

The use of GIS tools for decision-making support in sustainable energy generation on the example of solar photovoltaic technology

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Abstract. The study proposes a simple procedure for evaluating the suitability of various locations for the installation of micro-scale solar photovoltaic (PV) systems. The main aim of the study was to determine the applicability of GIS tools for assessing the suitability of different locations for solar energy generation. The applicability of open-source databases in geoinformation analyses was emphasized. The study was conducted in the urban municipality of Mrągowo in the Region of Warmia and Mazury, Poland. Mrągowo is characterized by considerable physiographic diversity, which influenced the results of the study. The evaluation focused on rooftops, which are most widely used for the installation of micro-scale solar PV systems. For the purpose of generalization, the results of the evaluation were presented for the districts of Mrągowo, so as to assist state agencies, local governments, and non-public institutions in implementing local policies that support renewable energy generation. The average amount of energy (MWh) that can be generated per building and the total amount of energy (MWh) that can be generated in cadastral districts were calculated to determine the solar energy potential of the study site.

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1. Introduction

The depletion of fossil fuels and climate change currently pose the greatest challenges for the global economy (Benedek et al., 2018). Due to the scarcity of fossil fuels and growing oil prices, alternative energy sources are urgently needed to guarantee global energy security (Owusu & Asumadu-Sarkodie, 2016). The aim of sustainable energy policies is to minimize the negative impact of energy generation on climate change by promoting renewable energy development and energy generation technologies that are less detrimental to the environment (Arroyo & Miguel, 2020).

Solar photovoltaic (PV) technology is one of the most significant sources of renewable and green energy. The amount of energy generated by solar PV systems continues to increase, but these systems will not make a substantial contribution to the global power sector unless installation costs are significantly decreased (Towler, 2014). In 2020, 1.4% of electricity in Poland came from solar power, which was below the forecast value of 1.8% (*Photovoltaic Market in Poland 2022 Report, 10th edition*, Institute for Renewable Energy, 2022). The PV technology captures and converts solar energy to electricity with the use of solar PV cells. A solar cell contains semiconductors such as transistors and microprocessors. It relies on the physical properties of semiconducting materials, such as silicon, to directly convert sunlight to electricity. The popularity of solar PV cells can be attributed to their simplicity and durability (Wang, 2019).

Support programs and financial incentives introduced by the Polish government and the EU have significantly increased the popularity and profitability of renewable energy generation projects in Poland (Rataj et al., 2021). Numerous campaigns promoting solar PV systems have been launched. The total installed capacity of PV systems has increased substantially since solar panels were introduced to the Polish market in 2011. In the EU, the total installed capacity of PV systems reached 158 GW at the end of 2021, with an annual growth rate of 21.4 GW, marking an increase of 15% from 2020. In terms of the increase in installed solar capacity, Poland ranked second after Germany in the EU in 2021 (*Photovoltaic Market in Poland 2022 Report, 10th edition*, Institute for Renewable Energy, 2022). However, the selection of optimal locations that guarantee the profitability of PV installations is a problem that has not been widely addressed in the literature. Therefore, the present study was undertaken to determine solar energy potential

within the administrative boundaries of a town. In the analyzed town, districts were classified based on the suitability of building rooftops for installing PV panels in view of geospatial conditions. The results of the study provide valuable inputs for government agencies and businesses that offer solar incentives and discounts, and they will enable central and local authorities to optimize their renewable energy policies. The main aim of the study was to determine the applicability of GIS tools for assessing the suitability of different locations for solar energy generation. Special emphasis was placed on spatial databases and micro-scale residential PV systems.

2. Literature review

At present, fossil fuels are the main energy source around the world (Azizkhani et al., 2017). Fossil fuels have a highly negative impact on the environment by contributing to greenhouse gas emissions and geological changes. These energy sources are also being rapidly depleted around the world (Shafiee & Topal, 2009). Alternative sources of energy are thus urgently needed to maintain current levels of economic growth (*Directive (EU) 2018/2001 of the European Parliament and the Council of 11 December 2018*). The Polish government has adopted the Energy Policy of Poland until 2040 (*Energy Policy of Poland until 2040*, 2021), which sets the framework for the country's energy transformation. The main aims of this strategic document are to guarantee uninterrupted supplies of fuel and energy, to increase economic competitiveness, improve energy efficiency, and minimize the power sector's negative impact on the natural environment (*Notice from the Ministry of the Economy of 21 December 2009 on the National Energy Policy until 2030*, 2009). Solar energy plays a very important role in the pursuit of sustainable energy goals (Knutel et al., 2020).

Solar energy offers a potential solution to the increased demand for new energy sources. In the future, PV systems will be installed mainly in urban (developed) areas. In highly developed countries, more than 80% of the population resides in the urban environment, which is characterized by a high demand for energy. Urban areas are also responsible for a large part of global greenhouse gas emissions. According to theoretical estimates, small-scale PV installations can fully cater to the energy demand of many countries. Therefore, the development of PV projects in the vicinity of large human settlements (urban areas) is economically and environmentally justified (Hofierka & Kaňuk, 2009b).

Solar-based sources of renewable energy have numerous advantages, including the absence of direct CO₂ emissions and noise-free operation (Lazzeroni et al., 2020). These advantages can compensate for certain limitations, mostly seasonal fluctuations in output, the need for locations with adequate sunlight exposure, variations in insolation, shading and cell ageing (Gorjian et al., 2021). Location is a very important consideration because it determines a PV system's output (Kádár, 2014) and the profitability of solar farms. Location is a critical parameter in micro-scale residential PV installations, which have to strictly conform to local zoning requirements. Residential users are unable to choose the location of their solar PV installations. Residential solar systems are usually designed and built on premises that constitute the investor's property and are bound by the provisions of the local zoning plan (Aghamolaei et al., 2020). The area to be covered by PV panels should be large enough to install the required number of panels with the required output and to ensure the profitability of the investment (Charlier, 2009). The following factors play key roles in the choice of the most suitable location: shading from neighboring properties, orientation relative to the cardinal directions, and roof pitch (tilt angle) (Gorjian et al., 2021). Locations that are shaded by neighboring objects (such as trees, chimneys or antennas) and sites with a suboptimal angle of insolation are not suitable for solar power generation (Giyantara et al., 2021). The optimal location and installation method should be determined individually for each location before a solar PV system is installed (Mayfield, 2010).

Atmospheric phenomena are among the key factors that affect the widespread use of solar energy. Considerable spatiotemporal variations in insolation patterns, which are influenced by numerous factors, affect the operation of PV systems and are difficult to predict in specific locations. Astronomical factors are largely responsible for seasonal and daily fluctuations in the amount of received sunlight, and they are also strongly modified by atmospheric conditions (clouds, aerosols, water vapor and ozone). Even greater fluctuations are observed at the local level due to variable local conditions, including the presence of obstacles that prevent reliable observations of the sky or temperature (Hofierka & Kaňuk, 2009a).

Geographic information system (GIS) tools are increasingly used in spatial analyses to plan, optimize and develop various engineering solutions and renewable energy generation projects (Nedović-Budić, 1998). GIS tools provide extensive

information about location, and they are widely used in construction and engineering projects (Cieślak et al., 2020; Cieślak & Górecka, 2021). The applicability of GIS data for optimizing the location of renewable energy generation projects has been analyzed by numerous researchers (Huang et al., 2019; Kucuksari et al., 2014; Pillot et al., 2020). Biłozor et al. (2020) examined the applicability of GIS data for spatial optimization. Decision-support methods have also been used to assess a site's suitability for the intended purpose (Mokarram et al., 2020; Ramirez Camargo & Stoeglehner, 2018). Therefore, GIS tools can also be expected to provide valuable information regarding the optimal location of solar PV systems.

Numerous researchers have relied on GIS tools to develop solar power potential maps (Borfecchia et al., 2013; Yushchenko et al., 2018; Mansouri Kouhestani et al., 2019). In many studies, SP was estimated for extensive areas with a lower urbanization rate because these calculations were performed to identify the optimal location of solar farms (Haurant et al., 2012; Uyan, 2013; Brewer et al., 2015). Fewer studies have evaluated the solar development potential of urbanized areas (Freitas et al., 2015). However, regardless of the modeled space and the urbanization rate, research on the optimal location of PV installations should be continuously updated due to technological progress, increased availability of data, and upgrades of GIS databases that are used in these studies.

Existing PV installations should also be considered in the process of planning new solar projects. This is a difficult task because there are no comprehensive registers of existing PV systems. The absence of reliable information about PV installations in databases was discussed by Bieda and Cięciała (2021). Databases containing information about the location of PV installations, their parameters, and the amount of generated energy would not only facilitate the planning and development of solar power networks but would be also very helpful in assessing the performance of existing installations and modeling the solar power potential of a given area.

3. Research procedure and data sources

In Poland, more than 75% of electricity derived from sunlight is generated by micro-scale residential PV systems (Derski, 2016; *Photovoltaic Market in Poland 2022 Report, 10th edition*, Institute for Renewable Energy, 2022). Rooftop solar panels are installed

by single-family homeowners to decrease their electricity bills. Most solar installation companies offer their services by contacting potential investors in person or via telephone. A simple GIS analysis can be performed to determine whether solar panels can be installed in a given site and to provide clients with information about potential profits. Open-source geospatial databases were used in this study to analyze built-up areas in the urban municipality of Mrągowo. Home solar electric systems are usually installed on rooftops. Therefore, rooftops in the study site were evaluated, and the optimal parameters for the installation of rooftop PV panels were described:

1. The roof pitch should not exceed 45° because steep slopes absorb less sunlight,
2. The minimum solar irradiance incident on the roof is 800 kWh/m^2 ,
3. Roof orientation: north-facing roofs receive least sunlight, and south-facing roofs are most desirable.

The criteria for the study were selected based on the guidelines for the installation of PV panels and a review of the literature (Brodziński et al., 2021; Delphine Khanna, 2022; *Fotowoltaika w Mrągowie. Sprawdź, Gdzie Słońce Świeci Najmocniej*, 2022). The research procedure was based on the above criteria, and it is described below. The study site was selected in the first stage of the study. The analyzed location should be well described by spatial databases, and it should be characterized by physiographic and

anthropogenic diversity to obtain variable results. In the next step, spatial data describing land cover, land use and landform were obtained and standardized to identify the potential locations of solar PV panels (rooftops) and describe their physical and environmental parameters. Locations that did not meet the specified criteria were eliminated from the dataset. In the next step, the accumulated data were used to determine the solar potential (SP) of selected locations. The potential output of solar PV cells (i.e., the minimum outcome of partial potentials) was calculated for the rooftops of selected buildings. The results were validated during a field study. The study site was inspected to determine whether solar PV installations had been built in the locations selected during the analysis. The results were classified based on the total SP of PV installations in the districts of Mrągowo. These findings can be used by local authorities to implement cohesive policies supporting residential solar energy generation.

3.1. Description of the study site

The study was conducted in the town of Mrągowo, which is characterized by high levels of economic development and high population growth. The town was selected for the study due to considerable variations in physiography (differences in elevation) and land-use types (extensive residential areas featuring single-family homes, green areas and water bodies) to examine the suitability of various

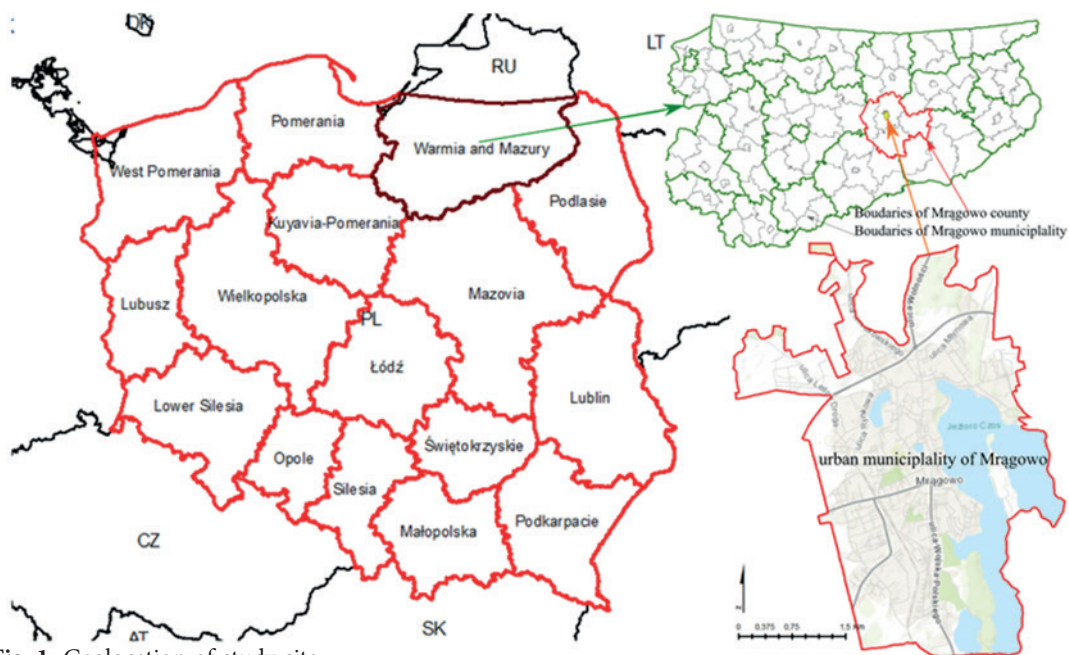


Fig. 1. Geolocation of study site
Source: Own elaboration

districts for rooftop solar installations. Mrągowo is also well covered by GIS databases, which facilitated the analysis (*Local Revitalization Plan for the Town of Mrągowo for 2009–2015*, 2009).

Mrągowo is situated in Mrągowo county in the Region of Warmia and Mazury (Fig. 1). It has an area of 14.81 km² and a population of approximately 22,000.

3.2. Source data and an analysis of geographic features

The urban municipality of Mrągowo is characterized by diverse development that includes single-family houses, apartment buildings, retail outlets, historical monuments and large industrial structures. In addition to urban development, climatic factors also play a very important role in identifying the optimal location for solar PV systems. In Mrągowo, urban development is influenced by the proximity of lakes and forests (*Strategic Diagnosis of Mrągowo Municipality*, 2021).

Insolation is a key climatic factor that affects the output of solar PV panels, and it is correlated with the climate zone. Photovoltaic systems positioned in full sunlight heat up quickly, which affects their performance. This parameter is used during system design to calculate energy loss (*Wymogi, Jakie Musi Spełniać Działka Pod Fotowoltaikę*, 2021). Air temperature is yet another climatic factor that influences the performance of solar panels (*Fotowoltaika. Zbiór Artykułów 2009–2012*, 2008). A PV system can be damaged by both extremely low and extremely high temperatures because its components are sensitive to atmospheric factors, in particular in summer. High temperatures exert a negative effect on PV modules (Foks et al., 2019).

The performance of solar PV systems is also determined by landform. Mrągowo is characterized by undulating terrain with numerous glacial lakes and hills that constitute the Wyszembork Ridge. Diverse terrain influences the microclimate of Mrągowo and the neighboring areas. The undulating terrain and lakes were formed during the latest glaciations in this part of Europe. Elevation ranges from 116 to around 200 m above sea level, with a maximum difference of 95 m, which contributes to variations in local landform.

Landform and land-use data were acquired for the analysis. The information about the location and size of buildings was obtained from the Database of Topographic Objects (BDOT10k) on the Geoportal website (opendata.geoportal.gov.pl, 2021) managed by the Head Office of Geodesy and Cartography.

The topography layer contains objects in the entire study site. The dataset was validated by comparing building contours in the vector layer with the raster layer of the Digital Land Cover Model (DLCM). New objects were added, and incorrectly positioned objects were removed from the vector layer.

Average insolation in the study site was analyzed to determine the amount of sunlight reaching PV panels. The information, available on the meteoblue.com platform (accessed on 15 May 2021), suggests that the number of sunny days in Mrągowo is highest between April and October. Insolation directly affects the amount of energy generated by solar PV systems. During the year, there are around 160 partly cloudy days and around 110 cloudy days in Mrągowo. Information about average monthly temperature was also obtained from the meteoblue.com website. Average summer temperature at the study site is 22°C, and it is considerably lower than in other Polish regions (central and western Poland) due to the abundance of water bodies in the vicinity of Mrągowo. Temperatures can exceed 30 °C between June and September.

4. Analysis and calculations: results

4.1. Insolation analysis

The height of all buildings in the study site was determined by analyzing the DLCM (opendata.geoportal.gov.pl, 2021). This resource contains information about land surface and land cover, including buildings, trees and various types of infrastructure. Shading losses in areas where solar PV systems could be developed were determined in the next step with the use of ArcGIS 10.7 tools (hillshade effect). The developed hillshade effect map is presented in Fig. 2.

Transformed data were used to generate a raster layer representing solar irradiance incident on rooftops throughout the year. The greater the amount of solar radiation reaching the roof surface, the higher the potential output of solar cells. The Area Solar Radiation tool in ArcGIS software was used to calculate solar irradiance incident on rooftops in different seasons of the year, which is determined by latitude. Solar irradiance was also modeled for different times of the day, as well as for various obstacles that can block or restrict sunlight exposure, such as trees, buildings, roof orientation and roof pitch.

The resulting raster layer presents the SP of rooftops in the urban municipality of Mrągowo. The SP in the study site ranged from 436 kWh/m² to 1,021,510 kWh/m² (Fig. 2).

4.2. Roof pitch and orientation

Building roofs with an inclination angle of 0° to 90° were considered in the analysis. The Slope tool was used to identify steep surfaces in each raster cell. The analysis was performed to identify roofs that are suitable for the installation of PV panels. The layer presenting the slope of various objects in the study site was generated based on DLCM data, and it was not limited to building roofs.

In the next step, the orientation of buildings in the study area was determined based on landform features. Orientation was identified in each raster cell of the DLCM with the use of the Aspect tool. The generated map presents the directions the physical slopes face. The following directions were used in the analysis: N, NE, E, SE, S, SW, W, and NW. The results are presented in Fig. 3.

Areas with a slope of up to 10° were also identified because, in these areas, orientation does not affect solar irradiance incident on rooftops in the urban municipality of Mrągowo. Based on the results of the above analyses, areas with unfavorable geographic parameters and landform were eliminated from the dataset. The SP of objects in Mrągowo, including slope and orientation relative to the cardinal directions, is presented in Fig. 4B.

Each object was analyzed for SP and its suitability for installing solar PV panels. Ultimately, SP values were calculated for all rooftops that met the indicated requirements (slope and solar irradiance). To guarantee a return on investment, PV solar systems should be installed on rooftops with a minimum area of 30 m² (Fig. 4C). The minimum area requirement was based on the recommendations of PV panel manufacturers and information available on online discussion forums. According to estimates, a 4 kW PV installation can generate around 12 kWh per day under optimal conditions, and it can cater to the average energy demand of a single-family home. Solar panels with a combined output of 4 kW occupy an area of 29 m² on average. The area of PV panels used in the analysis was set at 30 m² (*Find the Best Solar Panels in the UK Are Solar Panels the Right Choice for Your Home?*, 2022; *Ile Akumulatorów Potrzeba Do Zasilania Domu?*, 2022).

A procedure for calculating the return on solar investments was described by Krajewska and

Szopińska (Krajewska & Szopińska, 2018). In the described procedure, atmospheric factors, including shading, have to be considered in the process of calculating the amount of generated solar energy. The cited authors relied on ArcGIS software to account for the variations in atmospheric conditions (*An Overview of the Solar Radiation Toolset*, 2022). Average cloud cover is taken into account in the process of calculating the amount of solar radiation reaching a given location.

4.3. Determination of solar irradiance

A total of 3,434 buildings were identified in the study site, and 2,028 of those met the criteria for installing PV systems. Photovoltaic power potential (PPP) was calculated by multiplying average rooftop solar potential by roof area, and areas potentially shaded by the surrounding trees and buildings were subtracted from the result. The following formula was applied to calculate PPP.

$$PPP = (RTA * avSP) / 1000 \text{ [MWh]}$$

where:

PPP – photovoltaic power potential;

RTA – suitable rooftop area;

avSP – average solar potential.

The relevant data are presented in Table 1.

Solar irradiance values were converted to electricity to facilitate the interpretation of the results. The amount of electricity produced by solar panels is determined not only by solar irradiance, but also by their capacity and efficiency. According to the United States Environmental Protection Agency, PV panels are capable of converting around 15% of incoming solar energy into electricity, and 86% of that electricity is preserved as it flows through the installation. Photovoltaic power potential was converted to electricity with the use of the formula below:

$$E = PPP * EE * EL \text{ [MWh]}$$

where:

E – generated electricity;

EE – solar panel's energy efficiency;

EL – energy loss (energy lost during transmission)

Buildings with the highest PPP values are presented on the map in Fig. 5. Buildings that are best suited for the installation of solar PV systems are shown on the map. However, the map does not account for roof area in individual buildings, and

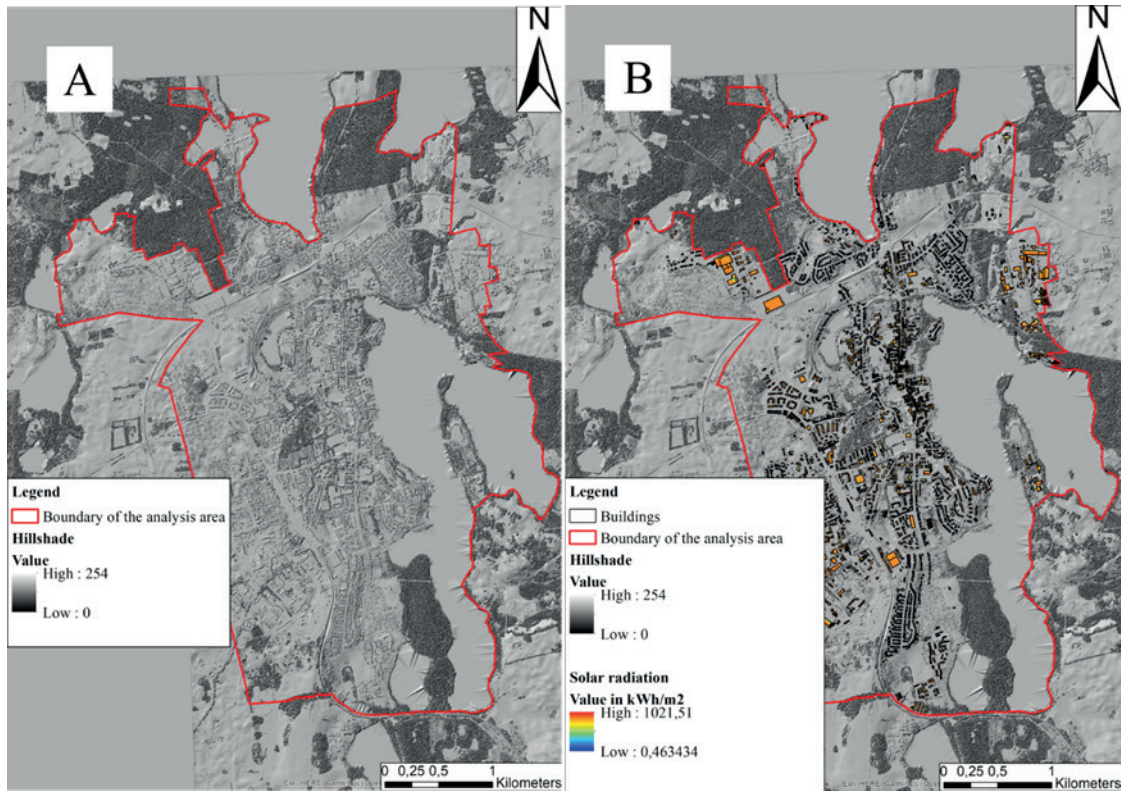


Fig. 2. (A) Hillshade effect map and (B) solar potential map
Source: Own elaboration

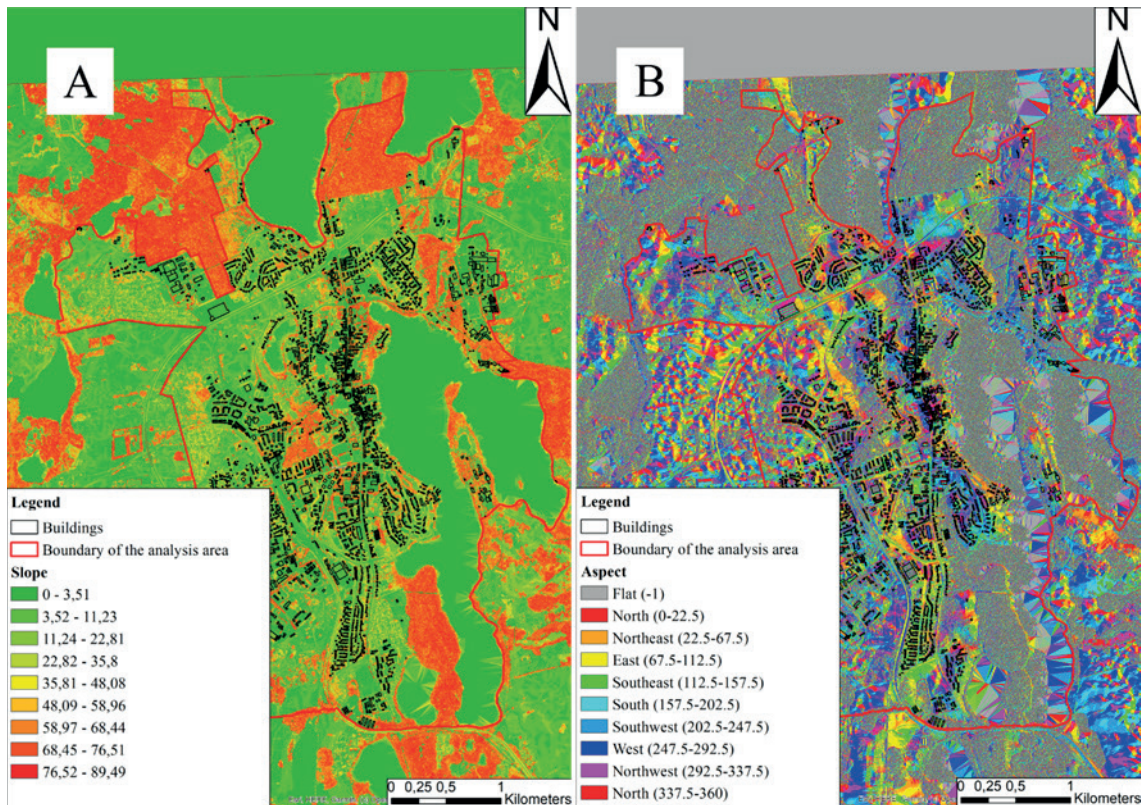


Fig. 3. Slope map of Mrągowo (A) and the orientation of buildings in the study site (B).
Source: Own elaboration

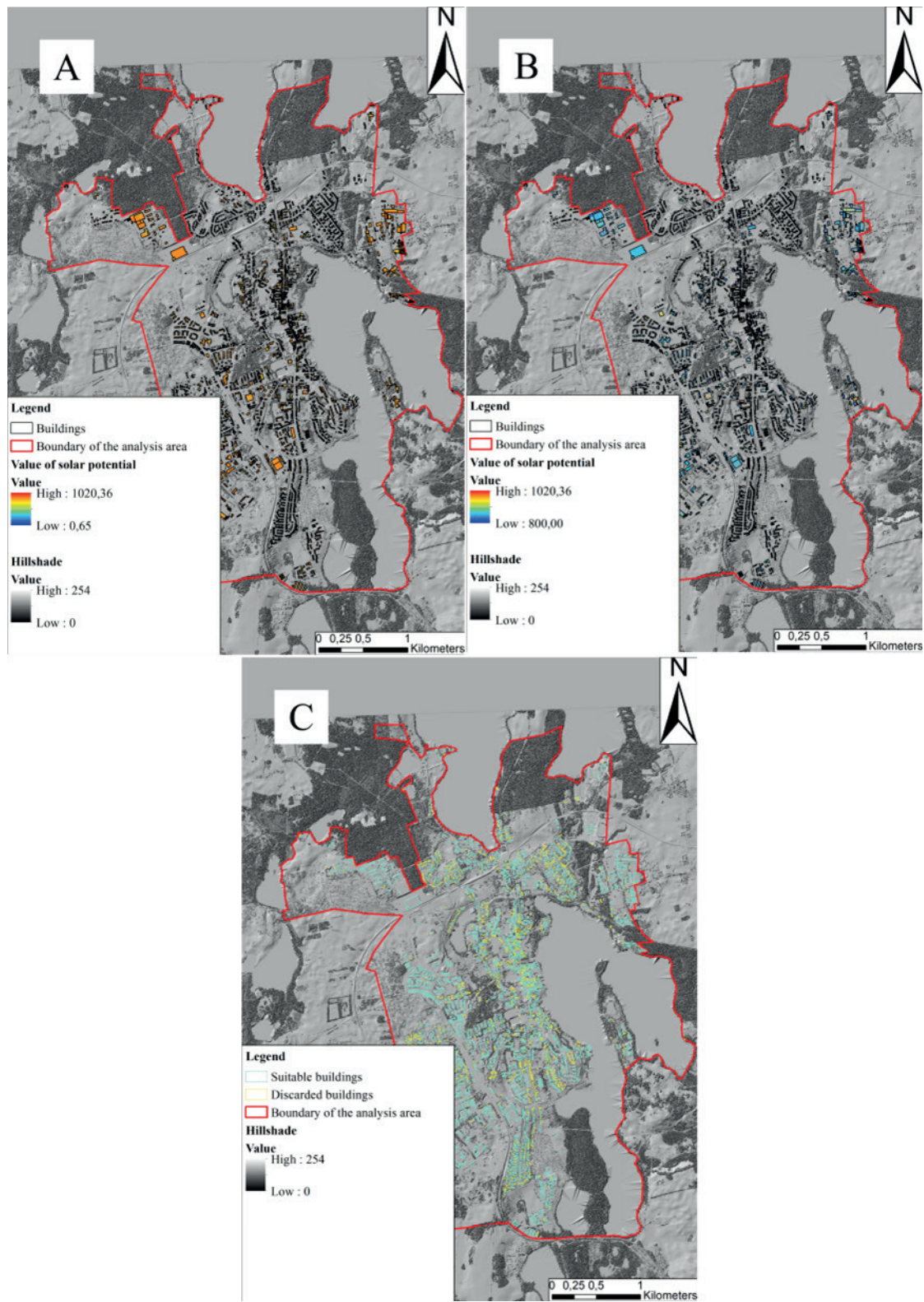


Fig. 4. (A) Map of areas with a slope of less than 45°; (B) map of areas that do not face north, and (C) map of areas with different orientation relative to the cardinal directions.

Source: Own elaboration

Table 1. Rooftop area in buildings suitable for installing solar PV systems and their photovoltaic power potential

	Min	Average	Max
Rooftop area in m ²	41.14	305.79	1713.98
Solar potential (SP) in MWh	4.57	34.49	15394.17

Source: Authors quoted from (Feng Li et al. 2009)

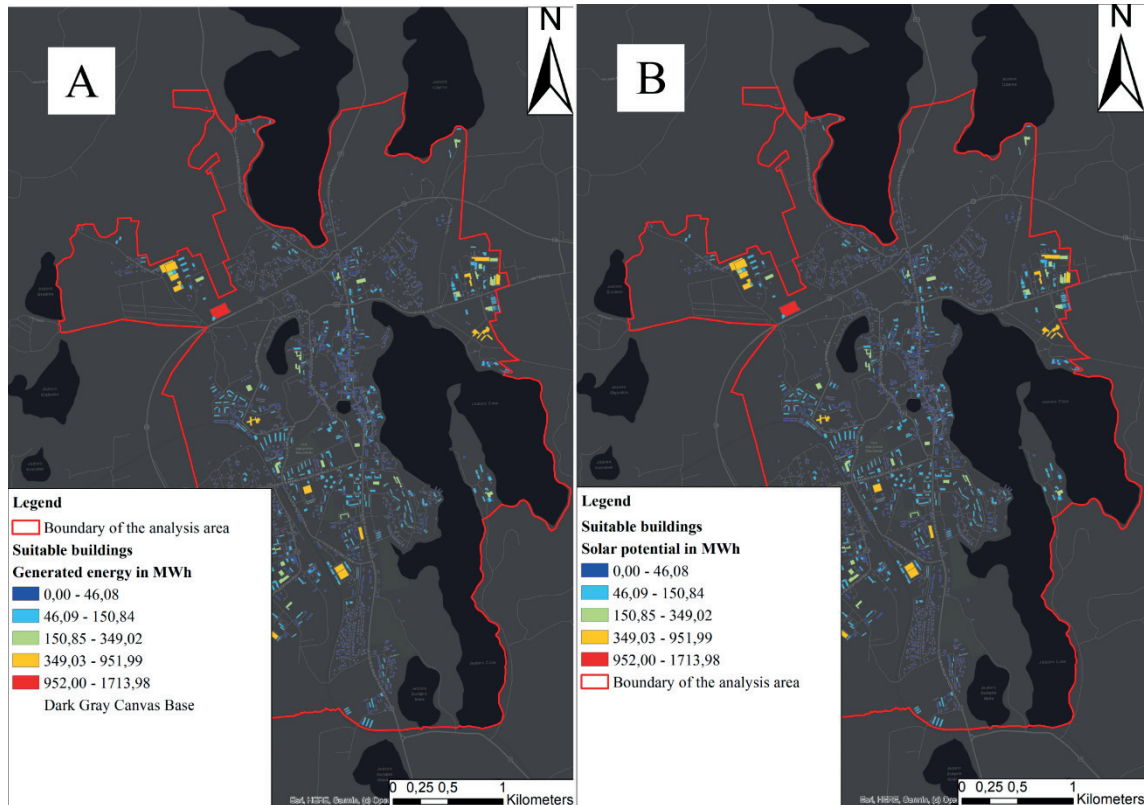


Fig. 5. Maps of (A) solar irradiance and (B) energy generation in MWh.

Source: Own elaboration

districts where investments in solar PV installations would be most profitable could not be identified.

4.4. Validation of results

The modeled results were validated in a field study. During a site inspection, buildings with rooftop solar panels were identified and compared with the results of the cartographic analysis.

The field study revealed that very few buildings in Mragowo were equipped with rooftop solar panels. The majority of PV systems had been installed in single-family homes, mostly new or refurbished buildings. A local inventory had to be performed

to generate reliable results because Mragowo has a diverse landform, and the model was based entirely on DLCM data. The SP determined during the analysis was used to identify buildings that meet the adopted criteria. Rooftop solar panels were evaluated based on these data.

The field study revealed that the majority of solar PV systems in Mragowo had been installed on buildings that were identified as most suitable for solar panel placement in the analysis. This observation implies that the results of the analysis can be used to select objects and areas where solar investments are most profitable.



Fig. 6. Distribution of solar PV panels on buildings, and buildings' location and solar potential
Source: Own elaboration

5. Discussion

The analysis performed in this study aimed to determine the SP of building roofs in the urban municipality of Mrągowo. A total of 2,028 buildings with a combined roof area of 347,350 m², which can generate 69,862.93 MWh of electricity, were selected for analysis. The average amount of electricity that can be produced per building was estimated at 34.45 MWh. The study site was divided into cadastral districts to identify areas where solar development projects would be most and least profitable. The results provide valuable information for private investors, state agencies and local governments that

implement environmental protection policies. The average amount of energy that can be generated per building (Fig. 7A) and the maximum amount of energy that can be generated in cadastral districts (Fig. 7B) are presented in Fig. 7. Average values were high in the proximity of the Adams plant, where a large number of solar panels could be installed on large factory buildings. Total values were highest in downtown Mrągowo. The data for buildings and districts are presented in Table 2.

The results of the analysis indicate that the solar power potential of a given area can be reliably evaluated with the use of open-source geospatial data and GIS tools. The generated information can have significant implications for planning and

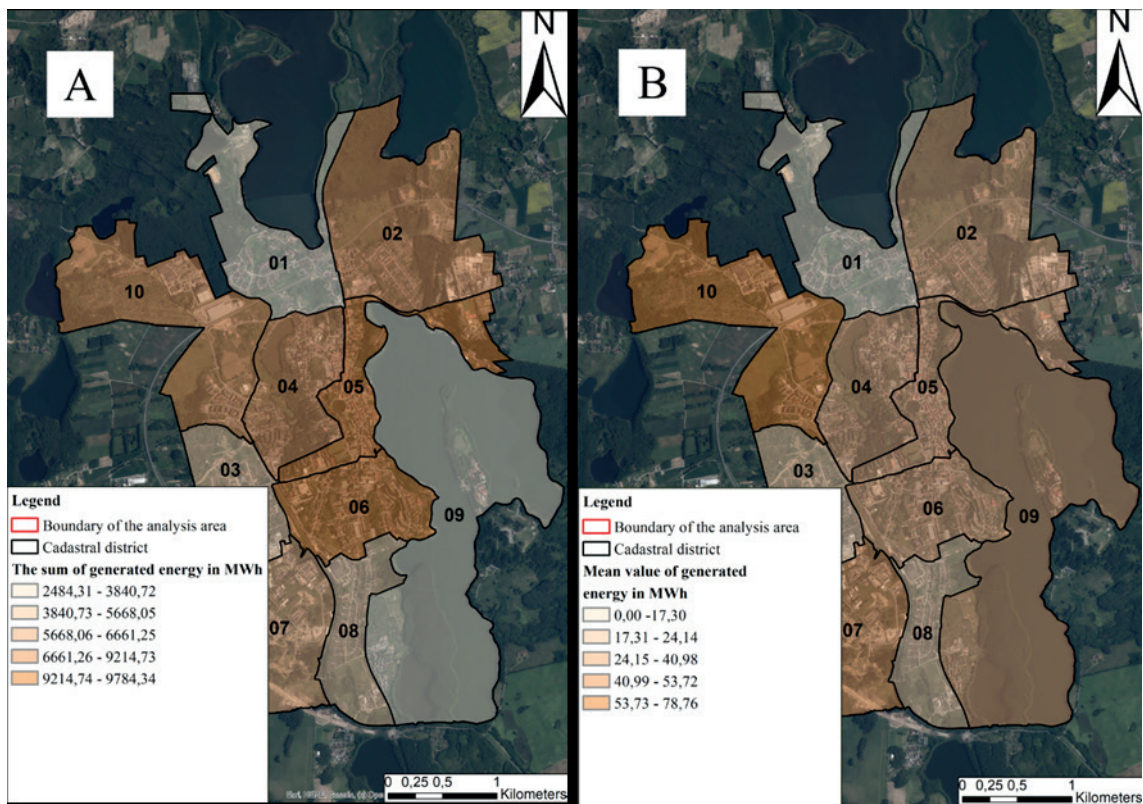


Fig. 7. (A) Average amount of energy (MWh) generated per building; and (B) total amount of energy (MWh) generated per cadastral district

Source: Own elaboration

Table 2. Average amount of energy (MWh) generated per building and total amount of energy (MWh) generated per cadastral district in the study site

Cadastral district	Total amount of generated energy [MWh]	Average amount of generated energy [MWh]
01	3,840.7170	17.3005
02	9,131.7165	34.7214
03	5,214.3219	24.1404
04	8,789.5311	32.7968
05	9,784.3404	35.7093
06	9,672.3555	40.9846
07	6,661.2504	53.7198
08	5,668.0536	23.1349
09	2,484.3078	31.0538
10	9,214.7280	78.7584

Source: Authors quoted from (Feng Li et al. 2009)

financing the development of new PV installations. Based on the information obtained from Mrągowo Town Hall, Mrągowo has a population of 20,147. According to Statistics Poland, average annual

energy consumption *per capita* is 632.16 kWh, which implies that Mrągowo has an estimated annual energy demand of 12,740 MWh. The maximum solar power output in the described

procedure was 58,990 MWh. The amount of energy generated by individual PV installations covers 463% of annual demand. However, GIS tools have certain limitations. They are effective in predicting solar power potential, but the generated results are not 100% reliable. According to many researchers, shading resulting from variations in cloud cover is one of the greatest obstacles in reliable SP predictions (Son et al., 2022).

The low accuracy of other data in the model also contributed to the uncertainty of the prediction. Roof slope was burdened by a certain error due to the low resolution of the analyzed data. It should also be noted that models of this type do not account for dynamic changes in climate or urban development. Political and social processes and their impact on the quality of space are also disregarded in such models. Despite the fact that the applicability of GIS tools is not limited to simple data inventories or visualizations, and that GIS systems support complex modeling tasks, a certain gap still exists between the SP maps developed for research purposes and the extent to which these maps are used by engineers, urban planners and designers in the process of designing and managing solar power installations (Freitas et al., 2015). However, the use of GIS tools in the optimization of PV projects produces much more satisfactory results than statistical optimization without geolocation data. The incorporation of spatial information not only improves the accuracy of data visualization, but also supplies additional information and increases its reliability. All factors that influence SP, including economic, environmental and social variables, are linked with the geospatial context. The growing availability of high-resolution geospatial data will minimize geolocation errors and increase the popularity of GIS tools in research. In the future, GIS technologies will be combined with other models and methods (empirical, theoretical and analytical). The future of solar energy is closely linked with the development of distributed energy generation systems and smart power grids, where topological parameters play an important role. Therefore, the applicability of GIS tools in the process of optimizing the design of solar energy systems requires further research (Choi et al., 2019).

The rapid development of photovoltaics is contributing to technological advancement and leading to changes in legal regulations. In this study, the SP of buildings in the urban municipality of Mrągowo was assessed based on an analysis of solar panels' efficiency and energy losses during transmission. The analysis relied on open-source data; therefore, certain inaccuracies can be expected.

The information about building shape, insolation and temperature in the evaluated cadastral districts was limited, which influenced the results. Temperature is a particularly important consideration because its extreme values affect the performance of solar panels and decrease their output. Factors such as the load-carrying capacity of buildings and roof condition were not considered in the analysis. These parameters cannot be determined in the early stages of the study, but they play a critical role during the installation of rooftop solar panels.

6. Conclusions

The aim of the present study was to identify areas with the highest SP values in the urban municipality of Mrągowo for the installation of PV panels. The measurements and calculations were performed based on open-source data and expert information with the use of geoprocessing tools in the ESRI ArcMap software. A raster layer representing SP values was generated based on DLCM data and information on the location of buildings within the administrative boundaries of the urban municipality of Mrągowo. Digital Land Cover Model data were also analyzed to eliminate locations with a high degree of shading. Roof pitch and orientation relative to the cardinal directions were also considered in the analysis. All of the above factors significantly affect the amount of sunlight reaching building roofs. A sufficiently large and unobstructed roof area is also required for the installation of PV panels. The results of the analysis were used to select buildings with SP higher than 800 kWh/m² which is the minimum value that guarantees a return on investment. Buildings in Mrągowo were divided into five categories based on their SP values. The results of the raster data analysis were also used to identify the optimal locations for the installation of solar PV panels with a classification accuracy of one pixel. The study revealed that PV panels can cover a maximum area of 1,713 m² and that the generated energy will cover 463% of the residents' annual energy demand. These observations will facilitate the choice of prime locations for developing micro-scale solar power systems. The results of this study provide valuable inputs for private investors and businesses. They can also support state agencies and local governments in implementing environmentally friendly solutions in local zoning plans and land management policies.

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