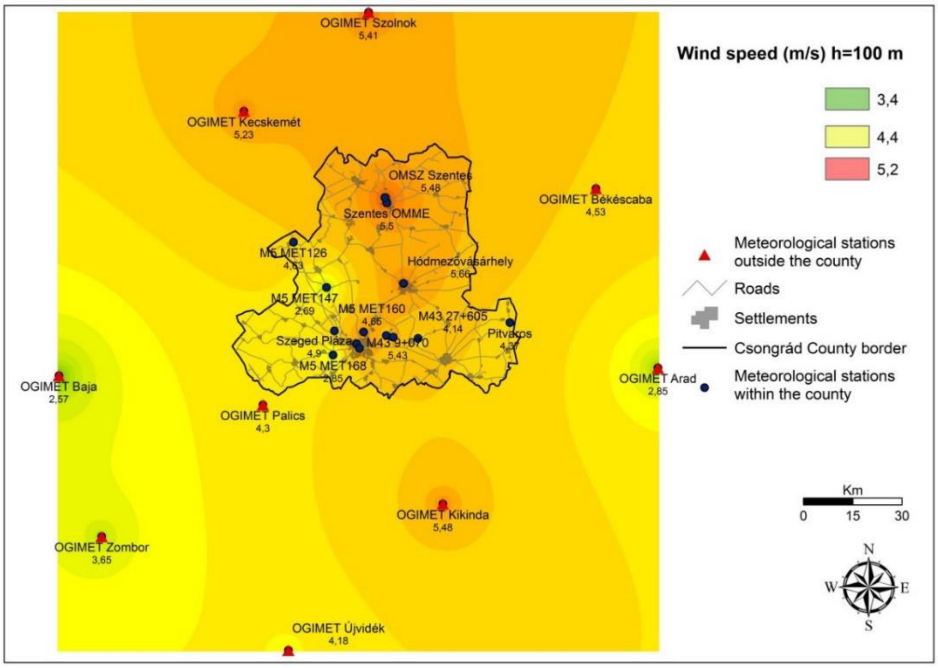

Figure 5. Wind potential map of the study area

3. Result and discussion

Delineation of the areas which are suitable for the installation of wind turbines within the study area (Csongrád County):

By merging the digital map databases of the supporting and limiting factors in the ArcGis 10 environment, the fairly and highly suitable areas for wind turbine installation have been delineated. Based on our results, we can conclude that Csongrád County is suitable for renewable energy development because it has good wind energy potential and many suitable areas for wind farms. The resulting wind potential map clearly shows that in the Northern parts of the county wind speed values are higher. Regarding the Eastern and South-Eastern parts of the county, higher values were obtained as well.

Henceforth, the maximum possible numbers of turbines were estimated inside the delineated suitable areas in Csongrád County. According to the suggestion of the dromstorre.dk website, turbines should be placed 7 diameters apart in the prevailing wind direction and 4 diameters apart in the direction perpendicular to the prevailing winds. A 2 MW turbine's rotor diameter is 90 m, which means that the turbines need to be placed 360 m and 630 m apart parallel and perpendicularly. 4.4 turbines fit in one square kilometre.

Based on our calculations, approximately 1744 wind turbines could be installed in the areas that are suitable or highly suitable for the establishment of wind farms. For the estimation of the total wind energy potential of the study area (Csongrád county), we calculated with 2 MW turbines, 25% of the actual performance and a space of 360 x 630 meters per turbine. Our results show that a total of 872 MW energy could be generated annually if we placed wind turbines in all suitable or highly suitable areas (Fig 6). Our results, regarding both the scale and the methdology, approximate the results of Munkácsy et al. (2015) research on Csongrád county and other counties of Hungary.

4. Conclusion

In the presented study we analysed the supporting and the limiting factors of wind farm establishment in digital thematic maps using different buffer zones.We created a windmill density map and a wind energy potential map with GIS methods based on historical maps and synoptic meteoroligical data. After we merged the supporting, limiting factors and the wind potential map, we could create two land use scenarios and were able to delineate the areas which are suitable or highly suitable for the establishment of wind farms. Lastly, we estimated the annual amount of electricity which can be produced in the areas that are perfectly suitable for the establishment of wind turbines inside the delineated suitable and highly suitable areas of the study area.

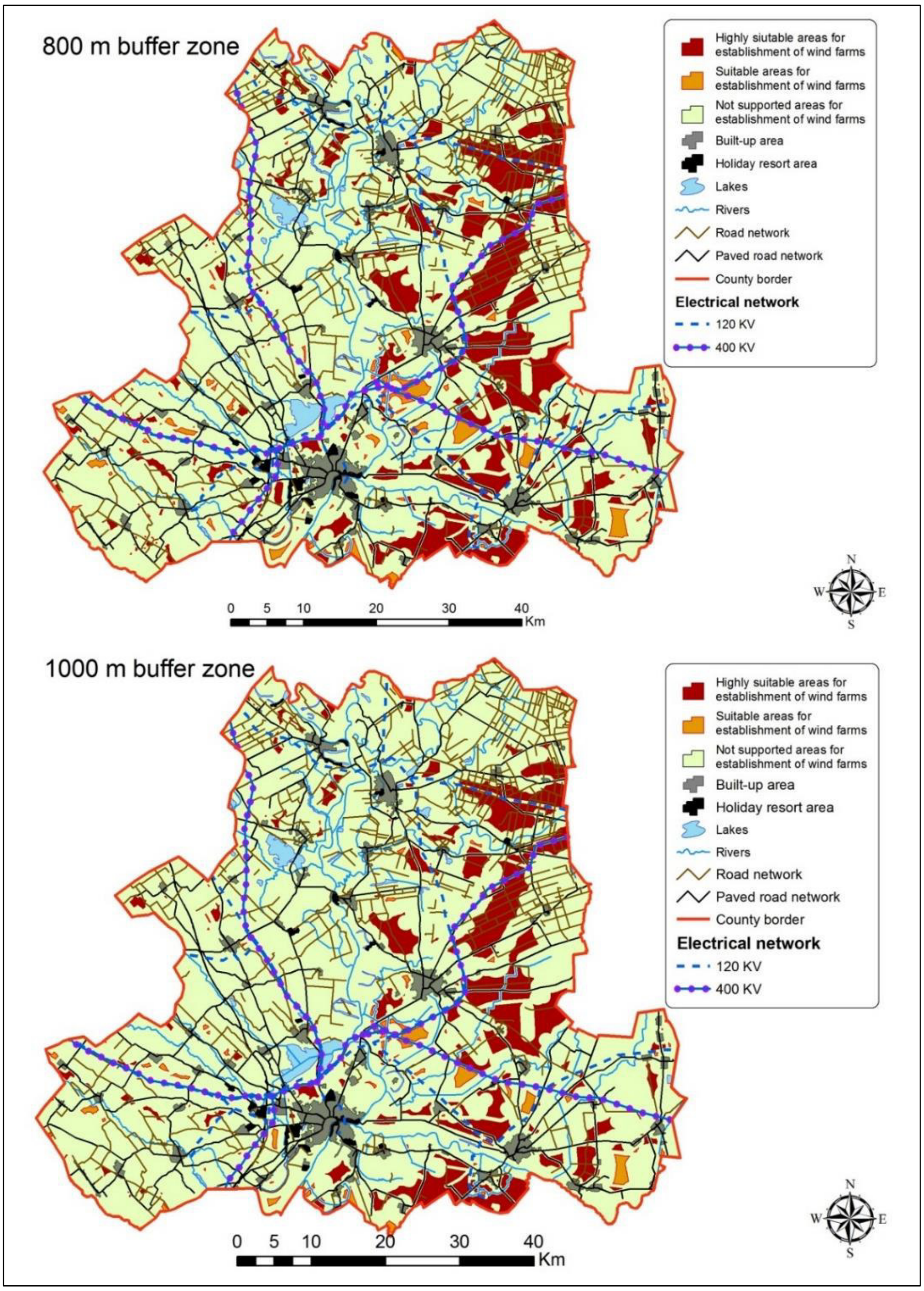

Figure 6. Suitable areas for establishment of wind farms of the study area (2 scenarios)

Summarizing our results, we concluded that indeed 91.02% of the study area is unsuitable for the installation of wind turbines due to some environmental restrictions and considerations. Based on the used GIS methods (overlaying different kinds of limiting and supporting factors, buffer zones and supporting factors maps), we created a county level wind potential map, and based on our calculations, we estimated the annual amount of electricity that could be produced by wind power in the study area. We found that approximately 1744 wind turbines could be installed in the areas which are suitable or highly suitable for the establishment of wind farms. According to our calculations, 872 MW of energy could be generated annually if we placed wind turbines in every suitable or perfectly suitable area.

The GIS and calculation methods we applied can also be used for analysing other areas with a similar purpose and for estimating their wind power potential.

From user aspect it is important to mention that this is a theoretical estimation and in practice, as a consequence of wind fluctuation there are several other limiting aspects which influence the final energy production.

Conflict of Interest

The authors declare no conflict of interest.

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