MONTENEGRO ENERGY GROWTH AND ACCELERATION (MEGA)

SMART SITING GUIDE: METHODOLOGY FOR PREPARATION OF LOW-CONFLICT MAPS FOR SOLAR AND WIND POWER PLANT DEVELOPMENT IN MONTENEGRO

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1. Introduction

The urgent need to transition to cleaner, renewable energy sources has never been greater, as fossil fuel consumption continues to drive greenhouse gas emissions and the world faces worsening climate impacts. At the same time, a global biodiversity crisis is unfolding – species and habitats are vanishing at alarming rates, and these losses undermine the ecosystems humanity relies on for food, water and resilience to climate shocks. The path forward must address both challenges in tandem.

Solar and wind technologies – mature, low-cost and scalable – offer a practical route away from fossil fuels. Montenegro currently satisfies about 45.5% of its energy needs from renewables and has set ambitious targets to reach 50% renewables by 2030 through leveraging strong solar and wind potential. While developer interest is high, progress is hindered by financing gaps, lengthy permitting processes and grid capacity constraints. These challenges risk creating delays or cancellations. These risks are magnified when projects intersect with other land uses and values.

As a Contracting Party to the Energy Community and a European Union (EU) accession candidate, Montenegro is committed to aligning national law with the EU energy, environmental and climate acquis. The most recent revision of the EU's Renewable Energy Directive (RED) introduced the concept of Renewables Acceleration Areas (RAAs) – designated zones intended to speed up the rollout of renewable energy projects. Within RAAs, projects are presumed to have limited environmental impact, allowing them to bypass full environmental impact assessments and benefit from simplified and faster permitting processes. Under the revised RED, artificial and built surfaces should be prioritized for RAA designation, ensuring that greenfields remain available for other uses to the greatest extent possible.

To support the RAA implementation process in Montenegro and help the country achieve its renewable energy targets while preserving its status as an ecological state, The Nature Conservancy (TNC) and Eco-team launched the Montenegro Energy Growth and Acceleration (MEGA) project in October 2024. Implementing TNC's smart siting approach, MEGA has developed a low-conflict solar and wind siting scenario for the entire country by mapping the highest-priority areas for solar and wind development that minimize environmental and social impacts. This initiative follows a pilot mapping project of the Nikšić municipality, which demonstrated substantial low-conflict solar and wind potential and highlighted the value of data-driven planning for reducing the risk of project delays.

Key national institutions across the energy, spatial planning, environment and financial sectors have supported the MEGA study through data sharing and participation in the project's advisory committee. The resulting maps provide a practical planning tool for stakeholders at all levels – from developers and grid operators to financial institutions and decision-makers – and can inform permitting decisions, investment prioritisation, and national energy generation and grid planning processes.

This document aims to present the methodology used to map the optimal areas for development of solar[1] and wind power plants in Montenegro, taking into account legal, technical, environmental, cultural and socio-economic aspects.

For the purpose of identifying optimal locations for the development of solar power plants and wind farms, the methodology starts from the legal and biophysical constraints on land use, thereby first identifying the areas that cannot be used for this purpose. Raw potential is defined by global solar irradiation, average wind speed and wind continuity. However, experience derived from the development of renewable energy source (RES) projects in Montenegro proved the great importance of infrastructure availability at the site, especially related to power grid connection. Therefore, the methodology considers the availability of the power grid (location, capacity), roads and electricity consumption centres in order to estimate development potential. Five relevant criteria have been adopted to evaluate the development potential of solar and wind power resources. The main results are development potential maps for solar and wind power where the level of potential is classified as:

- Very low;
- Low;
- Medium;
- High.

After evaluating solar and wind resource availability with respect to legal and technical circumstances, the intensity of land-value conflicts caused by the construction and operation of solar power plants and wind farms is analysed and evaluated.

The methodology was developed based on the available georeferenced data covering:

- Natural values;
- Cultural values;
- Socio-economic values.

These values were further differentiated through seven separately analysed criteria, which were then evaluated according to the proposed algorithm and finally combined into a resulting map showing the intensity of conflicts, categorised as:

- Low conflict;
- Medium conflict;
- High conflict.

By cross-referencing the results with maps that represent the development potential, the final maps clearly identify optimal locations for the construction of solar power plants and wind farms, taking into account both the availability of resources and the low conflict level. In this way, a foundation is created for managing the development of renewable energy sources in a sustainable manner.

The following chapters present the available data, data sources and the algorithm used for analysing and evaluating the selected criteria, as well as for their integration and the creation of the final conflict maps.

[1] Solar power in this document refers to photovoltaic (PV) solar power plants.

2. Input data

The application of the methodology involves the use of a broad set of data of different formats and from a large number of sources. This affects data reliability, making it necessary to process and validate the data before applying the methodology. Since the final result is a map, the foundation of the data consists of georeferenced datasets from various fields that comprehensively cover all desired aspects: legal constraints, technical potential (availability of solar and wind resources, biophysical constraints, grid and road infrastructure), the environment, culture and socio-economic aspects. The following data were used:

- Basic maps
  - Topographic maps (1:25,000 and 1:50,000)
  - Orthophoto imagery
  - Web-accessible basemaps
  - Digital Elevation Model (DEM)
- Legally defined constraints of space usage converted into maps
  - Transmission grid (110 kV, 220 kV and 400 kV, existing and planned)
  - Distribution grid (35 kV)
  - Substations
  - Existing and planned road infrastructure
  - Railways
  - Zones of sanitary protection
  - Rivers
  - Lakes
  - State borders
  - Protected areas
  - Areas of cultural and historical significance
  - Areas of touristic significance
  - Telecommunication infrastructure
  - Settlements
  - Airports
  - Areas of military interest
- RES potential maps
  - Global solar irradiation (250x250 m resolution)[2]
  - Average wind speed and continuity at an altitude of 100 m (50x50 m resolution)[3]
- Natural values
  - Legally protected areas in the third protection zone (National Parks, Nature Parks, Natural Monuments, etc.)
  - Emerald Network areas
  - Important Bird and Biodiversity Areas (IBA) and Special Protection Areas (SPA)
  - Ramsar wetlands
  - Proposed Natura 2000 Type A and B habitats, and Natura 2000 priority habitats for the EU
  - Areas proposed for protection
  - Bat-relevant habitats
- Cultural values
  - Religious sites
  - Potential cultural heritage sites

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[2] https://globalsolaratlas.info/

[3] https://map.neweuropeanwindatlas.eu/

- Socio-economic values
  - Settlements designated as urban areas (based on the Spatial Plan of Montenegro)
  - Other/rural settlements (based on the OSM/Google Maps), including:
    - Settlements within the areas of special purpose spatial plans (referring to coastal zones and national park territories)
    - Settlements outside the areas of special purpose spatial plans
  - Tourist-recreational areas (ski resorts)
  - Agricultural land (arable land, meadows and pastures)
  - Forest land (high forests, types of coppice forests, shrubland, barren land)[4]
  - Web-available data related to landscape values (Flickr API)

All data were converted into SHP format. The available datasets come in different formats and require varying levels of additional processing prior to use. The data sources are:

- Ministry of Agriculture, Forestry and Water Management
  - Agricultural land and its classification data
  - Forest land and its classification data
- Ministry of Ecology, Sustainable Development and Northern Region Development
  - Data regarding natural values
- Ministry of Energy and Mining
  - Data regarding mining sites
- Ministry of Spatial Planning, Urbanism and State Property
  - Spatial data for land-use planning at the national and local level (after data processing, some of this was assessed as having a low level of accuracy or reliability and other specific ministries had to be contacted to attain better data)
- Ministry of Tourism
  - Data on zones designated for tourism purposes
- Environmental protection agency
  - Data regarding natural values
- Administration for managing forests and hunting grounds
  - Forest land and its classification data
- Real estate administration
  - Part of the data on land use designation
- Water administration
  - Data regarding water sources, water bodies and watercourses
- Administration for protection of cultural property
  - Cultural values data
- Railway authority – government of Montenegro
  - Railway infrastructure data
- Transmission system operator
  - Transmission grid infrastructure and development plans
- Distribution system operator
  - Distribution grid infrastructure and development plans

The applied spatial resolution and the use of available national and international databases correspond to the strategic level of analysis and make it possible to identify broader zones of potential conflict. At the same time, spatial generalisation and the uneven frequency of updates for certain

[4] Data from the competent ministry were used here, as well as publicly available web data (Copernicus Land Monitoring Service).

input layers limited the possibility of precise ecological interpretation at the micro-location level. Therefore, the results should be interpreted as an indicative framework that requires additional spatial analyses and field verification during the project phases. Particularly noteworthy here are the data on forests, settlements and valuable landscapes. For the purpose of sustainable land-use planning, it is necessary to update the forest cadastre, as well as to prepare landscape studies where specific micro-locations are concerned.

3. Algorithm

The methodology is represented by the following steps:

- Step 1: Create constraint maps
  - Identification of legal, biophysical or resource constraints for RES development;
  - Exclusion of non-suitable areas.
- Step 2: Create development potential maps
  - Calculation of potential resource yield;
  - Estimation of potential resource development suitability based on potential resource yield and feasibility criteria (e.g proximity to major roads, power lines and consumption centres, availability of power grid connection capacity).
- Step 3: Create conflict maps
  - Selection of criteria
    - Selection of sensitivity (conflict-intensity) criteria based on available georeferenced data;
    - Selection of sub-criteria within each criterion, where applicable (depending on data availability).
  - Evaluation of individual criteria
    - Depending on the type of available georeferenced data (point or polygon) and their relevance to the observed criterion, buffer zones are selected for each criterion (for each criterion, available data and practical experience are analysed, based on which the buffer zones are proposed);
    - A score is defined for each zone. A scoring range from 0 to 5 is adopted, where a score of 0 means that there is no expected negative impact for the observed criterion and a score of 5 means that there is a likely high negative impact, i.e. a high conflict intensity regarding the construction of solar power plants and wind farms in relation to the observed criterion. It should be emphasised that, due to differing data availability and the varying nature of the criteria, not all scores within the proposed range necessarily need to be used (at minimum, scores 5 and 0 are used).
  - Combining the criteria to create the resulting conflict map
    - Selection of weighting coefficients used to assess the relative importance of the criteria;
    - Application of the formula that combines the conflict-intensity scores by criterion with the selected weighting coefficients.
- Step 4: Combining conflict maps and development potential maps
  - Combining zones evaluated as low conflict zones with development potential maps;
  - Filtering of isolated small areas;
  - Calculation of areas assessed as having high and medium development potential and estimation of potential.

3.1 Constraint maps

Areas which are not suitable for wind and solar siting should be identified and excluded from further analysis. Constraints which can lead to the exclusion of certain zones include the following:

- Legal – National legislation which regulates nature protection, infrastructure development, spatial planning and other relevant sectors can prohibit or restrict RES installation in some areas. Such areas may include national parks, strict reserves and other categories of protected areas where economic activities and any other activities which do not contribute to biodiversity conservation are prohibited.

- Existing infrastructure – Settlements (in urban and rural areas) and corridors along or around built infrastructure such as power lines, existing power plants, roads and airports are also not suitable for RES installation.
- Biophysical – The slope and orientation of the terrain is important for planning future RES projects (steeper slopes affect the complexity of the planned power plant). Certain types of land cover and features (e.g. rivers and lakes) are not suitable for RES installation.
- Economic constraints – Average wind speeds and wind constancy are the basic measures of the availability of the raw energy potential of a given area, and based on experience from previous studies as well as from the development of wind power projects, lower thresholds for these values have been adopted as the benchmark for the economic feasibility of a project.

An overview of constraints for RES suitability mapping is given in Table 3.1. The boundaries of specific areas/zones (e.g. protected areas, touristic/recreational zones and military zones) define the areas that are excluded from further analysis for suitability of RES development due to legal constraints. There are no legal provisions requiring additional zones around excluded areas where construction of solar power plants (SPP) and wind power plants (WPP) is forbidden. According to national regulations, there is no defined protection zone around cultural, historic and religious sites that would prohibit construction of SPP and WPP in their proximity.

Table 3.1 Overview of constraints for RES suitability mapping

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Legal constraints *Protected areas according to national legislation where construction is prohibited (IUCN categories); Areas designated as cultural heritage areas and archaeological sites; Specially designated areas (military zones, touristic and recreational zones (hotels, touristic settlements, camps, open air sport facilities))*					
Protected areas	feature	0	m	Law on nature protection ("O.G of Montenegro", No. 54/2016 and 18/2019)	Construction of facilities is forbidden in the first and second protection zone of the protected areas in accordance with Article 31 of the Law.
Cultural, historic and spiritual sites	feature	0	m	Law on cultural goods protection ("O.G of Montenegro", No. 49/2010)	In accordance with Article 4 of the Law, actions and activities that can change the appearance, property, personality, the meaning or significance of cultural property should be prevented. The protection zone adjacent to the cultural good is not defined. It will be further analysed as part of social/cultural values mapping. The majority of sites are available as points without buffer zones defined. However, there are some protected areas which will be included.
Recreational areas	feature	0	m	Spatial plan	In accordance with the spatial plan the purpose of the zone is recreation.

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Touristic zones	feature	0	m	Spatial plan	In accordance with the spatial plan, the purpose of the zone is the development of tourism.
Military zones	feature	0	m	Law on Defence ("O.G of Montenegro" No. 47/2007, 88/2009, 14/2012, 2/2017, 46/2019)	Article 44 of the Law prohibits access to military facilities and facilities designated as facilities of special importance for defence, as well as construction in the zones adjacent to these facilities, without the consent of the Ministry. The width of the zone adjacent to defence facilities is not specified.
Current Infrastructure *Settlements (in urban and rural areas) and corridors along or around infrastructure such as power lines, roads and airports*					
Settlements/Buildings	feature	0		Spatial plan	In accordance with the spatial plan, settlement areas are characterised by a high population density and a built infrastructure environment which is not suitable for larger SPP/WPP. Rural settlements are not taken into account due to low data reliability.
Roads				Law on Roads ("O.G of Montenegro" No. 82/2020)	In accordance with Article 92 of the Law, the width of the protection zone in which mines and quarries, construction of lime and brick quarries, extraction of gravel and sand, construction of gravel pits or clay pits, construction of industrial buildings and facilities, as well as similar facilities cannot be carried out without the consent of the administration or local administration authorities is: 60 meters next to highways, expressways and main roads; 40 meters next to regional roads; and 20 meters next to municipal roads, measured from the outer edge of the road strip. All existing road infrastructure and future highway corridors are taken into account.
Highways	feature + buffer	60	m		
Major	feature + buffer	40	m		
Minor	feature + buffer	20	m		
Airport (airfield)	feature	0	m	Law on Air Traffic ("O.G of Montenegro" No. 30/2012)	In accordance with Article 44 of the Law, construction and installation of aviation obstacles on the territory of the airport, including facilities and technical means of air navigation, construction and installation of aviation obstacles outside the airport area which may affect the safety of air traffic, as well as their marking and maintenance, is carried out in accordance with the decision of the Ministry. The protected zone outside of the airport area is not specified.

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Railways	feature + buffer	25	m	Law on Railway ("O.G of Montenegro" No. 27/13 and 43/13)	In accordance with Article 4 of the Law, the "infrastructure zone" is a zone on both sides of the railway, to a width of 25 m, counting from the axis of the end tracks, which serves for the use, maintenance and technological development of railway infrastructure.
Power lines				Rules for construction of transmission and distribution powerlines	Transmission line (400 kV, 220 kV and 110 kV) – The protection zone on both sides is in relation to the vertical projections of the end conductors. Distribution line (35 kV) - The protection zone on both sides is in relation to the vertical projections of the end conductors.
Transmission	feature + buffer	40 (400 kV) 30 (220 kV) 25 (110 kV)	m		
Distribution	feature + buffer	10 (35 kV)	m		
Power plants (wind, solar)	feature	0	m	Spatial plan	Locations of existing WPPs and SPPs and those with issued construction permits are given in the form of zones (polygon).
Radio/cell towers (wind only)	feature + buffer	200	m	Rulebook on the width of protection zones and types of radio corridors in which the planning and construction of other facilities is not allowed	The rulebook defines sizes of protection zones depending on the type, power and frequency of the radio centres which are relevant for construction of wind power plants.
Biophysical constraints *Slope of the terrain, elevation; River network, borders of basins and sub-basins, water springs and water sanitation zone; Land use*					
Slope of the terrain	values above				
PV	values above	10	degrees		
Wind	values above	15	degrees		
Water	feature + buffer	15	m	Water Resources Law ("O.G of Montenegro" No. 27/2007 32/2011)	In accordance with Article 10 of the Law, coastal land is a zone of land 15 m wide for waters of state importance and 10 m for waters of local importance from the border of the water land. As a rule, this serves for the maintenance of protective structures and troughs for large water bodies and other activities in water management.
Lakes	feature + buffer	15	m		
Rivers	feature + buffer	15	m		

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
					Also, the first and second sanitary protection zones around water sources are included.
Economic constraints					
Average wind speed (w)	values below	4 m/s			A wind speed below 4 m/s is recognised as an indicator of low wind potential for power plant development (non-feasible).
Wind continuity (k)	values below	1.2			The measurement k is a shape factor of Weibull wind distribution. Higher k corresponds to stable wind and more reliable wind production estimates.

In practical terms, selected constraints are mapped and converted to raster datasets (Figure 3.1) at a resolution of 28x28 m using the nearest neighbour resampling technique, and then combined to produce a binary dataset identifying RE suitability (i.e., 0-unsuitable and 1-suitable).

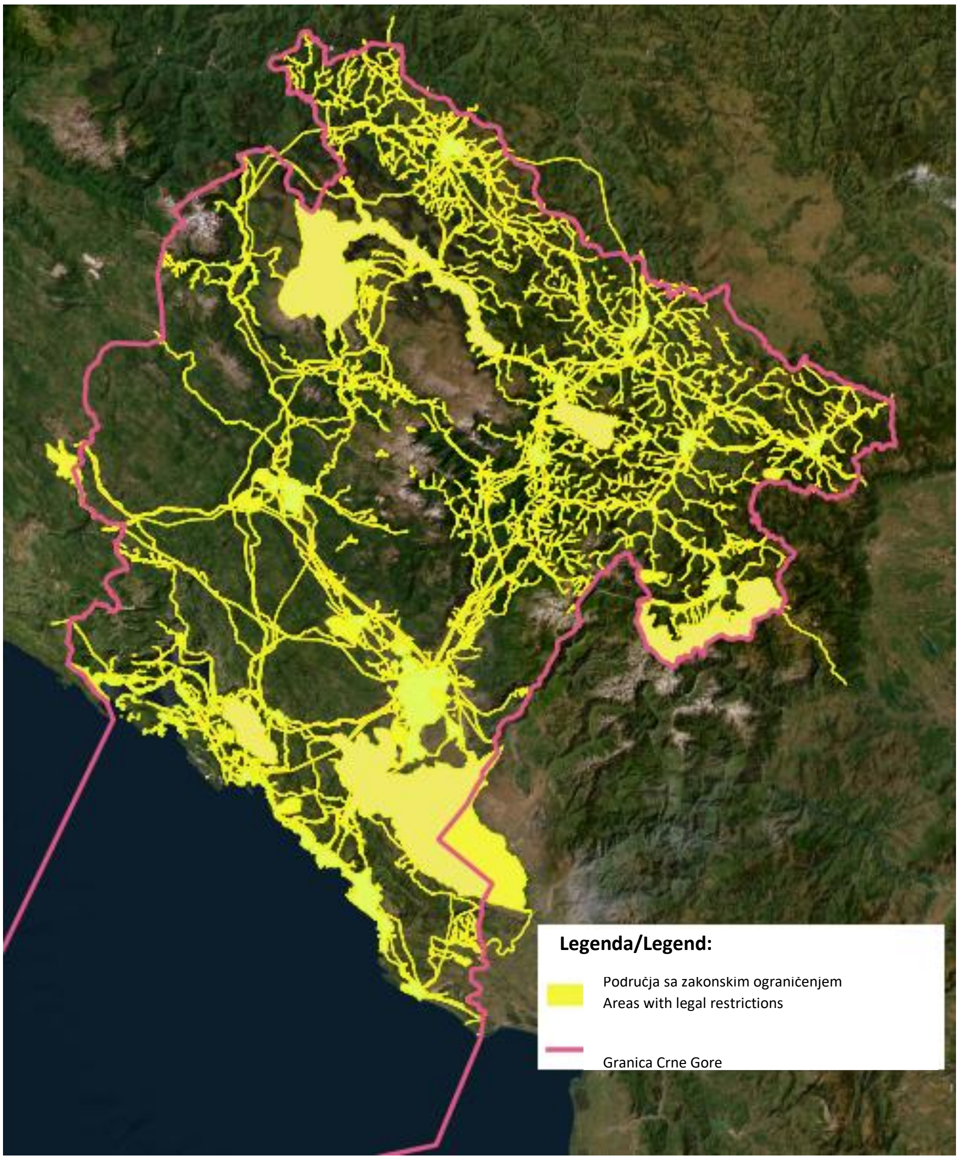

Figure 3.1 Areas with legal restrictions on the construction of energy facilities

This RE suitability map is then refined for both solar and wind based on slope and resource requirements. In addition to zones excluded due to legal and infrastructural constraints, areas with terrain slopes greater than 10° for solar power plants and 15° for wind power plants are also excluded from further analysis, due to the impact that steeper slopes may have on land-use efficiency and the complexity of facility construction (Figure 3.2 and Figure 3.3).

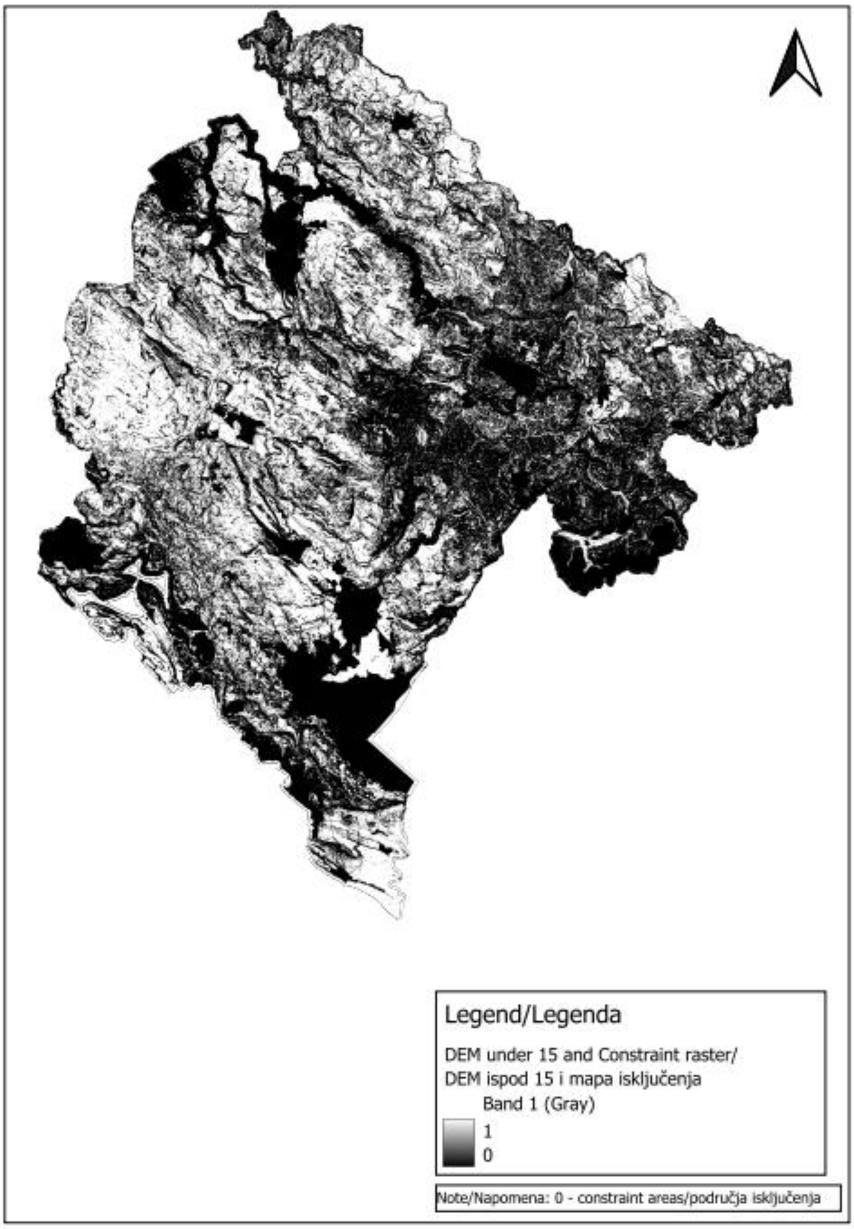

Figure 3.2 Map of areas excluded as candidates for wind power plant development due to biophysical constraints, i.e. slope of terrain more than 15 °

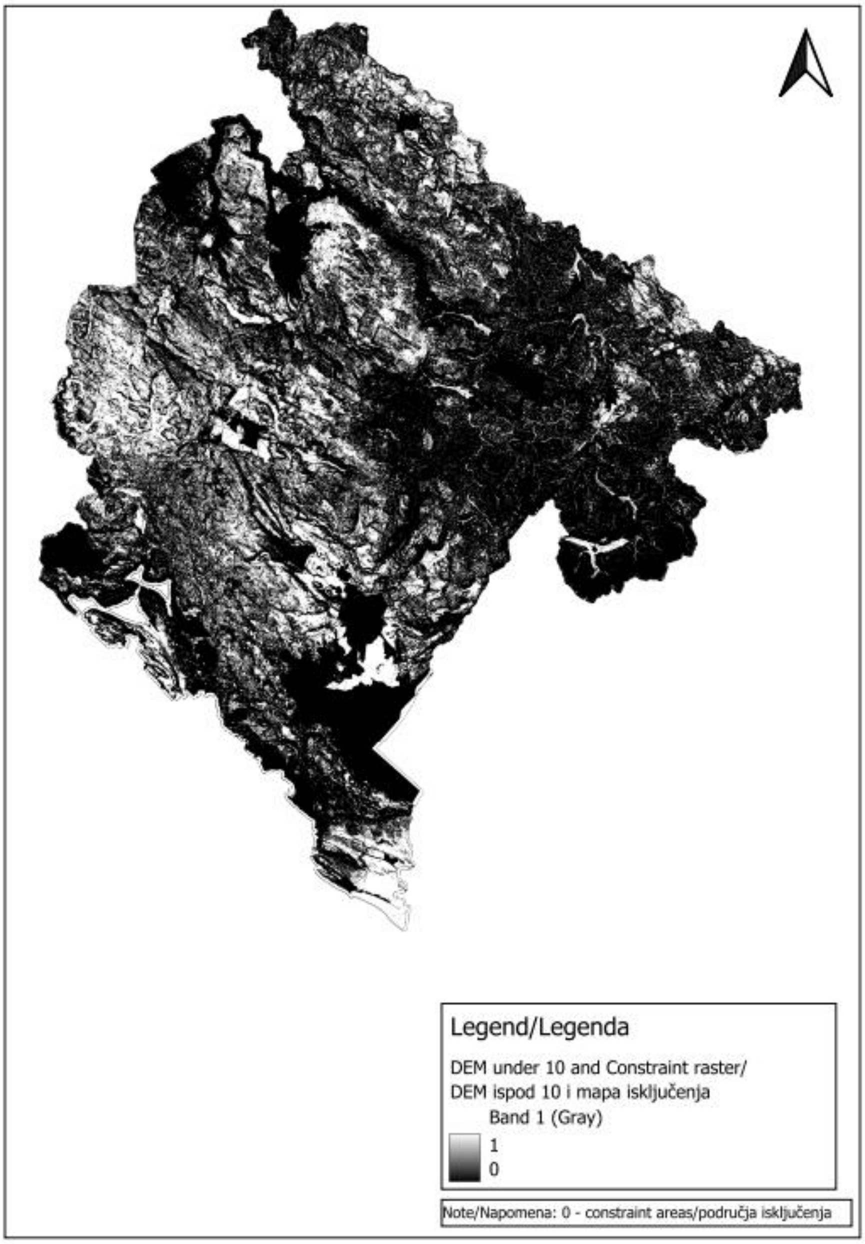

Figure 3.3 Map of areas excluded as candidates for solar power plant development due to biophysical constraints, i.e. slope of terrain more than 10 °

3.2 Development potential maps

RES development potential is assessed based on reliable data on solar irradiation, wind speed and wind continuity. As mentioned earlier, global atlas data are used for global horizontal irradiance (GHI), mean long-term microscale wind speed at 100 m height (w) and Weibull k parameter of the long-term microscale wind distribution. There are additional technical criteria which are recognized as important for reliable assessment of an area's RES potential:

- Grid connection capacity,
- Distance from transmission/distribution lines,
- Distance from consumption centres and
- Distance from roads.

Since all of the mentioned criteria are not of the same importance, it is necessary to estimate their weight. This is done by conducting meetings with experts from the field (governmental institutions from the energy sector, private investors, project developers, etc.) and through interviews.

The algorithm for development potential assessment can be presented by the following equation:

$$P = w_1 \times GHI_n + w_2 \times Cap_n + w_3 \times PGD_n + w_4 \times CCD_n + w_5 \times RD_n$$ – solar

$$P = w_1 \times WP_n + w_2 \times Cap_n + w_3 \times PGD_n + w_4 \times CCD_n + w_5 \times RD_n$$ – wind

$$WP = w \times k$$

Where,

P – quantification of total technical RES development potential (values from 0 to 1 interval)

GHI_n – global horizontal irradiation normalised by maximum value (values from 0 to 1 interval)

WP_n – product of average wind speed and factor k normalised by maximum value (values from 0 to 1 interval)

Cap_n – grid capacity normalised by maximum value (values from 0 to 1 interval)

$$Cap_n = \begin{cases} 0.2, & Cap \leq 100\ MW \\ 0.6, & 100\ MW < Cap \leq 500\ MW \\ 1, & Cap > 500\ MW \end{cases}$$ – transmission power grid[5]

$$Cap_n = \begin{cases} 1, & Cap \geq 5\ MW \\ 0, & PGD < 5\ MW \end{cases}$$ – distribution power grid[6]

It is important to emphasise that the value of *Cap* is determined by a detailed methodology[7] (developed for the purposes of this study) and model for analysing the capacity of Montenegro's existing transmission grid and planned expansions. The aim of the methodology is to ensure the grid's ability to reliably accommodate current demands, integrate renewable energy sources and meet projected growth requirements. Special attention is given to the unique characteristics of Montenegro's energy mix, geographic conditions, and strategic goals for renewable energy integration and cross-border energy exchange.

[5] In the area around transmission grid nodes with radius of 10 km.

[6] In the area around 35 kV grid nodes with radius of 5 km.

[7] Methodology for grid modelling, TNC, 2025.

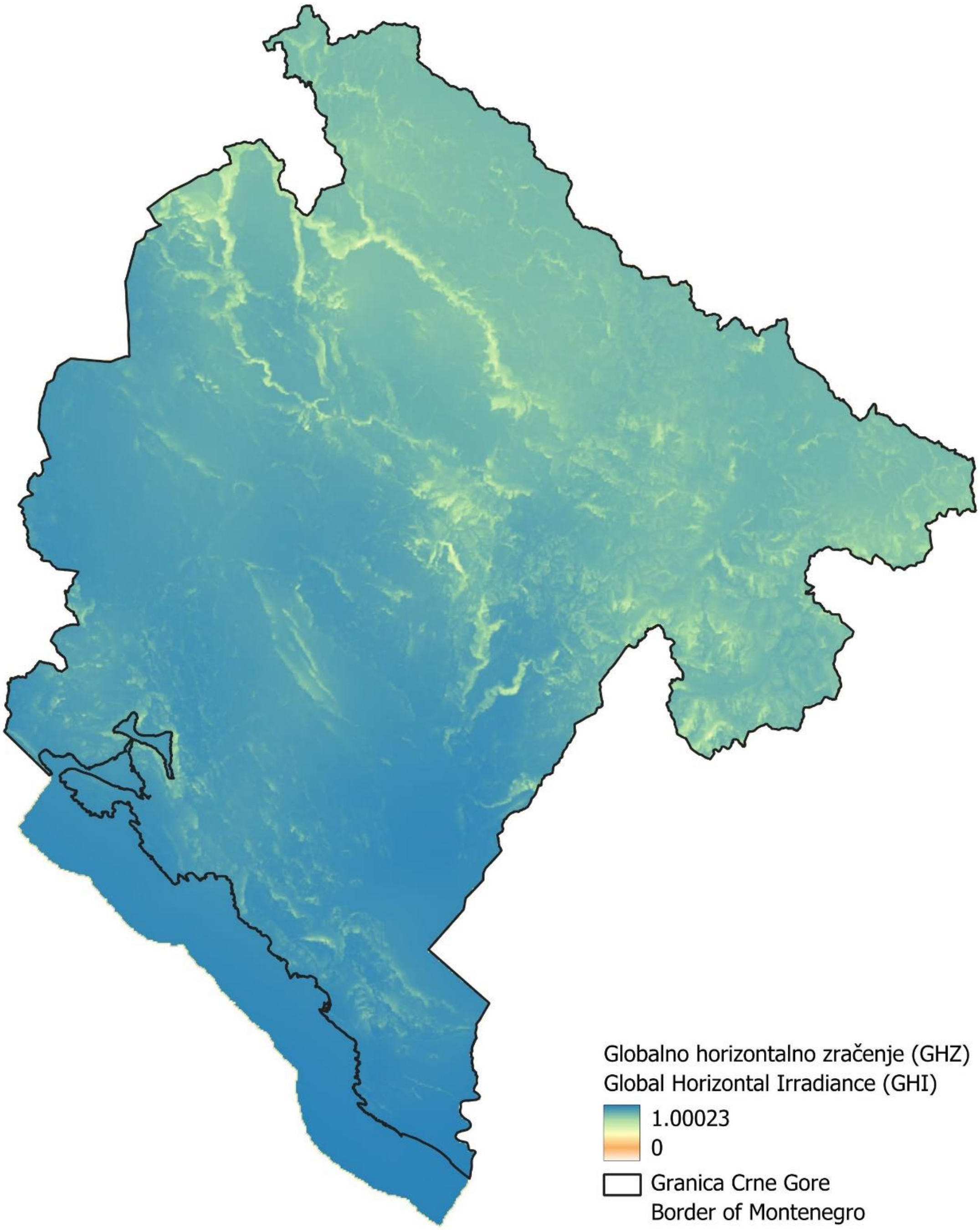

Figure 3.4 Global Horizontal Irradiance

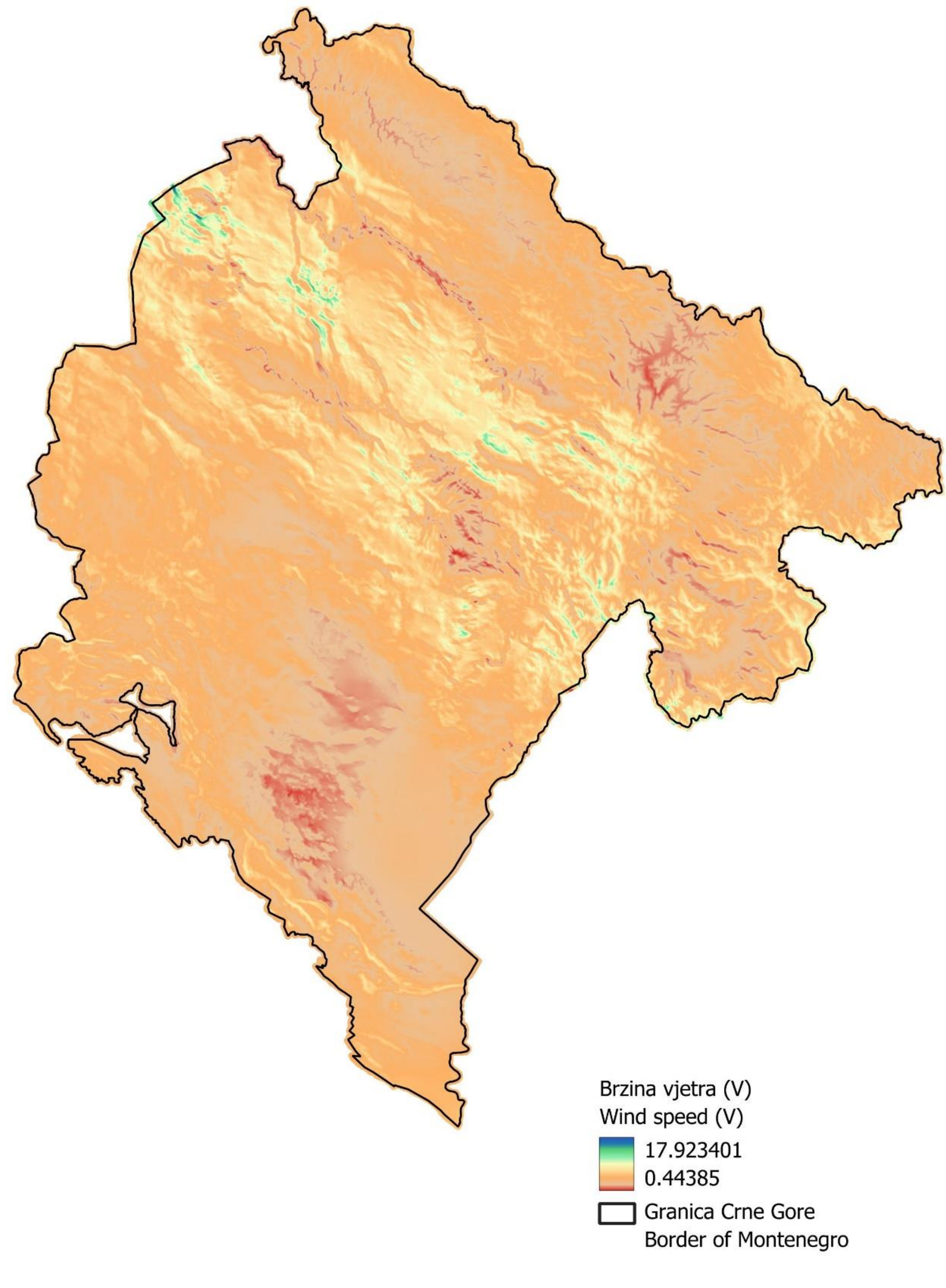

Figure 3.5 Wind speed

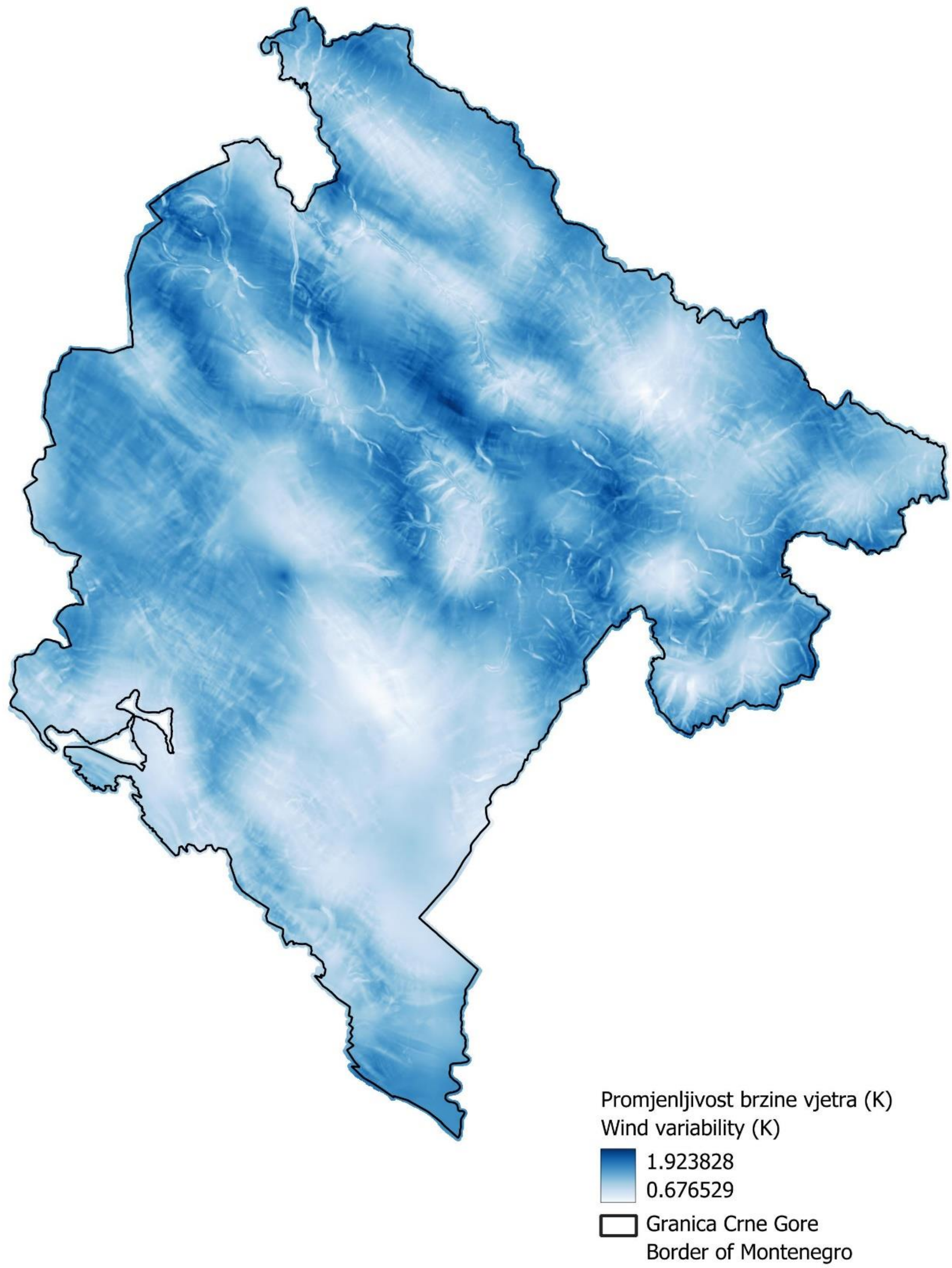

Figure 3.6 Wind variability (Weibull k factor)

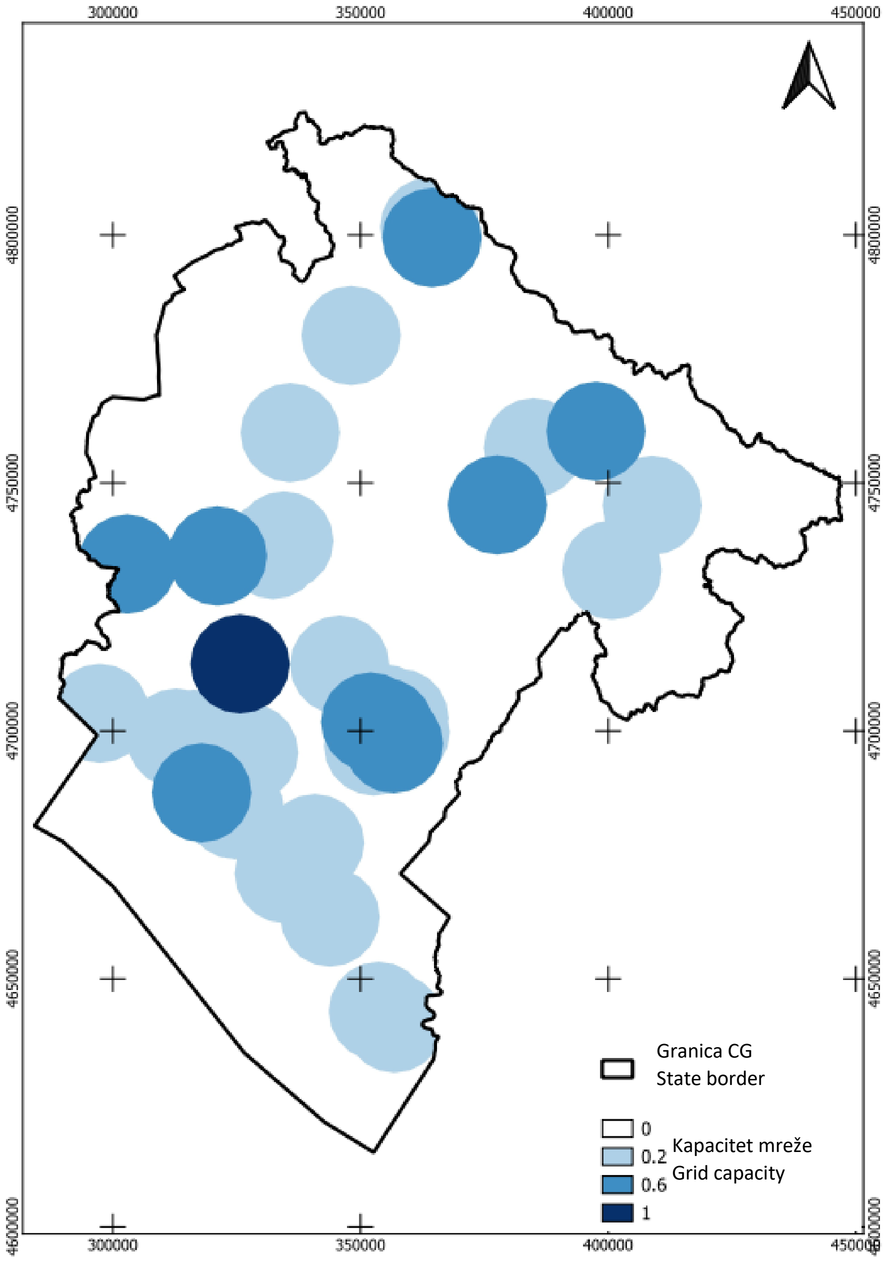

Figure 3.7 Resulting map with values of Cap_n – Criterion Power grid capacity (transmission grid)[8]

[8] The presented grid capacity locations are determined according to the methodology from appendix (5.1).

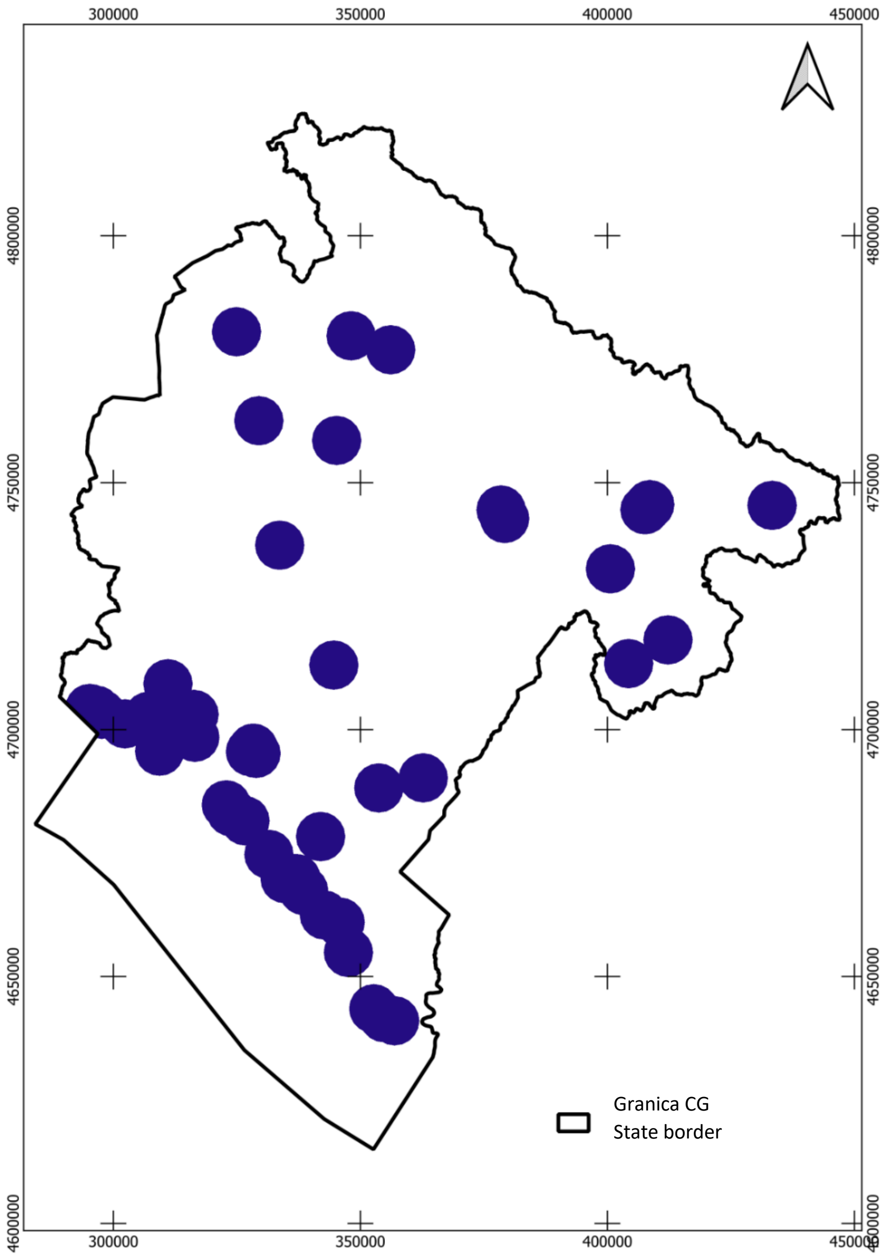

Figure 3.8 Resulting map with values of Cap_n – Criterion Power grid capacity (distribution grid)[9]

PGD_n – distance from power grid normalised by maximum value (values from 0 to 1 interval)

$$PGD_n = \{\frac{(10-PGD)}{10}, PGD \leq 10\ km\ 0, PGD > 10\ km$$ – transmission power grid

$$PGD_n = \{\frac{(5-PGD)}{5}, PGD \leq 5\ km\ 0, PGD > 5\ km$$ – distribution power grid

[9] The presented grid capacity locations are determined according to the methodology from appendix (5.1).

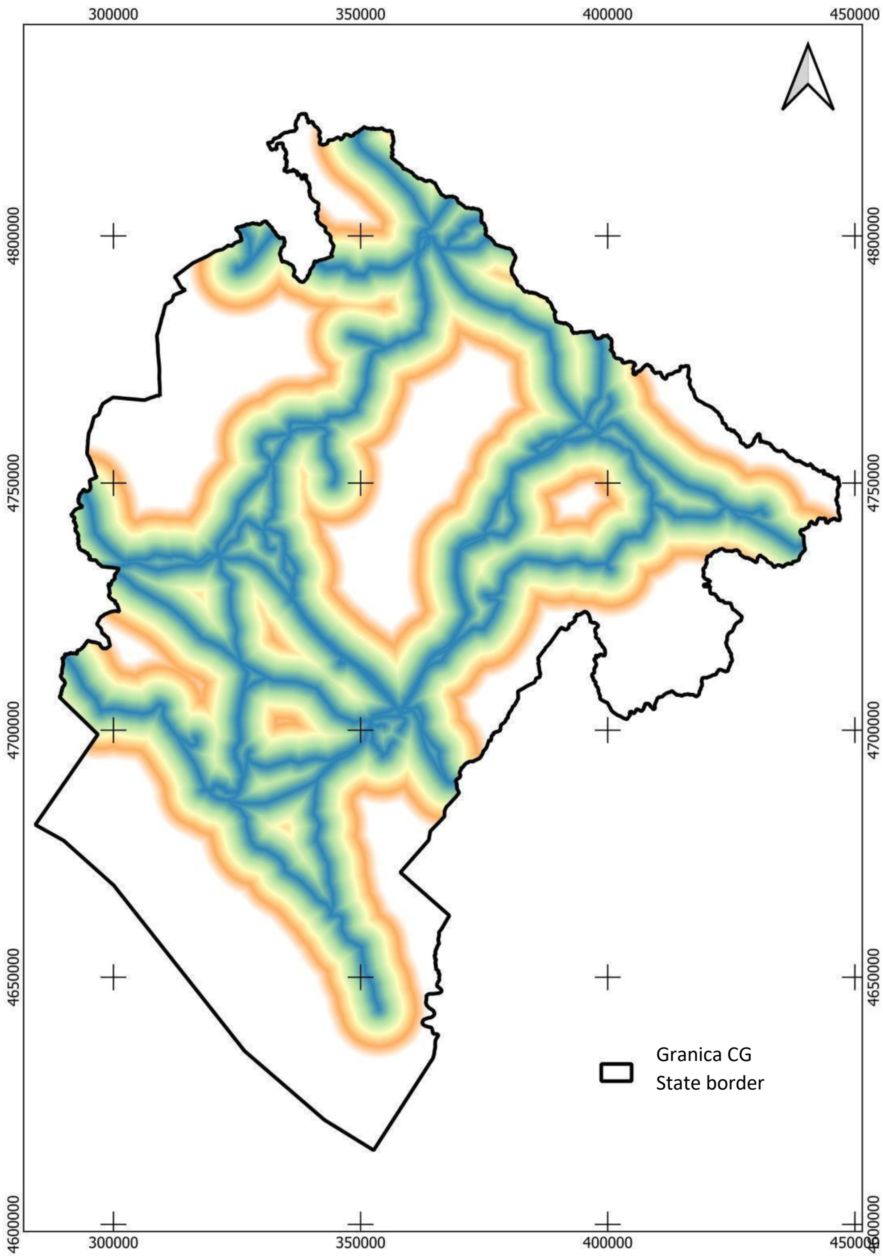

Figure 3.9 Resulting map with values of PGD_n – Criterion Distance from power grid (transmission grid)

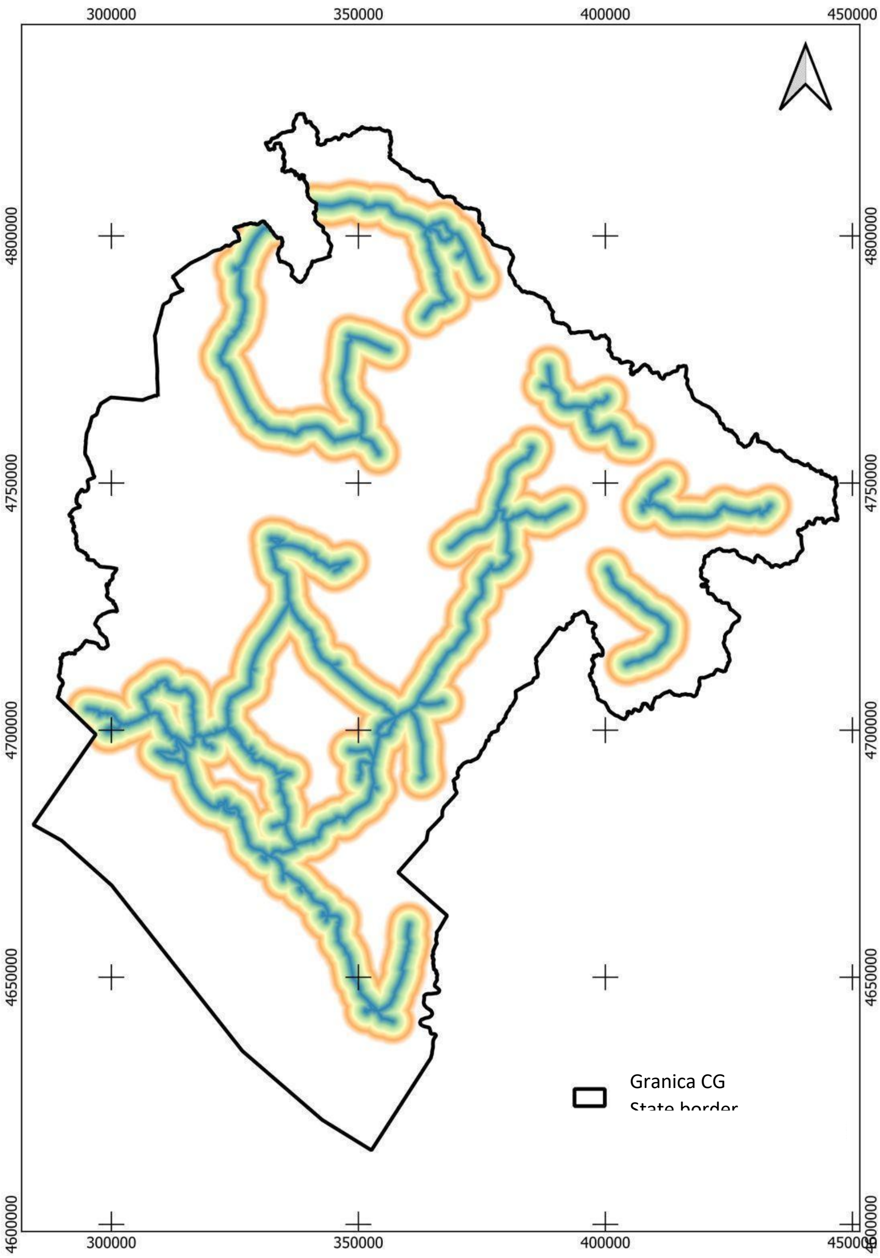

Figure 3.10 Resulting map with values of PGD_n – Criterion Distance from power grid (distribution grid)

CCD_n – distance from consumption centres normalised by maximum value (values from 0 to 1 interval)

$$CCD_n = \{\frac{(20 - CCD)}{20}, CCD \leq 20\ km\ 0, CCD > 20\ km$$

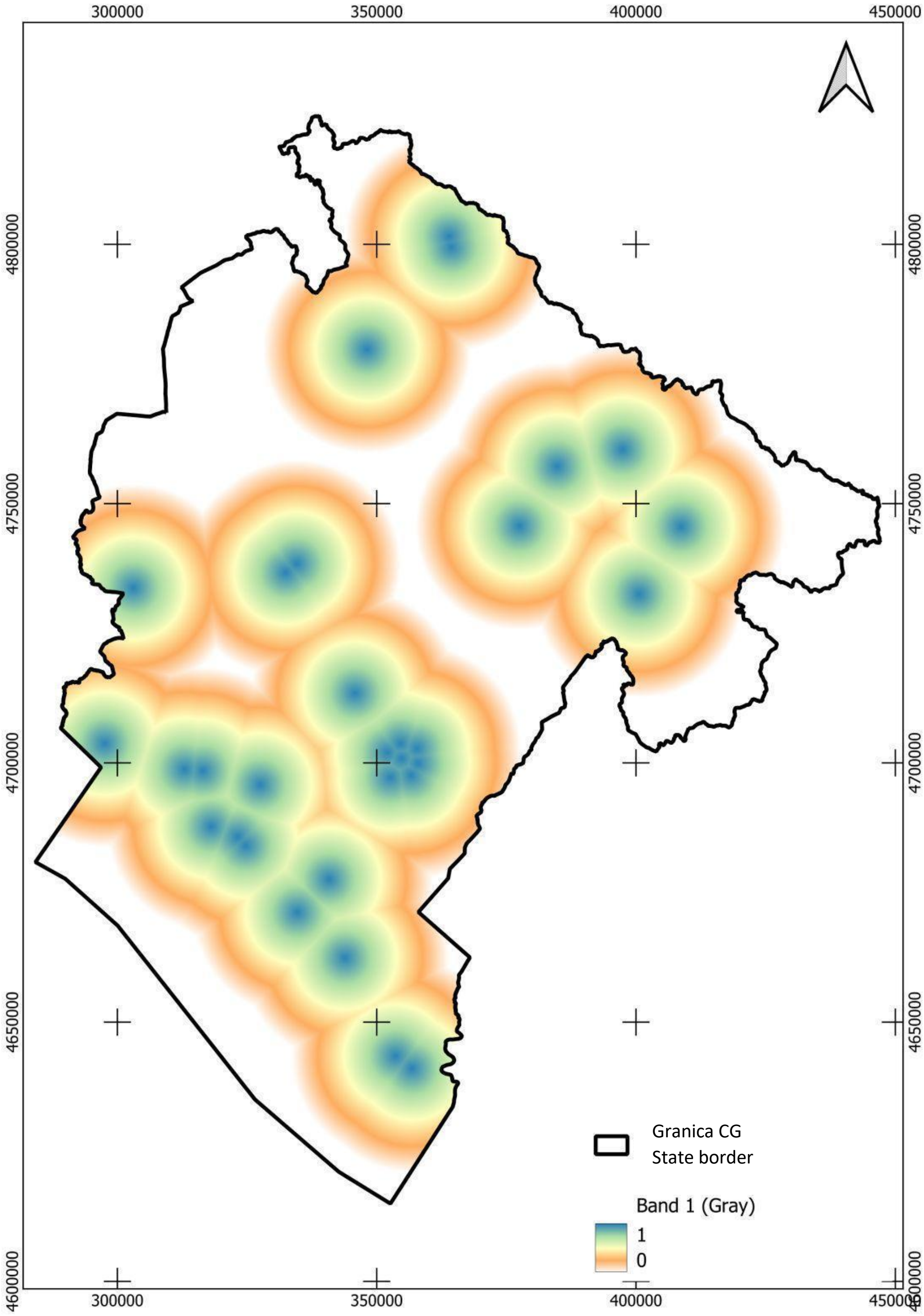

Figure 3.11 Resulting map with values of CCD_n – Criterion Distance from consumption centres

RD_n – distance from road infrastructure normalised by maximum value (values from 0 to 1 interval)

$$RD_n = \{\frac{(10 - RD)}{10}, RD \leq 10\ km\ 0, RD > 10\ km$$

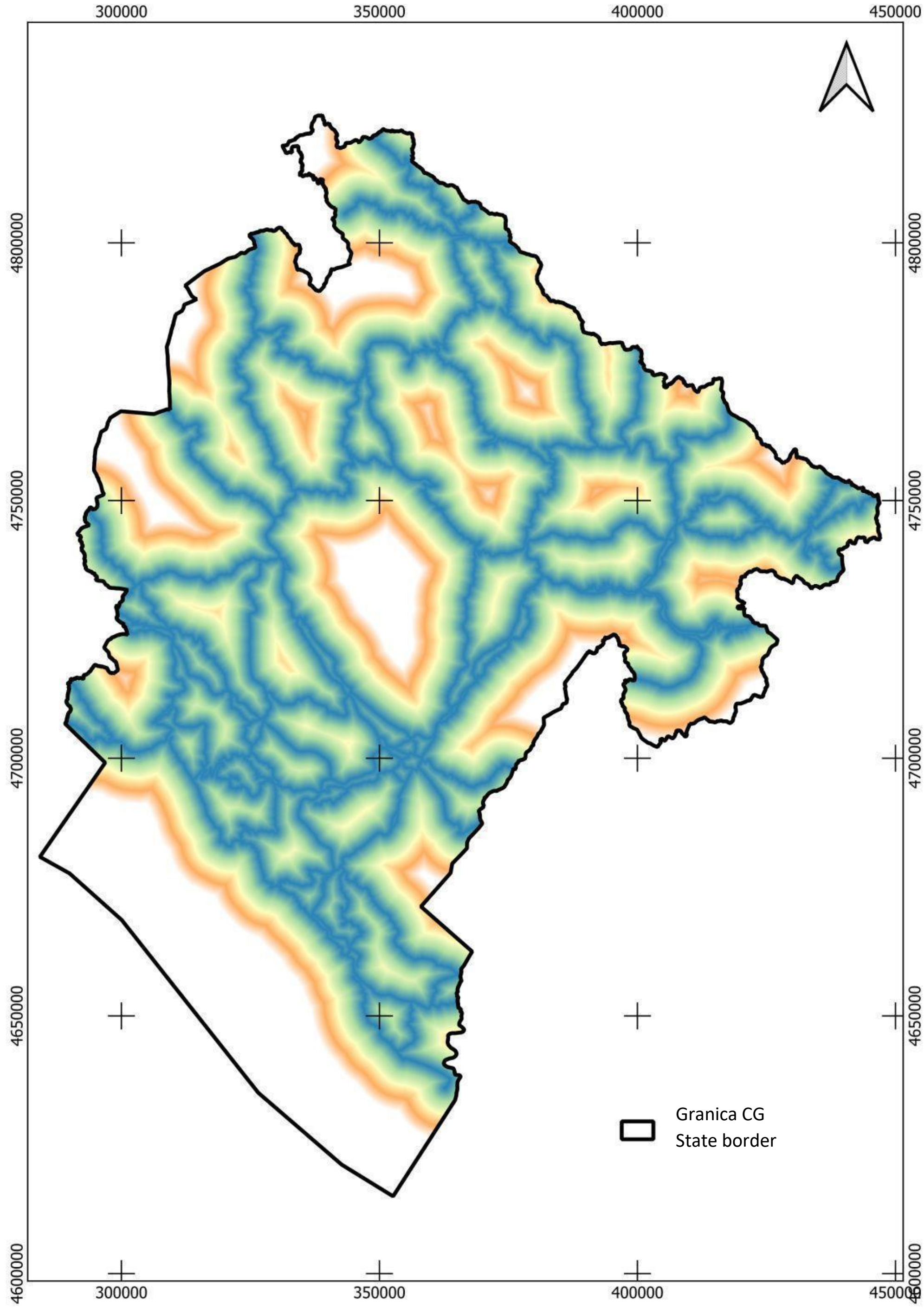

Figure 3.12 Resulting map with values of RD_n – Criterion Distance from road infrastructure

w_i – weighting factors for all criteria (Table 3.2)

Table 3.2 Weighting criteria

Weighting factor	Description	Value
w_1	Solar/Wind resource	0.188035842
w_2	Distance from power grid	0.239625583
w_3	Power grid capacity	0.372013738
w_4	Distance from consumption centres	0.093687873
w_5	Distance from road infrastructure	0.106636964

Weighting factors were determined using the Analytic Hierarchy Process[10] method from structured survey results with a sample size of n=14 energy sector experts. The survey asked experts to rank the importance of different factors on a Saaty scale. The individual preferences of each expert were calculated as dominant eigenvectors and aggregated as normalised mean values to calculate the final weighting factor. Factors related to the distribution power grid are defined differently than the respective factors for the transmission grid due to their significant differences with respect to power grid capacity and feasible connection distance:

- The typical maximum connection capacity of the 35 kV distribution grid in Montenegro is 5 MW.
- The typical connection capacity of the transmission grid in Montenegro starts from 50 MW and can be over 1000 MW (400 kV grid).
- A connection distance over 5 km is highly questionable in terms of feasibility in the case of connection to the distribution grid. On the other hand, this distance is deemed as small when connection to the transmission grid is in question.

When it comes to the electric power grid infrastructure of Montenegro, it should be emphasised that georeferenced data were available for the entire transmission grid and for the distribution grid at the 35 kV voltage level. Since these are technically very different networks in terms of purpose, configuration, geographical coverage, operating characteristics, reliability and capacity, it is clear that they must be considered separately with regard to the potential for connecting new renewable energy sources.

Put simply, the transmission grid can accommodate significantly larger power plants. (Given the current state of Montenegro's power infrastructure, the smallest plant connected to the transmission grid is at least ten times larger than the largest plant connected to the distribution network.) As a result, the analysis of development potential was carried out completely separately for small solar power plants (connected to the distribution grid) and large solar power plants (connected to the transmission grid).

Additionally, connecting small power plants to the transmission grid is financially unfeasible because the cost of the grid connection would be significantly higher than the cost of constructing the power plant itself. By conducting a separate analysis of the development potential for small and large power plants, a more comprehensive approach is achieved. This is especially relevant given that at present active efforts in Montenegro are focused on the construction of small solar power plants (several small plants have already been built, and several more are under construction).

Taking all this into account, it was necessary to apply different weighting factors related to power grid capacity and distance.

Also, due to the limited grid capacity of the distribution power grid, wind potential valorisation is evaluated only for connection to the transmission grid.

After evaluating all the above-mentioned variables using input data from chapter 2, final equations for development potential can be calculated (solar and wind potential). The calculation is performed for each georeferenced pixel from the input map (Figure 3.10, Figure 3.11). As mentioned earlier, total development potential (*P*) takes values from an interval of 0 to 1 where a higher value means higher RES potential. The final result is two maps of development potential (solar and wind). The maps are

[10] Saaty, R.W., 1987. The analytic hierarchy process—what it is and how it is used. *Mathematical modelling*, *9* (3-5), pp.161-176.

made more observable by defining of four potential level categories (Figure 3.12, Figure 3.13 and Figure 3.14):

- Solar potential
    - Very low potential – $P \leq 0.2$
    - Low potential – $0.2 < P \leq 0.4$
    - Moderate potential – $0.4 < P \leq 0.8$
    - High potential – $P > 0.8$
- Wind potential
    - Very low potential – $P \leq 0.2$
    - Low potential – $0.2 < P \leq 0.4$
    - Moderate potential – $0.4 < P \leq 0.7$
    - High potential – $P > 0.7$.

The threshold for high development potential varies slightly between solar and wind projects. The reason is that wind potential is characterised by higher energy production for the same installed power when compared to solar potential. Therefore, more demanding grid connection conditions that would be acceptable for wind power generation projects can be less feasible for solar power generation projects.

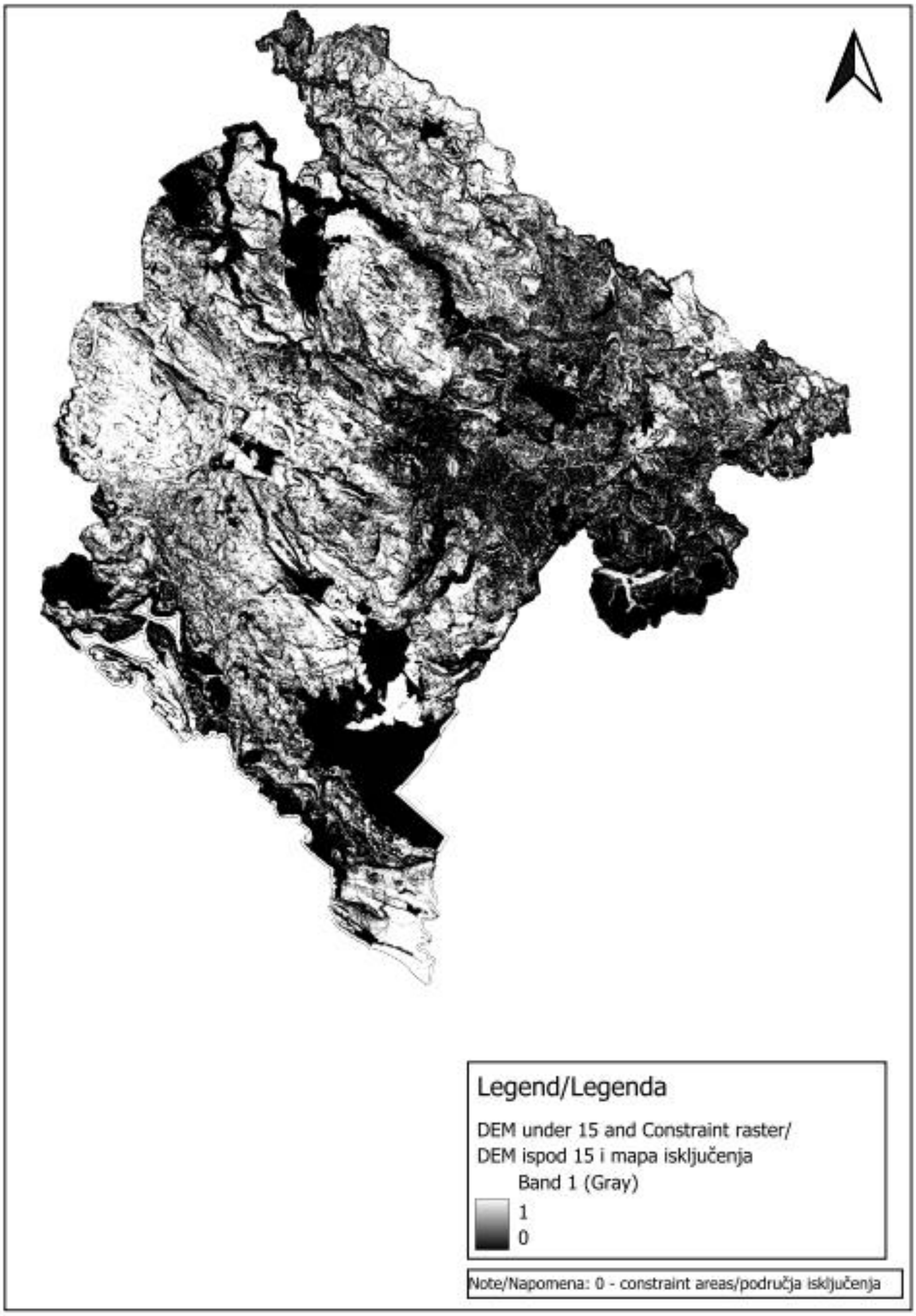

Figure 3.13 Resulting map of development potential after combining all criteria and map with excluded areas – wind development potential

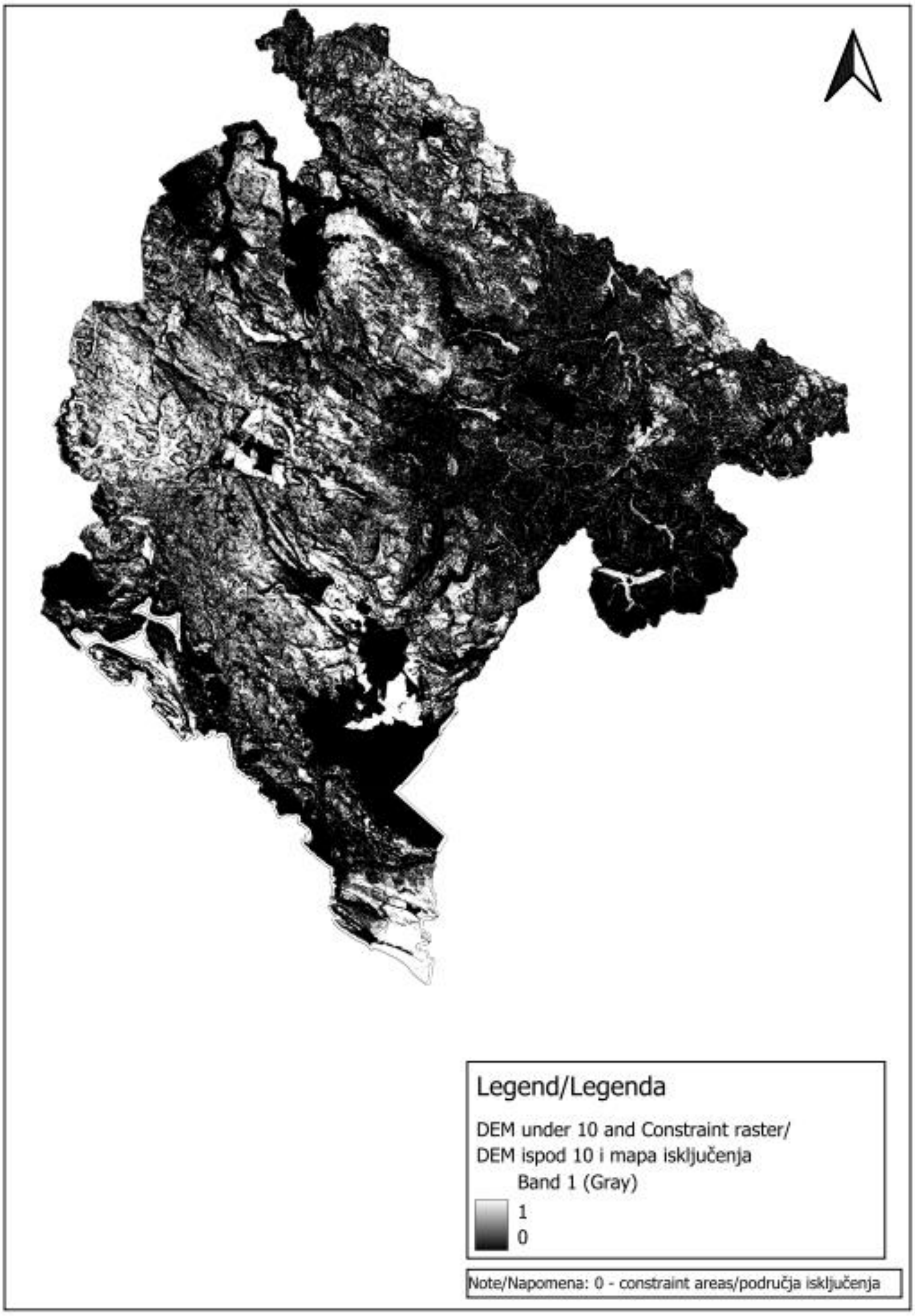

Figure 3.14 Resulting map of development potential after combining all criteria and map with excluded areas – solar development potential

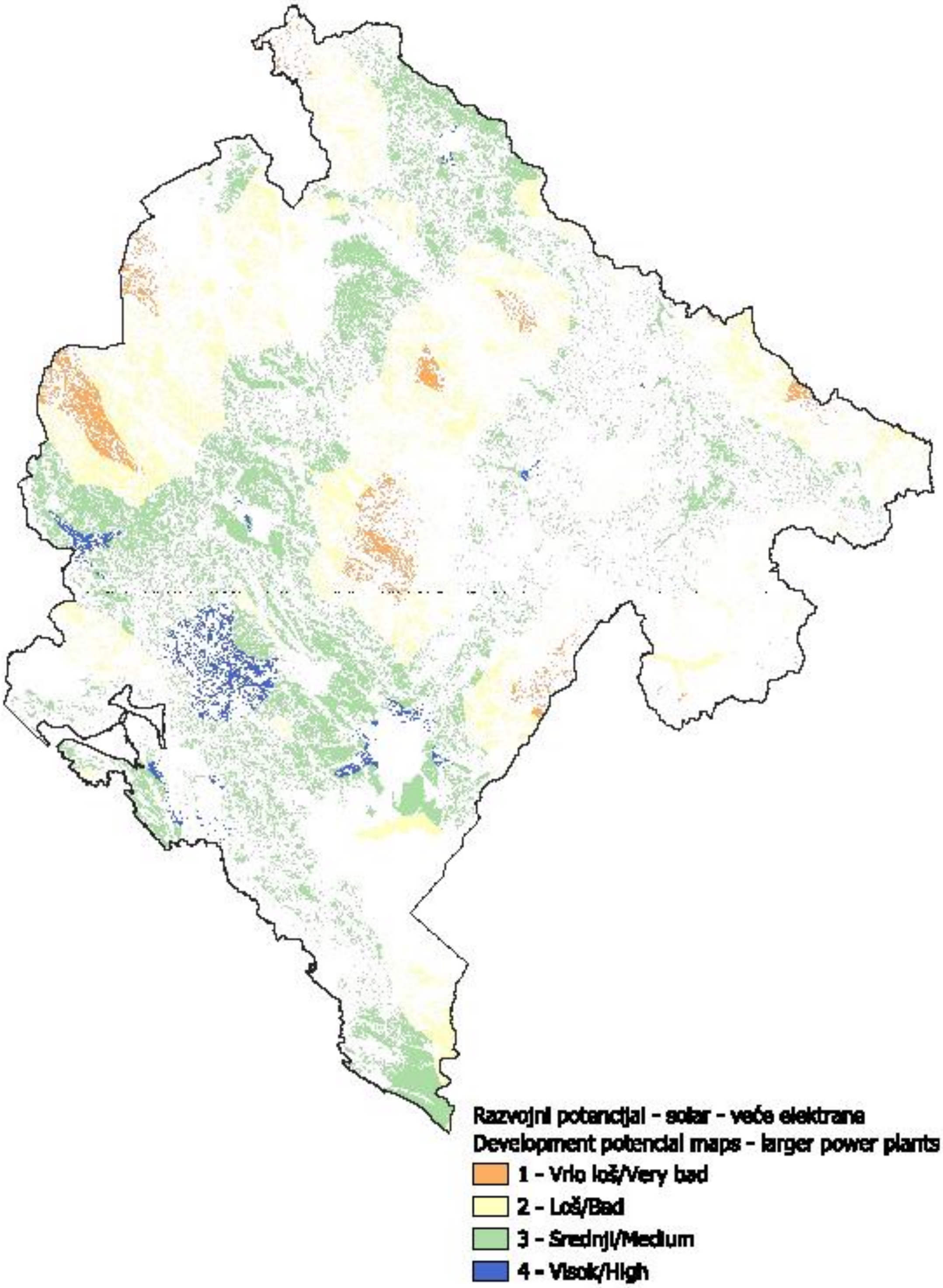

Figure 3.15 Solar power development potential – transmission grid

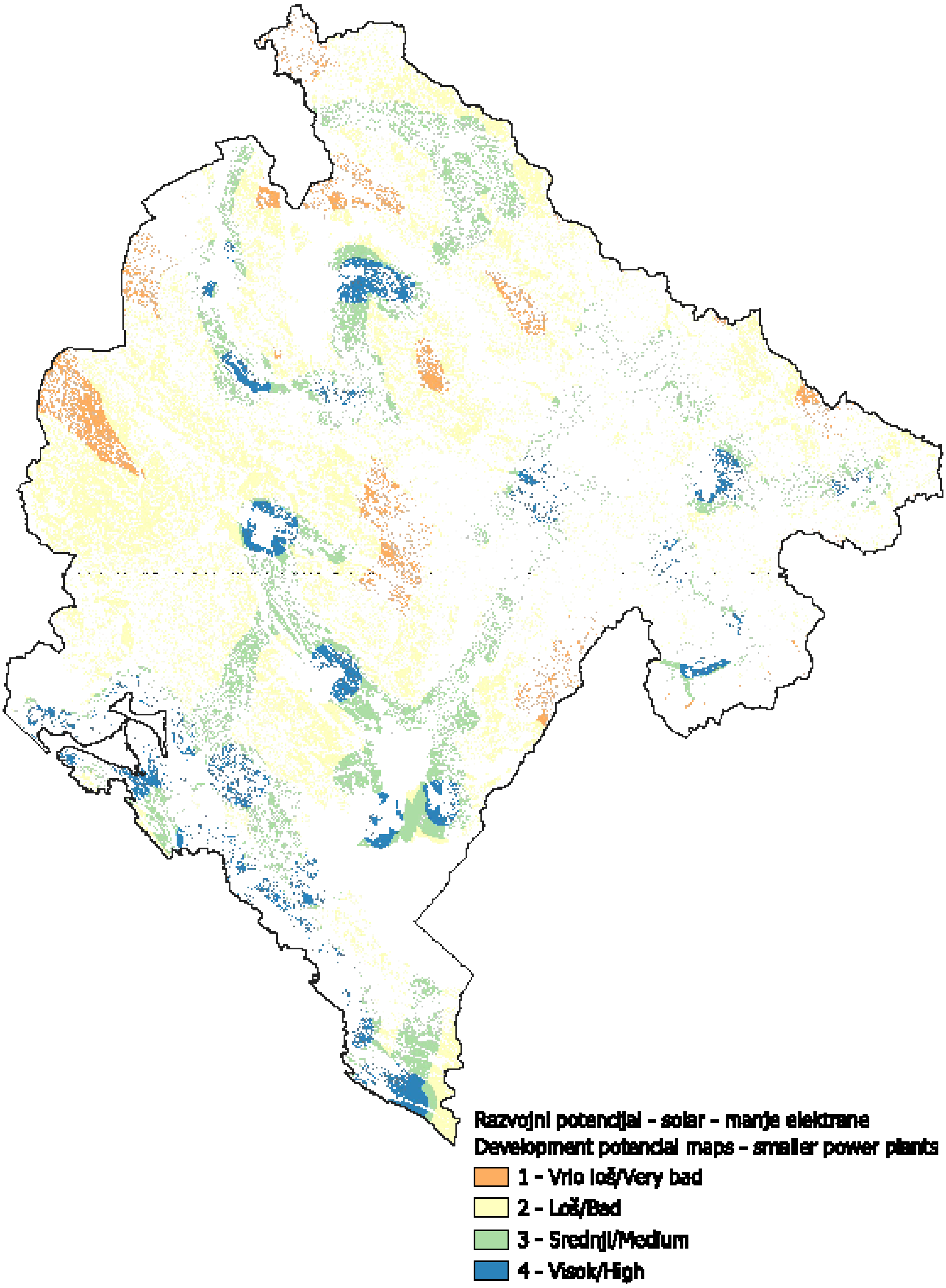

Figure 3.16 Solar power development potential – distribution grid

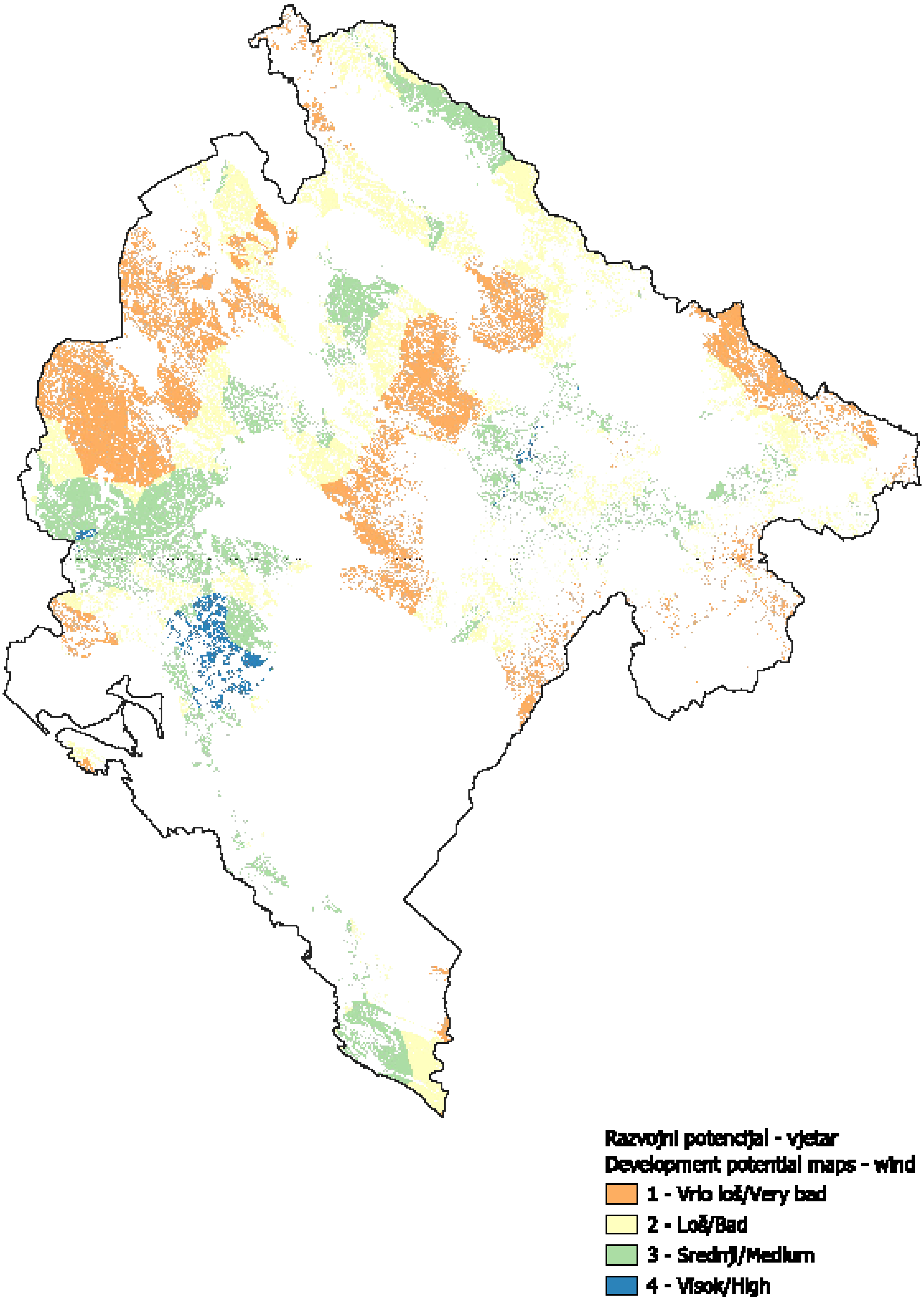

Figure 3.17 Wind power development potential – transmission grid

3.3 Conflict maps

After analysing and processing the available georeferenced data, the following criteria and sub-criteria were identified:

- Areas of ecological value
    - Legally protected areas in the third protection zone (National Parks, Nature Parks, Natural Monuments)
    - Emerald Network areas
    - IBA and SPA
    - Ramsar wetlands
    - Proposed Natura 2000 Type A and B habitats, and Natura 2000 priority habitats for the EU
    - Areas proposed for protection
    - Habitats significant for bats
- Agricultural land
    - Arable land
    - Meadows
    - Pastures
- Forests
    - High forests
    - Coppice forests
    - Shrublands
    - Barren land
- Settlements
    - Urban and rural settlements within areas of special purpose spatial plans (coastal zone and national parks)
    - Other urban and rural settlements
- Tourism and recreational areas
    - Ski resorts
- Landscape-valuable areas
- Cultural and historical heritage
    - Religious sites
    - Potential cultural heritage sites

It should be emphasised that for each of the criteria, a separate map was created showing the intensity of conflict related to the construction of solar power plants and wind farms in relation to the respective criterion. Essentially, this means that every unit area on the map has a quantified conflict-intensity score in accordance with the previously mentioned rating scale (ranging from 0 to 5).

3.3.1 Evaluation of Criteria

Evaluation of the level of conflict for each criterion is carried out independently of the other criteria. The scoring is defined based on the type of available data, the importance of the data and experiences from renewable energy project development in Montenegro, the region and the EU. Conflict-level scores are separately assigned to the zones on the map for each criterion, using a scale from 0 to 5. The zones are selected by using the available georeferenced data for each criterion, presented as polygons. For example, where information was available on areas that could potentially be protected (in some stage of the procedure but without a final decision), the highest conflict-intensity score was assigned. In areas where such information was not available, buffer zones were applied, each assigned a different conflict-intensity level.

Table 3.1 provides an overview of the scoring approach for all criteria. The following sections present the explanations for the selection of sensitivity levels for each criterion.

Areas of ecological value

In this case, georeferenced layers in polygon (zone) format were available, some of which are recognised by law as sensitive, although construction is not prohibited. Some of the zones (Emerald, Natura) are in the process of being granted protected status.

Agricultural land

After processing all available data, all datasets were grouped into three categories: arable land, meadows and pastures, and ratings were assigned as shown in Table 3.1. The highest conflict intensity was assigned to arable land, for which data were available on fields, greenhouses, plastic tunnels, orchards, vineyards, olive groves and mixed plantations.

For fields, the installation of solar power plants would lead to a significant loss of this land type and the plants' shading would adversely affect productivity. Wind power plants may also alter the microclimatic conditions of surrounding fields. Overall, fields are assessed as highly sensitive, particularly due to the fragmentation of plots and their small share in the total agricultural land area. Changes in microclimatic conditions also affect other types of arable land. The impacts of solar power plants on air temperature and humidity are evident in that they affect the stability of greenhouse production, vineyards, olive groves and other plantations, while wind power plants can affect pollination and yield.

Meadows have both ecological and economic functions. Shading (solar power plants) may reduce their value for grazing, so they are assessed as moderately sensitive. Additional analysis is needed, as field conditions may differ from cadastral data. The impact of wind power plants may be reflected in microclimate changes and the accessibility of meadows. They are considered moderately sensitive, and the actual impact can be evaluated through studies on specific locations.

Shading (solar power plants) of pastures may reduce their usability. Due to the large areas they occupy within the overall agricultural land structure, they are assessed as having low sensitivity. Wind power plants may affect microclimate and water availability. They are assessed as low-sensitivity areas.

Forests

Georeferenced data for forests by classes are not fully available in Montenegro's official spatial planning documentation. Reliable data by forest classes are available only for economically viable forests. In order to cover the entire territory of Montenegro, it was necessary to use an additional source of data. Following the recommendations of the competent ministry, web-available data from the Copernicus Land Monitoring Service were used. By combining these data sources, georeferenced data for more than 200 forest management classes were obtained. After analysing all the data, a categorisation was carried out for the purpose of evaluating the level of conflict:

- High forests
- Certain types of coppice forests
- Certain types of coppice forests and shrublands
- Barren land

- Areas that are spatially shown in official data as forest land, for which no more detailed information exists

The conflict levels were assigned to the listed categories as presented in Table 3.1.

Settlements

The specificity of Montenegro's spatial planning system, which recognises special purpose areas (national park areas and the territory of the six coastal municipalities)[11], was taken into account in the sensitivity analysis. The analysis covered all settlements, both urban settlements for which official georeferenced data exist and rural settlements for which no official georeferenced data are available (for the latter, OSM and Google Maps were used). Construction areas outside settlements were not taken into consideration. Due to the lack of data, areas important for traditional agricultural practices (katuns) were not included.

The potential impacts of solar power plants and wind farms on settlements – that is, on people's quality of life and on economic activity, as well as on the functionality and attractiveness of recreational areas – were considered. Available information on distancing requirements applied in EU countries and in similar studies was also reviewed.

The proposed buffer zones were differentiated depending on the type of area in which the settlement is located. Larger buffer zones were applied in special purpose areas due to their higher sensitivity and the need to preserve their natural characteristics, which form the basis for income generation and community development. The proposed buffer zones for settlements were also differentiated depending on the type of RES facility (solar power plants or wind farms).

The distances applied in this study are of a general nature and are intended to guide RES development towards the most suitable locations. During the development and construction of specific projects, smaller or larger protective zones than those recommended in the study may be determined through environmental impact assessments, depending on specific conditions.

The objectives of rural development and the need to preserve landscapes, particularly in special purpose areas, were taken into account when defining recommendations for applying different buffer zones. When determining buffer zones, some of the inputs gathered during public participation meetings held in September 2025 in three municipalities (Nikšić, Cetinje and Pljevlja) were also considered (see Appendix 5.2 on the use of PPGIS tools and discussions on public attitudes toward RES development).

The buffer zones, i.e. sensitivity scores, applied for settlements in this study were determined taking into account possible negative impacts of wind and solar projects, as well as comparative experiences presented in Table 3.3.

The main negative impacts of wind farms on residential areas (considering human health, quality of life and unhindered performance of economic activities that local communities depend on) are noise, visual effects (landscape alteration) and shadow flicker caused by turbine rotation. For solar power plants, the main negative impacts on settlements include land loss, habitat degradation, visual effects (landscape alteration) and potential microclimate changes (creation of heat islands).

[11] Special purpose areas are considered to be parts of the territory that share common natural, regional or other characteristics and are of particular importance for Montenegro; these areas require a special regime for their organisation, planning, use and protection.

Table 3.3 Different experiences with determination of setback requirements for RES projects

According to the 2018 JRC study[12], most EU Member States applied setback distances of 500-1000 m for large wind turbines, with variations from one region to another. Exceptions include Belgium (Wallonia) and the Netherlands, with setbacks of 400 m, and Austria, Germany and Poland, where setbacks of around 1.2 km were applied in some regions. In some parts of Austria, large wind turbines were not permitted at all. In Scotland, a 2 km setback was applied. For the 2024 study "Renewable energy production and potential in EU rural areas"[13], a uniform 700 m buffer zone was applied for all residential areas. In the TNC study for Zadar County, settlement sensitivity (including designated construction areas outside settlements) to RES development was analysed as an additional component of the study. Six sensitivity categories with corresponding setback distances were used. For solar power plants, sensitivity scores 6 and 5 (highest sensitivity) were assigned to the settlements themselves and the surrounding zone of 100 m, while a score of 1 (lowest sensitivity) was assigned to areas at a distance of 1000 m or more from the settlement. For wind farms, a 6 was assigned to the settlements themselves and to the zone of 500 m surrounding the settlement, while the lowest sensitivity (score 1) was assigned for distances of 2.5 km or more from the settlement.

The sensitivity scores and buffer zones for settlements are presented in Table 3.4.

Tourism and recreational areas

For this criterion only ski resorts are taken into account because no other georeferenced data were available. When determining buffer zones and sensitivity levels, experiences from the region and the EU were consulted.

Landscape-valuable areas

Since no official spatial-planning documentation was available that clearly defines landscape-valuable areas, and since this criterion was identified as an important value that should be taken into account when assessing conflict intensity, it was necessary to define an approach for identifying these values. In this regard, the results of a scientific study[14] were used. The detailed algorithm is provided in the study itself, and three basic steps are highlighted here:

- Social media data, including metadata, were queried using the Flickr API for designated coordinates arranged in a diamond grid across mainland Montenegro, each within a 5 km radius. Flickr uploads were filtered using a multilingual keyword system (Montenegrin, Serbian, Croatian, Portuguese, English, Spanish, German, Italian) to capture relevant content.

[12] Dalla Longa, F., Kober, T., Badger, J., Volker, P., Hoyer-Klick, C., Hidalgo, I., Medarac, H., Nijs, W., Politis, S., Tarvydas, D. and Zucker, A., Wind potentials for EU and neighbouring countries*:* Input datasets for the JRC-EU-TIMES Model, EUR 29083 EN, Publications Office of the European Union, Luxembourg, 2018

[13] The study identified areas suitable for the development of RES in rural regions based on a broad set of factors such as land use, environment, agriculture, topography, accessibility and climatic conditions. Protected natural areas and zones important for biodiversity, forests and water bodies (except those suitable for floating PV installations) were excluded. The use of agricultural land for energy production was subject to strict limitations. Furthermore, buffer zones were applied around infrastructure (500 m) and settlements (700 m) in order to minimise disturbances and the phenomenon known as NIMBY ("not in my backyard"), meaning the potential opposition of local communities to new RES projects and their impacts.

[14] B.T. van Zanten, D.B. Van Berkel, R.K. Meentemeyer, J.W. Smith, K.F. Tieskens, & P.H. Verburg, Continental-scale quantification of landscape values using social media data, Proc. Natl. Acad. Sci. U.S.A. 113 (46) 12974-12979, https://doi.org/10.1073/pnas.1614158113 (2016).

To reduce bias, only one upload per user per 1 km^2 cell was retained. The resulting data were classified into low, medium, and high landscape value categories using head/tail breaks classification.

- Cells with medium and high landscape value were converted into observation points, representing locations of cultural or aesthetic significance.
- A digital surface model was used to apply a line-of-sight algorithm to each viewpoint. Two distance thresholds were considered: 3 km (high sensitivity) and 10 km (low sensitivity). Composite national visibility maps were generated and masked using the Human Modification Index (HMI) to eliminate highly modified areas (HMI > 0.4).

A detailed analysis was carried out, and the evaluation presented in Table 3.4 was adopted.

Cultural and historical heritage

The available georeferenced data are point-based, so a single high-sensitivity buffer zone around them has been adopted, while for a few potential areas of cultural and historical significance (which are currently under consideration for official designation), a moderate-sensitivity rating has been proposed.

Table 3.4 Evaluation of the conflict intensity of solar power plants and wind farms in relation to the selected criteria

Criterion	Relevance	Sensitivity scoring (5 – high conflict, 1 – low conflict, 0 – no conflict)					
		(5)	(4)	(3)	(2)	(1)	(0)
Areas of ecological value	SPP and WPP	Legally protected areas in the third protection zone (National Parks), Emerald, IBA, Ramsar, proposed Natura 2000 Type A habitats and Natura 2000 priority habitats for the EU	-	Legally protected areas in the third protection zone (nature parks, nature monuments, etc.), areas proposed for protection, and proposed Natura 2000 Type B habitats	-	-	Outside areas of ecological value
Habitats important for bats	SPP	500 m around habitats: ● Rhinolophus hipposideros ● Rhinolophus ferrumequinum ● Rhinolophus Euryale ● Myotis emarginatus ● Barbastella barbastellus.	-	500 m around habitats (other species)	-	-	Areas outside of habitats important for bats

Criterion	Relevance	Sensitivity scoring (5 – high conflict, 1 – low conflict, 0 – no conflict)					
		(5)	(4)	(3)	(2)	(1)	(0)
	WPP	500 m around habitats: • Nyctalus noctula • Nyctalus leisleri • Tadarida teniotis • Miniopterus schreibersii • Pipistrellus kuhlii • Pipistrellus nathusii • Hypsugo savii • Eptesicus serotinus (Cnaepheus serotinus) • Barbastella barbastellus.		500 m around habitats (other species)			
Cultural-historic goods	SPP and WPP	250 m around cultural-historic goods; High-risk zones in the Bay of Kotor (Boka Kotorska)	-	Potential zones of cultural significance; Medium-risk zones in the Bay of Kotor (Boka Kotorska)	-	-	Areas outside of cultural-historic zones
	SPP	< 300 m		300 - 1000 m			> 1000 m

Criterion	Relevance	Sensitivity scoring (5 – high conflict, 1 – low conflict, 0 – no conflict)					
		(5)	(4)	(3)	(2)	(1)	(0)
Distance from settlements (urban and rural) in the special purpose areas			-		-	-	
	WPP	< 500 m	-	500 - 1500 m	-	-	> 1500 m
Distance from settlements (urban and rural) outside of special purpose areas	SPP	< 250 m	-	250 - 500 m	-	-	> 500 m
	WPP	< 300 m	-	300 - 700 m	-	-	> 700 m
Distance from tourist-recreational areas (ski centres)	SPP and WPP	< 300 m	-	300 - 700 m	-	-	> 700 m
Agricultural land	SPP and WPP	Arable land	-	Meadows	-	Pastures	Outside agricultural land
Forests and forest land	SPP and WPP	**High woods** (Table 3.4) **CLC2023 for categories 2, 3 and 4** 2: Woody needle leaved trees 3: Woody broadleaved deciduous trees		**Specific coppice forest types** (Table 3.4) **CLC2023 for categories 5 and 6** 5: Low-growing woody plants 6: Permanent herbaceous	**Specific coppice forest types and shrubland** (Table 3.4) **CLC2023 for category 7** 7: Periodically herbaceous	**Barren land** (Table 3.4) Undefined polygons in a .shp file (forest areas with no data) **CLC2023 for category 9**	**Outside forest land** **CLC2023 for categories 1,10,253, 254,255** 1: Sealed 10: Water 253: Coastal seawater buffer 254: Outside area

Criterion	Relevance	Sensitivity scoring (5 – high conflict, 1 – low conflict, 0 – no conflict)					
		(5)	(4)	(3)	(2)	(1)	(0)
		4: Woody broadleaved evergreen trees				9: Non and sparsely vegetated	255: No data
Areas of high landscape value (11 or more landscape photos within 1km cell)	SPP and WPP	Areas with substantial visual impact potential (visible sites within 3 km) around locations of high landscape value (11 or more landscape photos within 1 km cell)		Areas with lower visual impact potential (visible sites within 3–10 km) around locations of high landscape value (11 or more landscape photos within 1 km cell)	-	-	Areas with no expected visual impact (visible sites beyond 10 km) around locations of high landscape value (11 or more landscape photos within 1 km cell)
Areas of moderate landscape value (4-10 landscape photos within 1 km cell)	SPP and WPP	-		Areas with substantial visual impact potential (visible sites within 3 km) around locations of moderate landscape value (4-10 landscape photos within 1 km cell)	-	Areas with lower visual impact potential (visible sites within 3–10 km) around locations of moderate landscape value (4-10 landscape photos within 1 km cell)	Areas with no expected visual impact (visible sites beyond 10 km) around locations of moderate landscape value (4-10 landscape photos within 1 km cell)

Table 3.5 Forest Management Classes – sensitivity grading

Code	Management class	Value
101	Beech forests on better sites	5
102	Beech forests on poorer sites	5
103	Fir, spruce and beech forests on better sites	5
104	Fir, spruce and beech forests on poorer sites	5
105	Fir and spruce forests on better sites	5
106	Fir and spruce forests on poorer sites	5
107	Fir and beech forests on better sites	5
108	Fir and beech forests on poorer sites	5
121	Fir, spruce and beech forests on better sites	5
122	Fir, spruce and beech forests on poorer sites	5
123	Fir and beech forests on better sites	5
124	Fir and beech forests on poorer sites	5
131	High beech forests of middle and lower regions on better sites	5
132	High beech forests of middle and lower regions on poorer sites	5
133	High beech forests of higher regions on better sites	5
134	High beech forests of higher regions on poorer sites	5
135	High beech forests of high regions on better sites	5
136	High beech forests of high regions on poorer sites	5
141	Black pine forests on better sites	5
142	Black pine forests on poorer sites	5
143	Black pine and spruce forests	5
151	Scots pine forests on better sites	5
152	Scots pine forests on poorer sites	5
153	Scots pine and spruce forests	5
161	Bosnian pine forests	5
162	Bosnian pine and spruce forests	5
171	Macedonian pine forests	5
172	Macedonian pine and spruce forests	5
181	Fir and spruce forests of lower and middle regions	5
182	Fir and spruce forests of higher regions	5
191	Spruce forests of lower and middle regions	5
192	Spruce forests of higher regions	5
193	Spruce forests of high regions	5
201	High sessile oak forests on better sites	5
202	High sessile oak forests on poorer sites	5
203	High sessile oak and Turkey oak forests on better sites	5
204	High sessile oak and Turkey oak forests on poorer sites	5
205	High sessile oak and hornbeam forests on better sites	5
206	High sessile oak and hornbeam forests on poorer sites	5
211	High Turkey oak forests on better sites	5
212	High Turkey oak forests on poorer sites	5
221	High downy oak forests	5
222	High pedunculate oak forests	5
231	High holm oak forests	5
232	High Macedonian oak forests	5

Code	Management class	Value
241	High hornbeam forests	5
251	High beech forests on better sites	5
252	High beech forests on poorer sites	5
253	High hornbeam forests on better sites	5
254	High hornbeam forests on poorer sites	5
261	High hop hornbeam forests	5
262	High manna ash forests	5
263	High hop hornbeam and manna ash forests	5
271	High sweet chestnut forests	5
281	High alder forests	5
282	High birch forests	5
283	High willow forests	5
301	High beech forests of middle and lower regions on better sites	5
302	High beech forests of middle and lower regions on poorer sites	5
303	High beech forests of higher regions on better sites	5
304	High beech forests of higher regions on poorer sites	5
305	High beech forests of high regions on better sites	5
306	High beech forests of high regions on poorer sites	5
401	High degraded beech forests	5
402	High degraded beech and fir forests	5
403	High degraded Turkey oak forests	5
411	High degraded black pine forests	5
421	High degraded Scots pine forests	5
431	High degraded Bosnian pine forests	5
441	High degraded Macedonian pine forests	5
451	High degraded beech, fir and spruce forests	5
452	High degraded fir and spruce forests	5
461	High degraded spruce forests	5
511	Black pine plantations on pine sites	5
512	Black pine plantations on better sites	5
521	Scots pine plantations on pine sites	5
522	Scots pine plantations on better sites	5
531	Aleppo pine plantations	5
532	Maritime pine plantations	5
533	Cypress plantations	5
541	Stone pine plantations	5
542	Douglas fir plantations	5
543	Larch plantations	5
544	Other conifer plantations	5
561	Spruce plantations	5
571	Plantations of noble broadleaves	5
572	Oak plantations	5
573	Other broadleaf plantations	5
601	Coppice sessile oak forests on better sites	3
602	Coppice sessile oak forests on poorer sites	2
603	Coppice sessile oak and Turkey oak forests on better sites	3

Code	Management class	Value
604	Coppice sessile oak and Turkey oak forests on poorer sites	2
605	Coppice sessile oak and hornbeam forests	2
611	Coppice Turkey oak forests on better sites	3
612	Coppice Turkey oak forests on poorer sites	2
613	Coppice Turkey oak and hornbeam forests	2
621	Coppice downy oak forests	2
631	Coppice holm oak forests	2
632	Coppice Macedonian oak forests	2
641	Coppice hornbeam forests	2
651	Coppice beech forests on better sites	3
652	Coppice beech forests on poorer sites	2
653	Coppice beech and heliophyte forests on better sites	3
654	Coppice beech and heliophyte forests on poorer sites	2
655	Coppice beech and hornbeam forests on better sites	3
656	Coppice beech and hornbeam forests on poorer sites	2
661	Coppice hop hornbeam forests	2
662	Coppice manna ash forests	2
663	Coppice hop hornbeam and manna ash forests	2
664	Coppice oriental hornbeam forests	2
665	Coppice oriental hornbeam and manna ash forests	2
671	Coppice sweet chestnut forests	2
701	Coppice degraded sessile oak forests on better sites	3
702	Coppice degraded sessile oak forests on poorer sites	2
703	Coppice degraded sessile oak and Turkey oak forests on better sites	3
704	Coppice degraded sessile oak and Turkey oak forests on poorer sites	2
705	Coppice degraded sessile oak and hornbeam forests	2
711	Coppice degraded Turkey oak forests on better sites	3
712	Coppice degraded Turkey oak forests on poorer sites	2
713	Coppice degraded Turkey oak and hornbeam forests	2
721	Coppice degraded downy oak forests	2
731	Coppice degraded holm oak forests	2
732	Coppice degraded Macedonian oak forests	2
741	Coppice degraded hornbeam forests	2
751	Coppice degraded beech forests on better sites	3
752	Coppice degraded beech forests on poorer sites	2
753	Coppice degraded beech and heliophyte forests on better sites	3
754	Coppice degraded beech and heliophyte forests on poorer sites	2
755	Coppice degraded beech and hornbeam forests on better sites	3
756	Coppice degraded beech and hornbeam forests on poorer sites	2
761	Coppice degraded hop hornbeam forests	2
762	Coppice degraded manna ash forests	2
763	Coppice degraded hop hornbeam and manna ash forests	2
764	Coppice degraded oriental hornbeam forests	2
765	Coppice degraded oriental hornbeam and manna ash forests	2
771	Coppice degraded sweet chestnut forests	2
801	Sessile oak shrublands	2

Code	Management class	Value
802	Turkey oak shrublands	2
803	Sessile oak and Turkey oak shrublands	2
804	Other oak shrublands	2
805	Beech shrublands	2
806	Beech and other sciophyte shrublands	2
807	Marsh shrublands	2
851	Holm oak maquis	2
971	Oriental hornbeam bushlands	5
972	Hop hornbeam bushlands	5
973	Manna ash bushlands	5
974	Hop hornbeam and manna ash bushlands	5
975	Hazel bushlands	5
976	Pomegranate bushlands	5
977	Thorn bushlands	5
978	Juniper bushlands	5

3.3.2 Combining criteria into an individual map

After the individual evaluation of conflict intensity for all criteria, it is necessary to determine the overall impact of all criteria combined. Since the mentioned criteria do not all have the same level of importance relative to one another, it is necessary to assess their weight. This was done through meetings with experts in the field (state institutions, relevant ministries, local reference experts, etc.) and through interviews.

The algorithm for development potential assessment can be presented by the following equation:

$$P = w_1 \times EV_n + w_2 \times AL_n + w_3 \times FL_n + w_4 \times S_n + w_5 \times TR_n + w_6 \times LV_n + w_7 \times CH_n$$

Where,

P – quantification of total conflict intensity for RES development potential

EV_n – Conflict intensity of areas of ecological value normalised by maximum value (values from 0 to 1 interval)

AL_n – Conflict intensity of agricultural land normalised by maximum value (values from 0 to 1 interval)

FL_n – Conflict intensity of forests and forest land normalised by maximum value (values from 0 to 1 interval)

S_n – Conflict intensity of settlements normalised by maximum value (values from 0 to 1 interval)

TR_n – Conflict intensity of tourist-recreational areas normalised by maximum value (values from 0 to 1 interval)

LV_n – Conflict intensity of landscape value normalised by maximum value (values from 0 to 1 interval)

CH_n – Conflict intensity of cultural-historic goods normalised by maximum value (values from 0 to 1 interval)

w_i – weighting factors for all criteria (Table 3.4).

Table 3.6 Weighting criteria

Weighting factor	Description	Value

		Solar	Wind
w_1	Areas of ecological value	0.23642	0.20875
w_2	Agricultural land	0.14794	0.14852
w_3	Forests and forest land	0.16286	0.16169
w_4	Settlements	0.10082	0.12421
w_5	Tourist-recreational areas	0.09375	0.10445
w_6	Areas with landscape value	0.11120	0.11302
w_7	Cultural-historic goods	0.14702	0.13936

The result obtained after applying the above formula is a single map that encompasses all analysed criteria and provides information on the overall conflict intensity related to the construction of solar power plants and wind farms in relation to these criteria. In order to improve the map's clarity and make it easier to use, the map with the final conflict-intensity results is reclassified by designating three levels of conflict intensity:

- Low conflict – *P* values below 30% of the maximum value;
- Medium conflict – *P* values between 30% and 50% of the maximum value;
- High conflict – *P* values above 50% of the maximum value.

After this reclassification, it becomes possible to identify zones with low conflict intensity. These zones are then compared with the previously generated development-potential maps to select the optimal locations for the development of solar power plants and wind farms.

3.4 Resulting conflict map

The results were prepared in the form of georeferenced maps using QGIS. The following images present each step of the methodology, thus illustrating its application for the case of Montenegro.

- Step 1 – Criteria were selected as stated in the previous chapter
- Step 2 – Evaluation of conflict intensity by criterion (Table 3.4)
    - Areas of ecological value for solar and wind resources (Figure 3.18, Figure 3.19)
    - Agricultural land (Figure 3.20)
    - Forests (Figure 3.21)
    - Settlements (Figure 3.22, Figure 3.23)
    - Tourism and recreational areas (Figure 3.24)
    - Landscape-valuable areas (Figure 3.25)
    - Cultural and historical heritage (Figure 3.26)
- Step 3 – Determination of the overall impact of all criteria combined and reclassification in order to obtain the resulting maps of conflict intensity for solar power plants and wind farms in relation to all selected criteria (Figure 3.13, Figure 3.14).

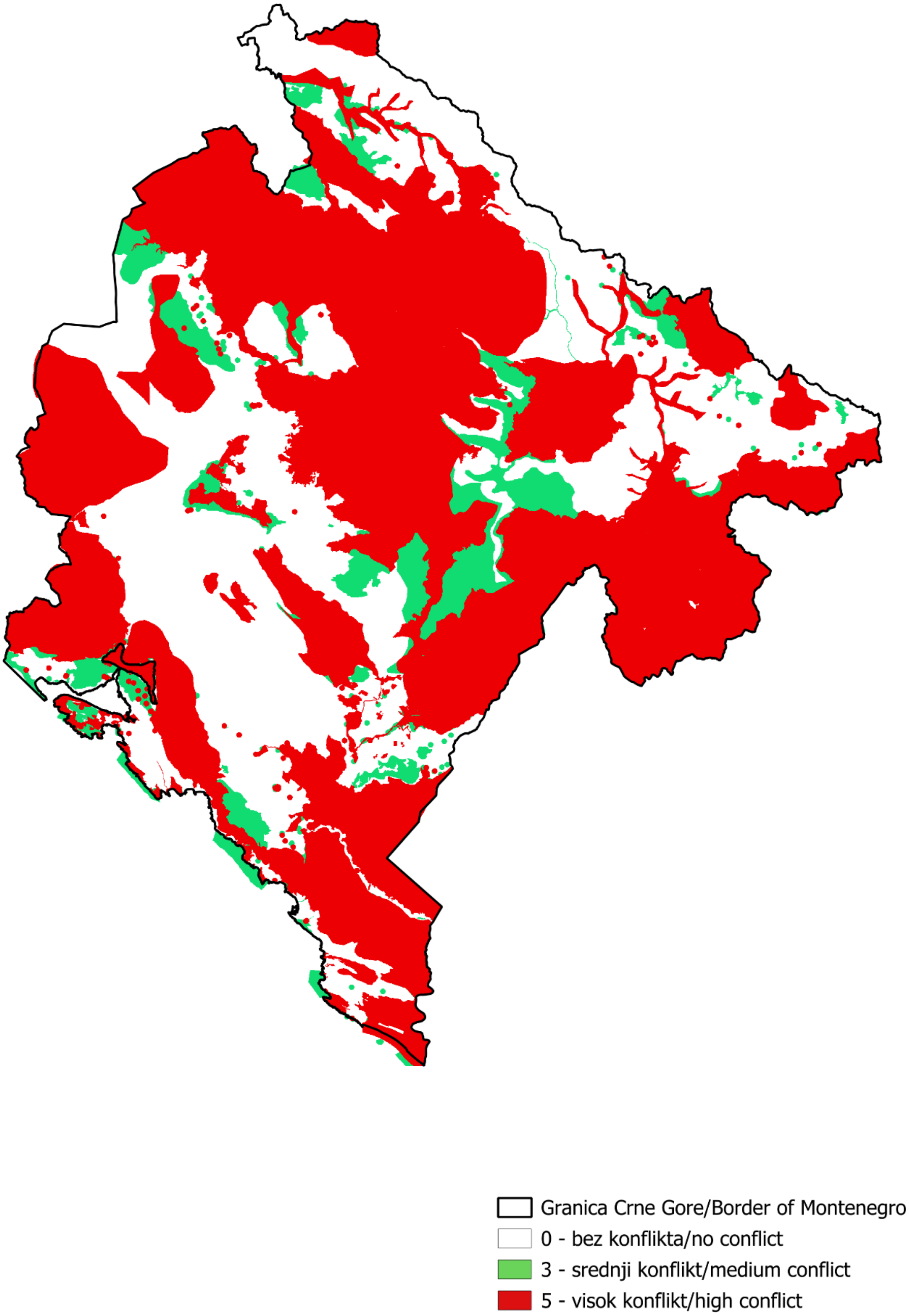

Figure 3.18 Resulting map after evaluating the criterion Areas of ecological value (solar)

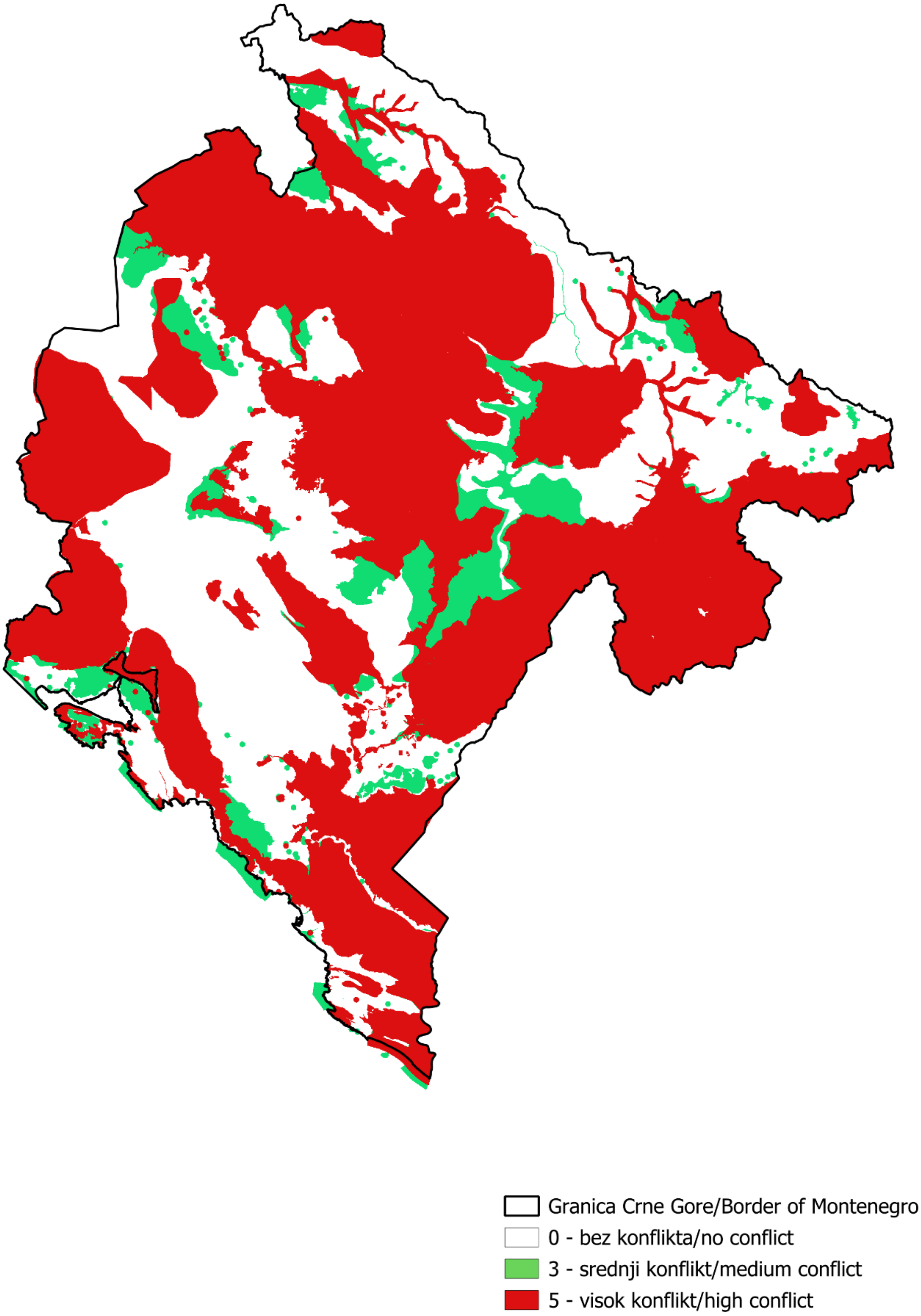

Figure 3.19 Resulting map after evaluating the criterion Areas of ecological value (wind)

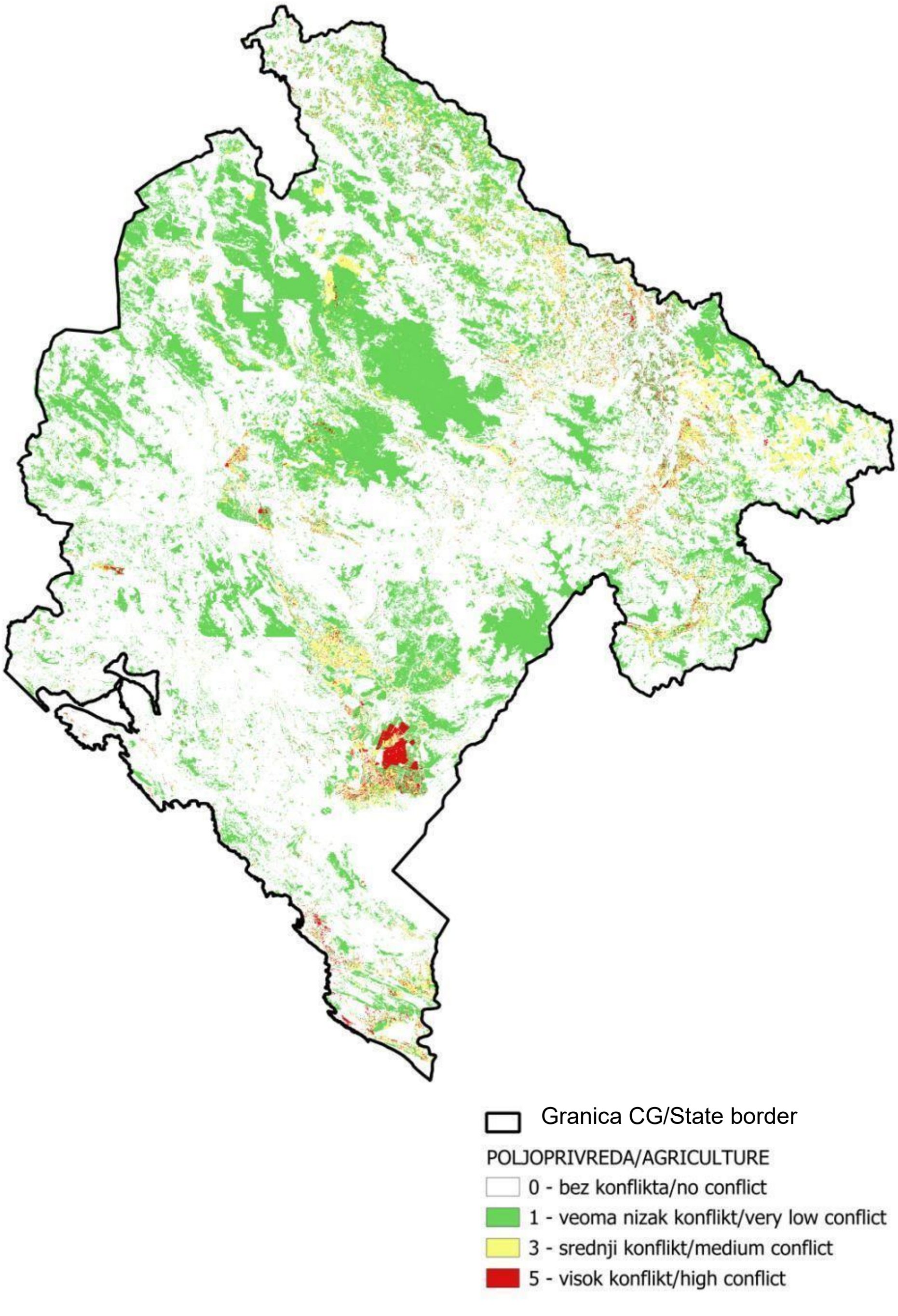

Figure 3.20 Resulting map after evaluating the criterion Agricultural land

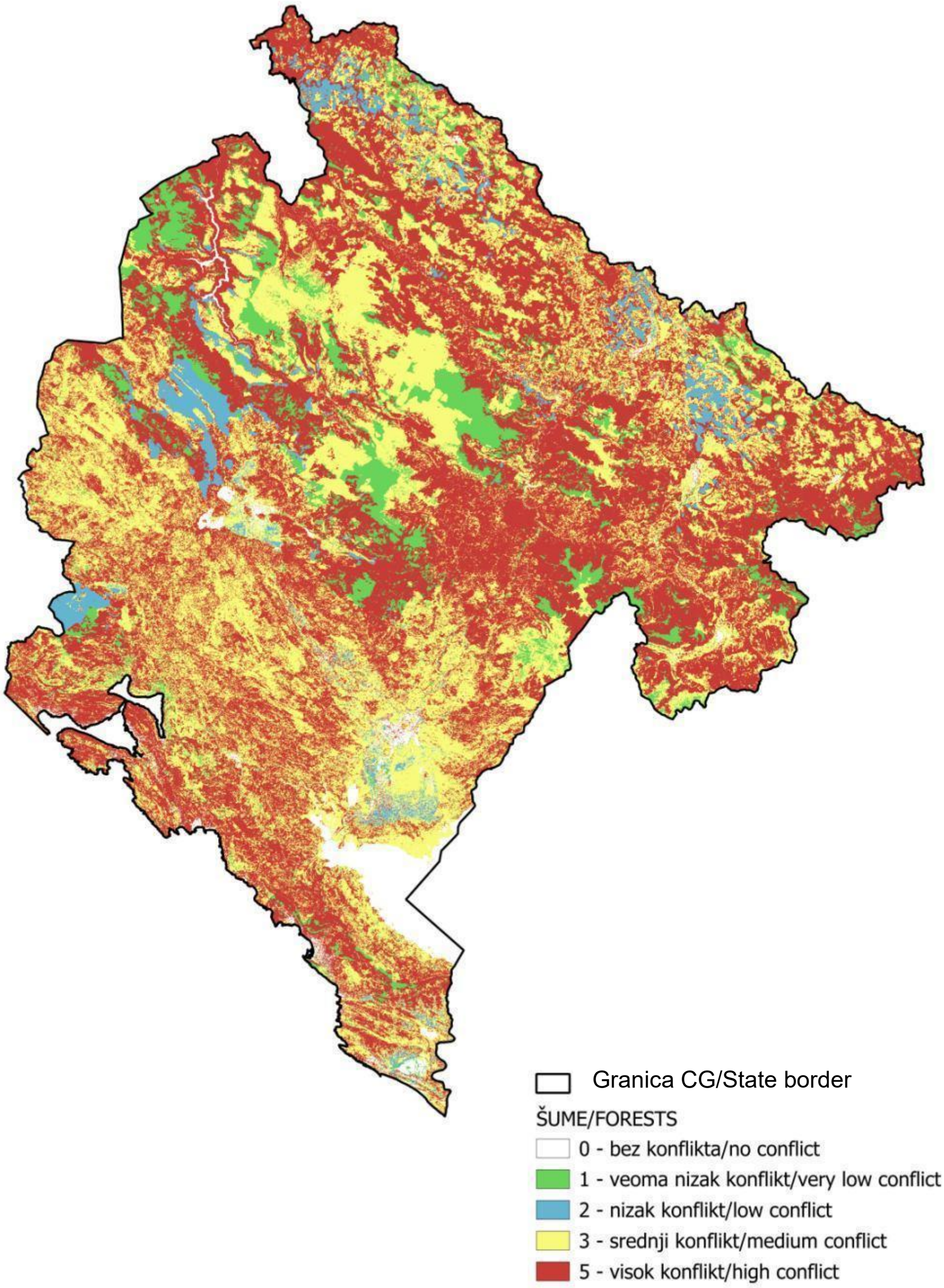

Figure 3.21 Resulting map after evaluating the criterion Forests and forest land

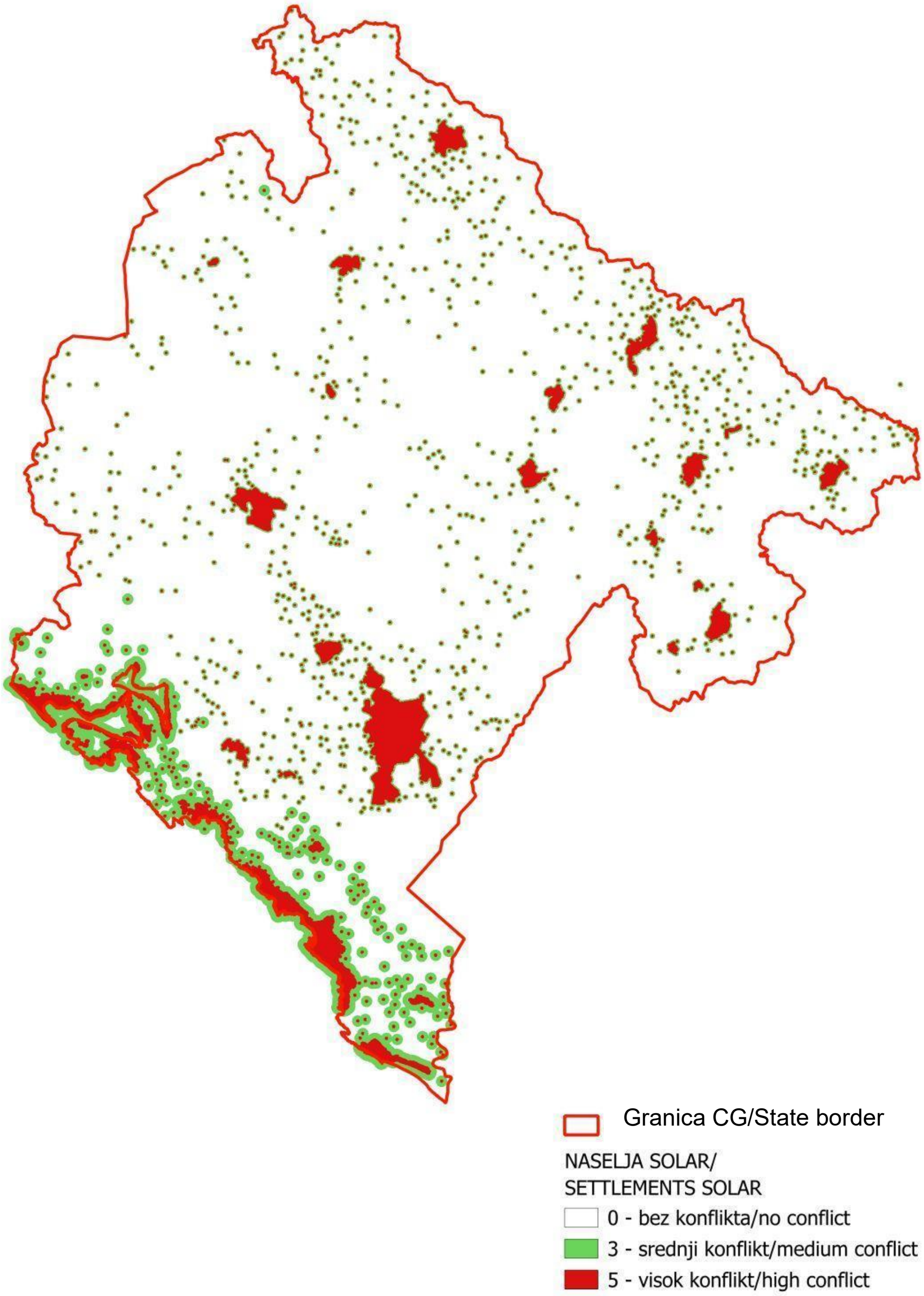

Figure 3.22 Resulting map after evaluating the criterion Settlements – solar power plants

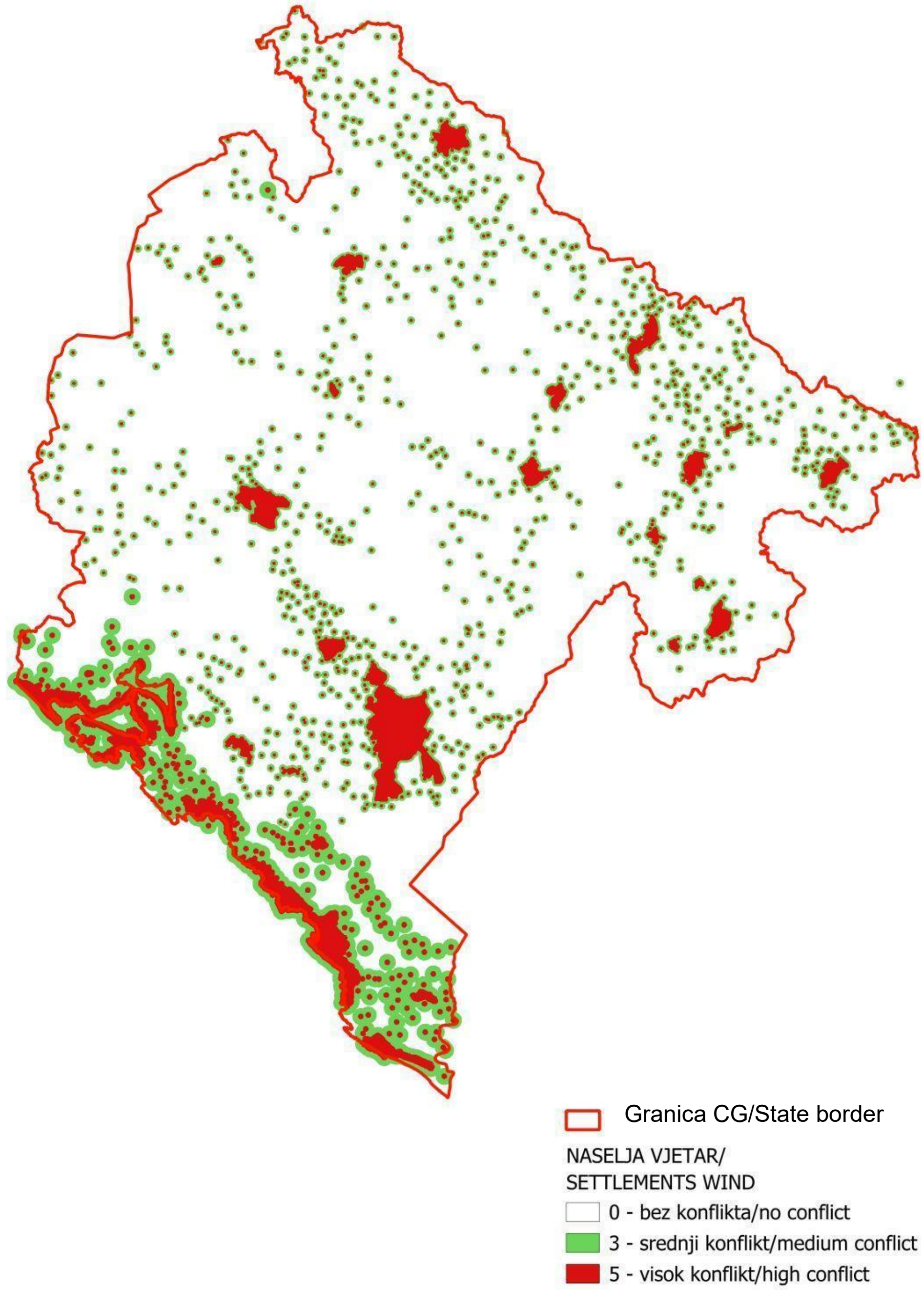

Figure 3.23 Resulting map after evaluating the criterion Settlements – wind power plants

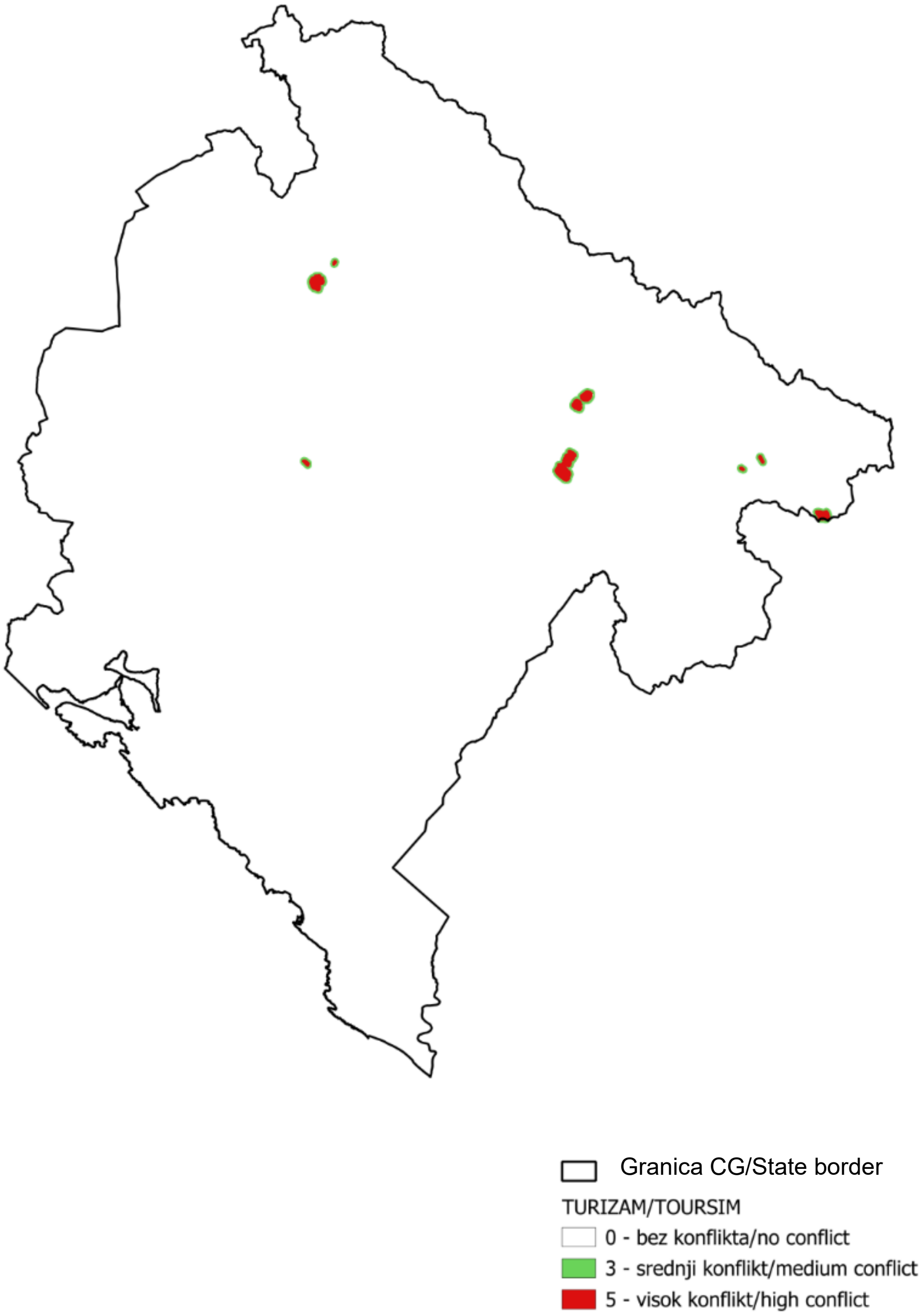

Figure 3.24 Resulting map after evaluating the criterion Tourist-recreational areas

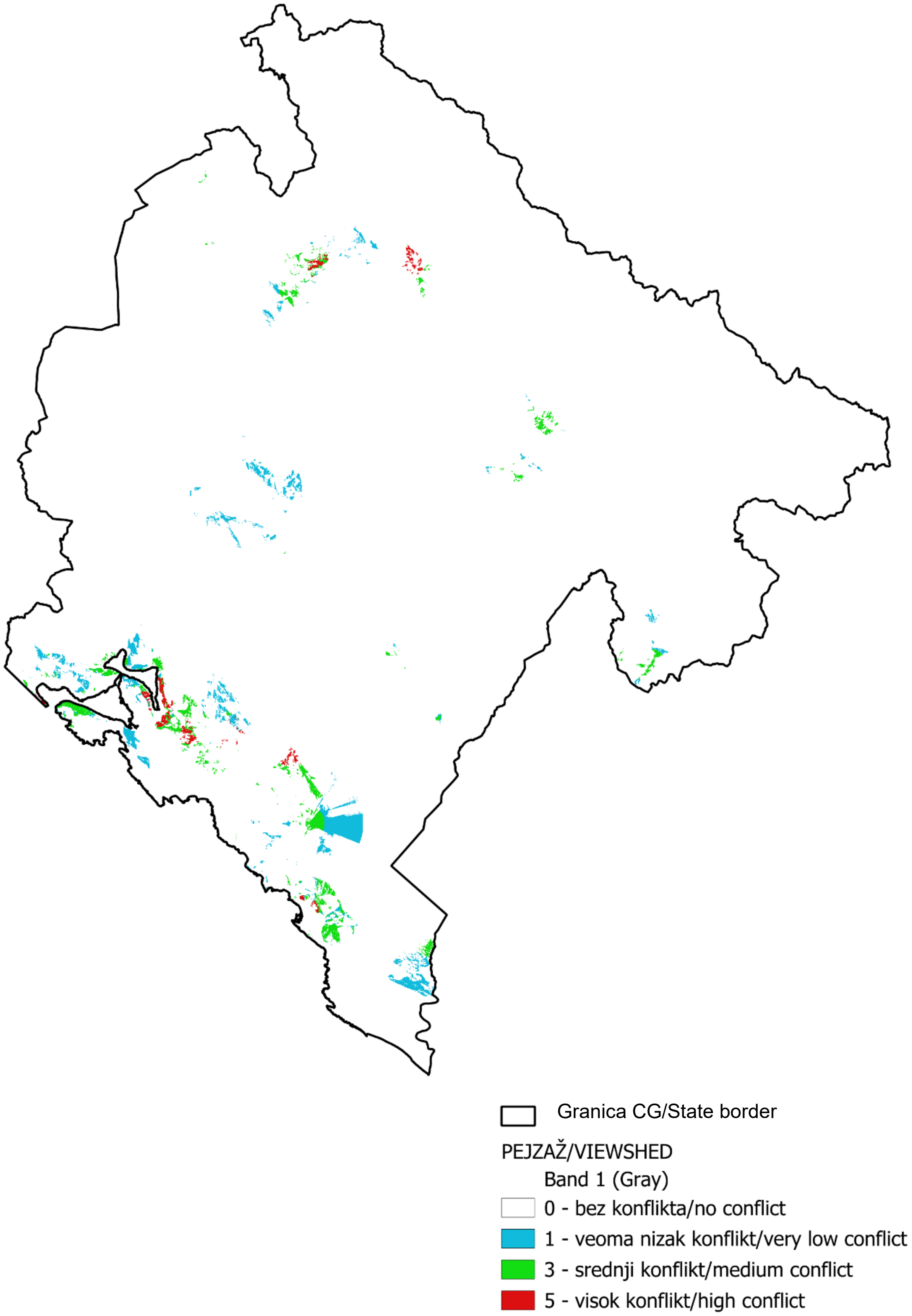

Figure 3.25 Resulting map after evaluating the criterion Landscape-valuable areas

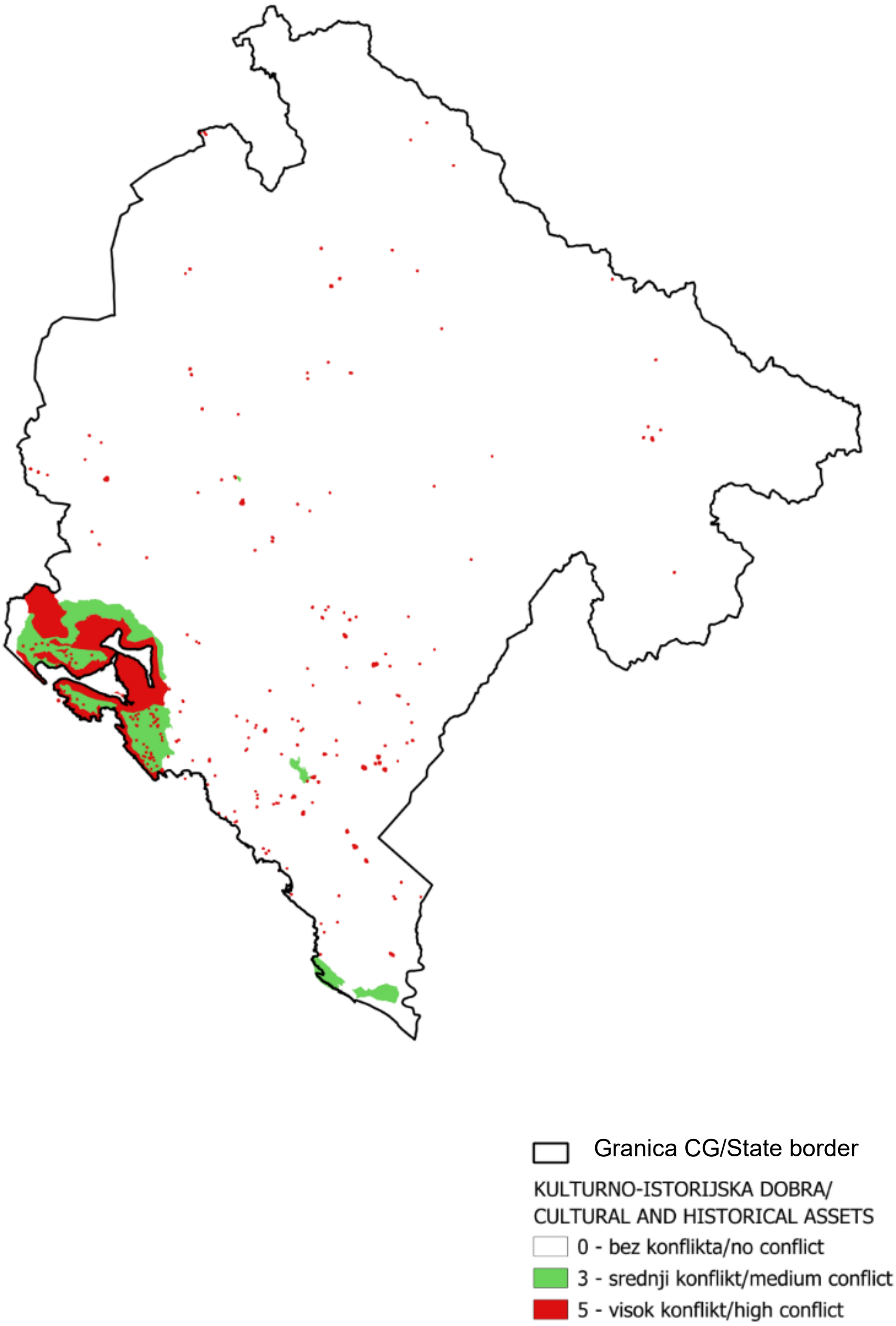

Figure 3.26 Resulting map after evaluating the criterion Cultural and historical heritage

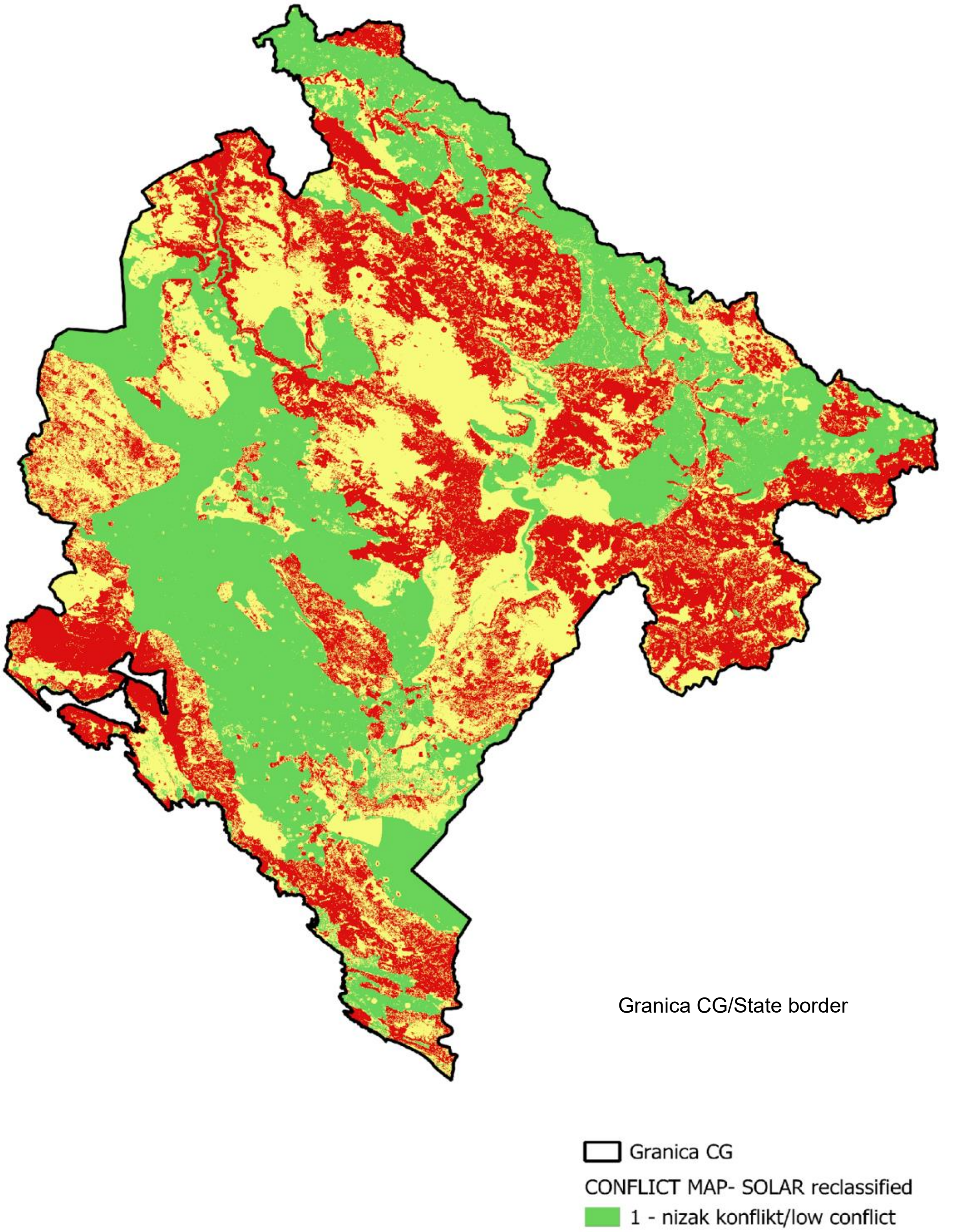

Figure 3.27 Resulting reclassified conflict map for solar power plants[15]

[15] The top 0.0016% cells, representing extreme outliers, were clamped to a heuristically calculated value of 3.79, which in practice avoids skewing the conflict categories toward rare values while still providing a simple and understandable way to reclassify the conflict scores into low-medium-high categories.

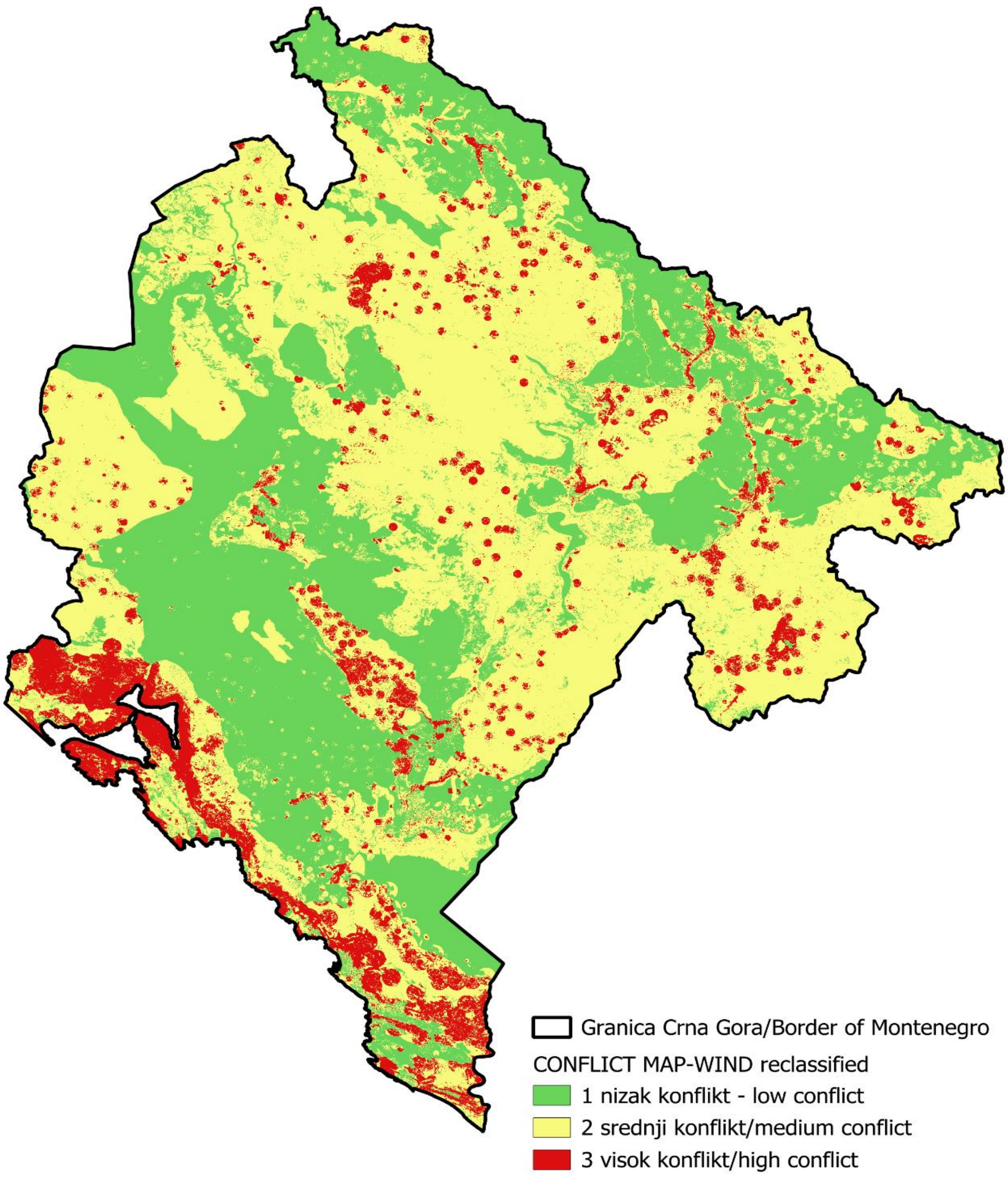

Figure 3.28 Resulting reclassified conflict map for wind power plants[16]

[16] The top 0.0016% cells, representing extreme outliers, were clamped to a heuristically calculated value of 3.79, which in practice avoids skewing the conflict categories toward rare values while still providing a simple and understandable way to reclassify the conflict scores into low-medium-high categories.

3.5 Resulting maps

The final step involves combining the identified zones that have a low assessed level of conflict for the construction of solar power plants and wind power plants with the corresponding map of technically available potential (Table 3.6). Prior to the final quantification of potential, these maps are filtered in order to remove zones that would form isolated "islands" whose areas are too small[17] to be used for power plant development (Figure 3.26, Figure 3.27 and Figure 3.28). In these cases, the small areas would correspond to low-capacity power plants and their grid connection would only be meaningful if connected to lower voltage levels (below 35 kV), which are not covered by this study.

Table 3.7 Area of all evaluated zones with development potential [ha]

Zone	Solar power plants – transmission grid	Solar power plants – distribution grid	Wind power plants
1	2,932	3,977	27,799
2	25,043	80,822	41,104
3	71,439	27,590	47,663
4	7,352	8,435	6,563

Taking into account common practice in Montenegro and the surrounding region, the identified areas with high potential can be assigned indicative potential quantifications in terms of expected installed capacity, as follows:

- Solar potential – 1 ha = 1 MW
- Wind potential – 10 ha = 1 MW

Based on the above, and on the derived maps of development potential characterised by a low level of conflict with other land uses, the following indicative high-suitability potential is obtained:

- Solar power plants connected to the distribution network – 8,435 MW[18]
- Solar power plants connected to the transmission network – 7,352 MW
- Wind power plants – 656 MW

The identified potentials for solar power plants connected to the distribution grid and to the transmission grid should not be summed, as certain zones (equivalent to ~158 MW in total) are suitable for both smaller and larger power plants. Therefore, the combined potential for smaller and larger solar power plants combined is about 15,630 MW. It should be emphasised that the quantified potential for the construction of solar power plants and wind farms represents an indicative value. The construction of any new generation facility changes the situation regarding the security and quality of operation of the power system. This primarily refers to its micro-location and technical characteristics, which influence the need for continuous updating of the usable renewable energy potential, taking into account the limitations of the existing and future grid infrastructure. For example, the areas suitable for the construction of solar power plants that would be connected to the distribution network correspond to an installed capacity that significantly exceeds the capability of the grid infrastructure to accommodate them.

[17] The filtered sections are below 3 ha for distribution and below 10 ha for transmission.

[18] Locations with high technical potential and low conflict have a potential that significantly exceeds the grid's ability to accommodate all possible production. Taking into account the current condition of the grid and the issued technical connection requirements, it is currently possible to utilise 235 MW of the identified solar potential.

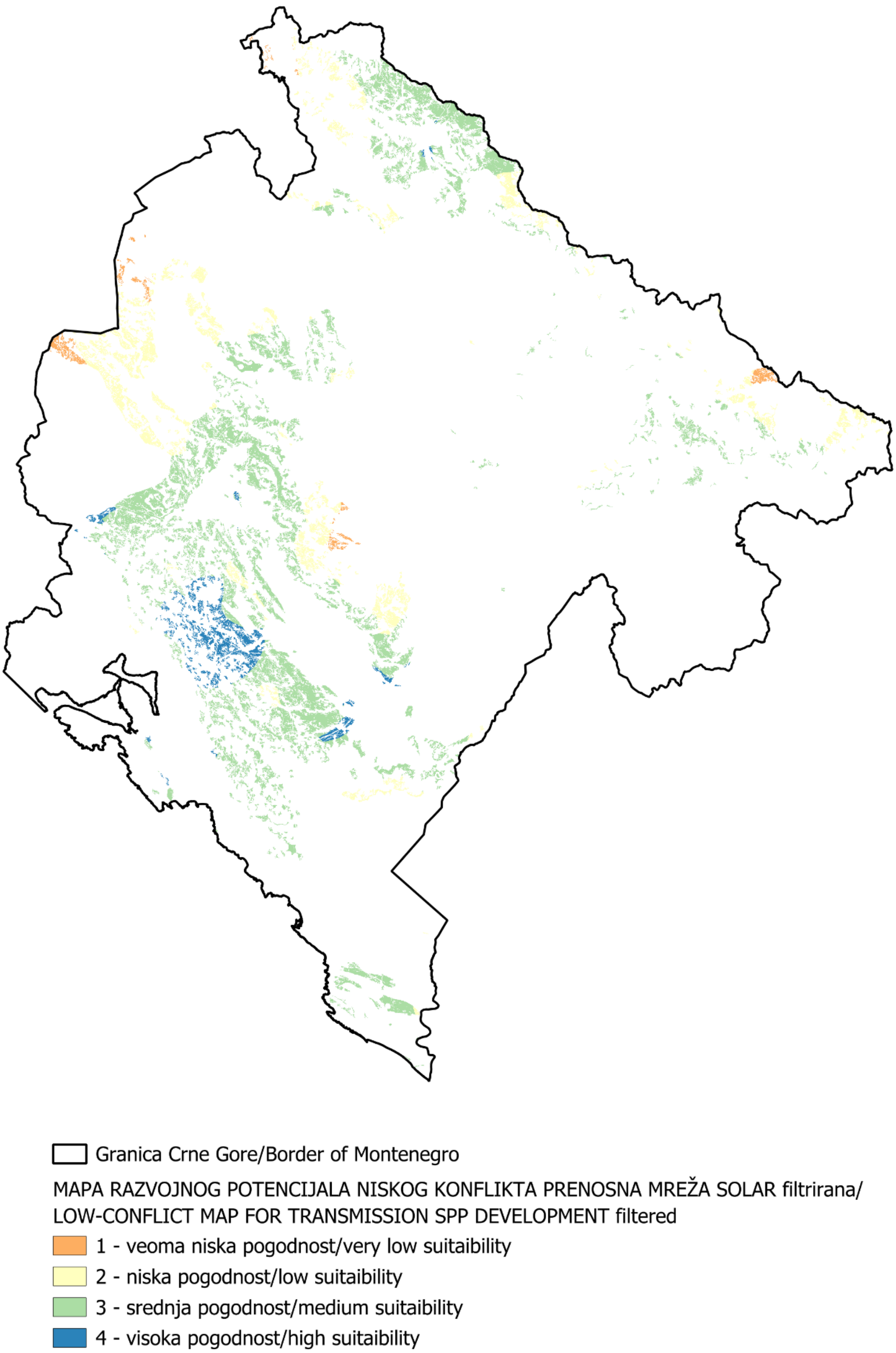

Figure 3.29 Low conflict map for transmission solar power plant development

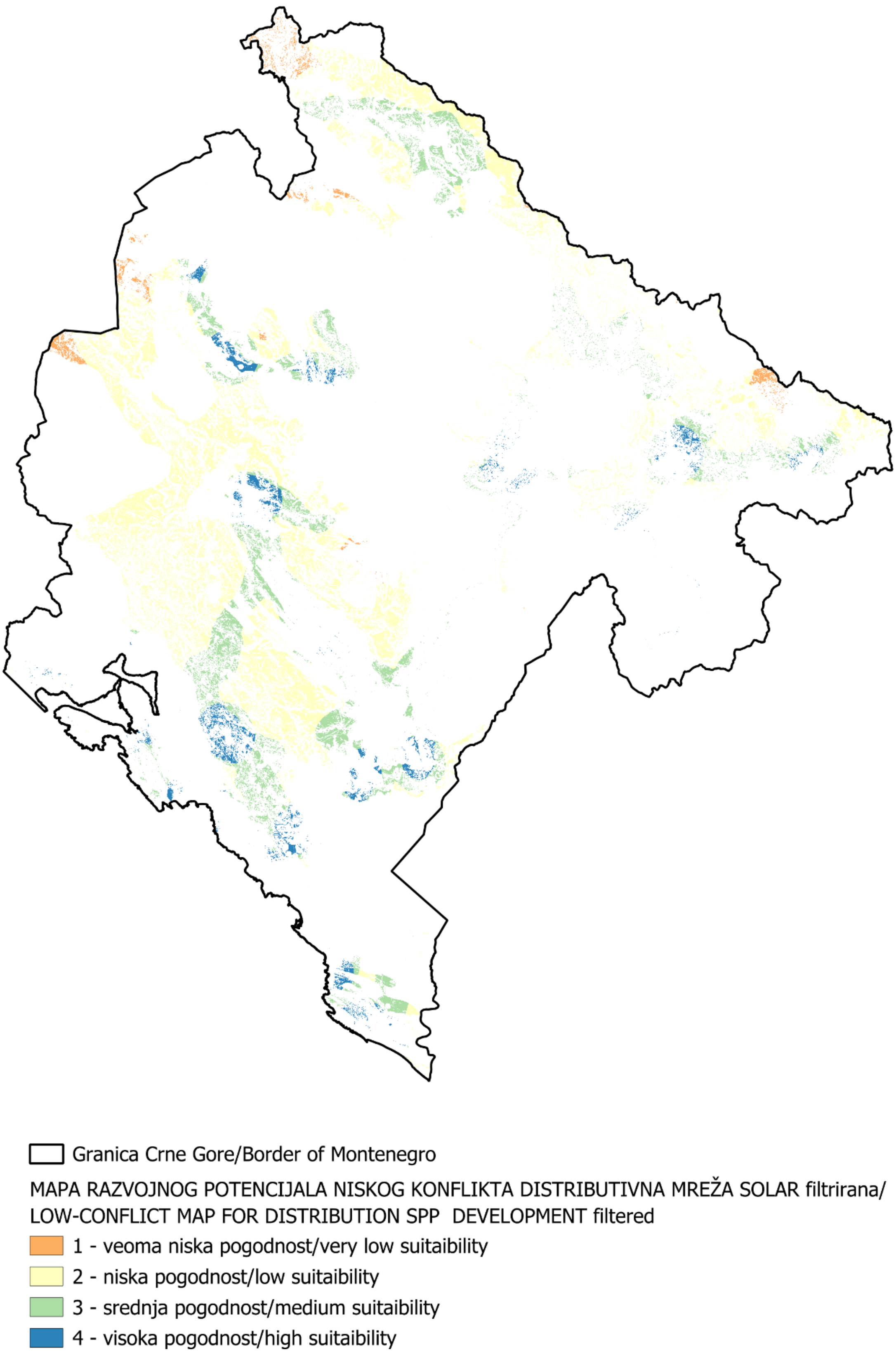

Figure 3.30 Low conflict map for distribution solar power plant development

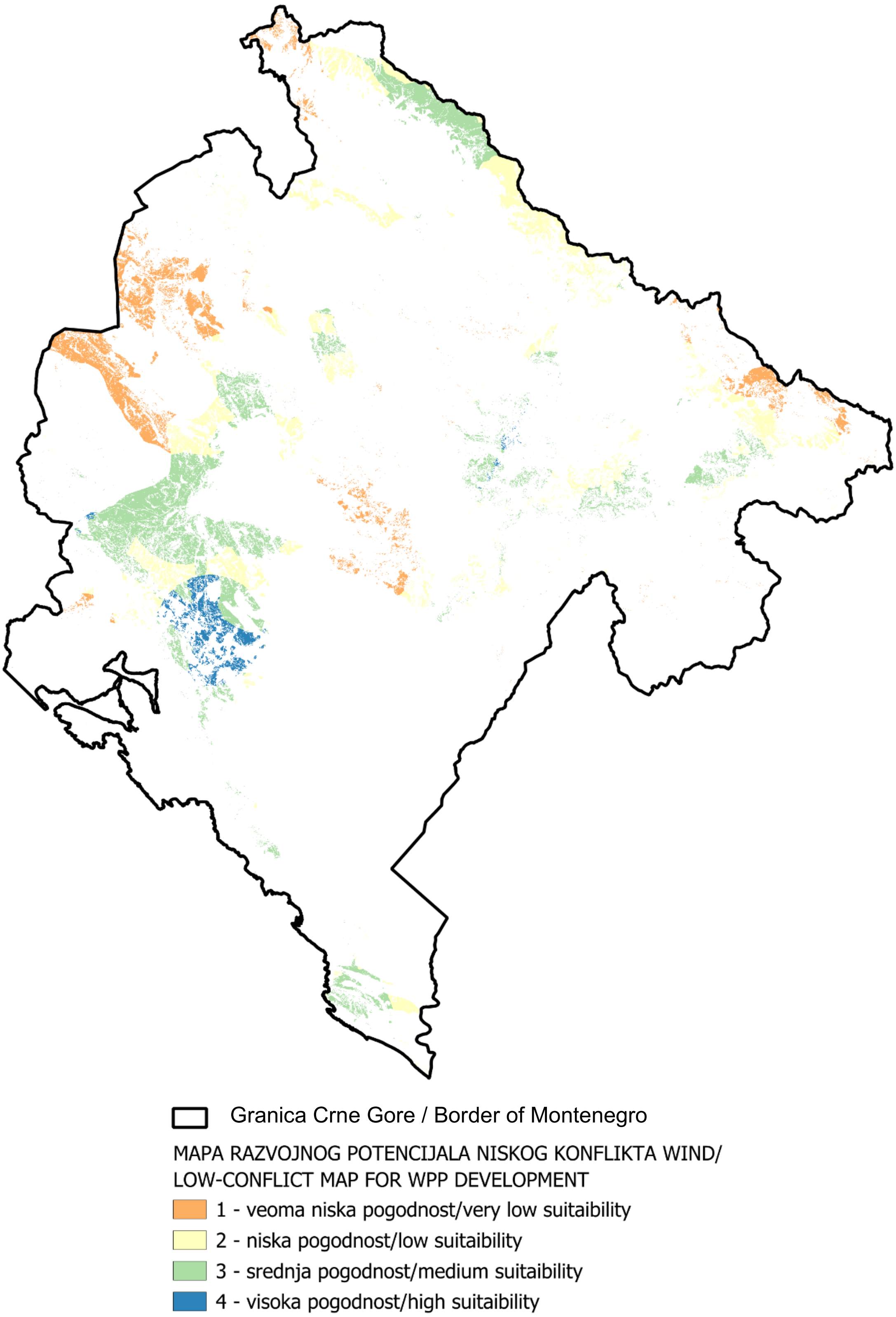

Figure 3.31 Low conflict map for wind power plant development

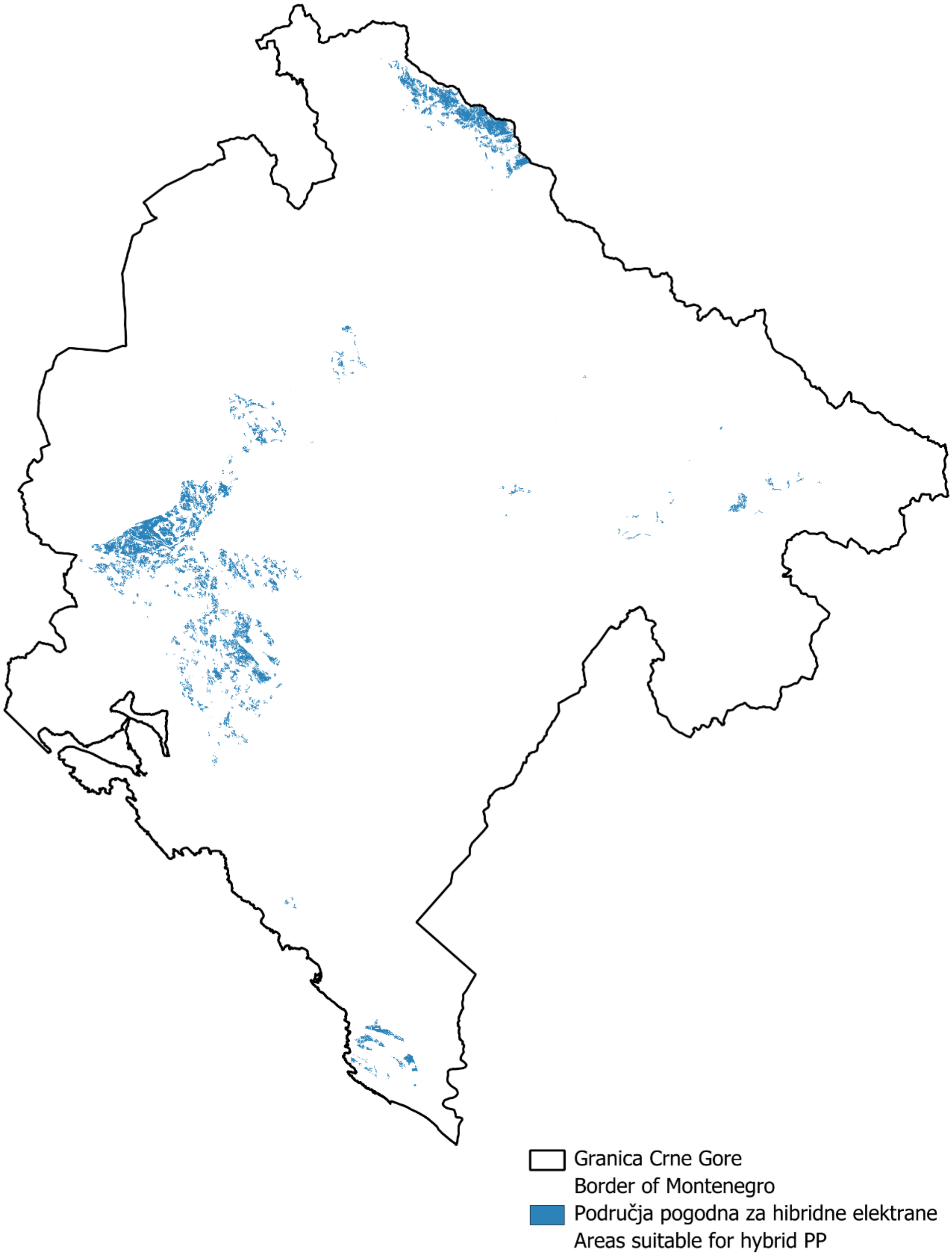

Figure 3.32 The resulting map showing good solar and wind energy potentials

3.6 Brownfields

Brownfields are abandoned, derelict or underutilised land and sites that were previously used for industrial, commercial, infrastructural or military purposes and that today represent a potential for redevelopment. These locations are typically characterised by existing or former development and, in many cases, by the presence of soil, groundwater or building contamination, which can complicate their reuse. Nevertheless, brownfield sites are usually well connected to infrastructure, as they are most often located in urban or peri-urban areas and are close to transport and energy networks.

In the context of spatial planning and energy development, brownfield sites are of particular importance because they enable new projects to be developed without occupying natural or agricultural land. Redeveloping brownfield sites reduces conflict with environmental protection, biodiversity conservation and other land-use functions. For this reason, brownfields are frequently identified as suitable locations for energy facilities, especially solar power plants, energy storage systems, substations and other energy-related infrastructure.

The redevelopment of brownfield sites contributes to sustainable development, urban regeneration and efficient land use. In contemporary strategic and energy planning documents, particularly at the EU level, such areas are often given priority over greenfield sites, which are undeveloped and natural areas.

By collecting data on brownfields in Montenegro, a total of 321 locations (Table 3.7) with a combined area of over 2,607 hectares were identified. These areas have various former or current uses, including industry, landfills and quarries, and a large number of them are still in operation. There is no official inventory of brownfields, and the available data are of limited reliability, particularly with regard to their boundaries and future land use. However, given their importance for sustainable land use, an analysis of all available data was carried out here with respect to their potential for solar energy utilisation. Since the data on brownfields are of insufficient reliability, all locations were analysed in three ways:

- potential for the construction of large solar power plants connected to the transmission network (Figure 3.29, Table 3.8),
- potential for the construction of small solar power plants connected to the distribution network (Figure 3.30, Table 3.9), and
- technical potential for the construction of solar power plants (Figure 3.31, Table 3.10).

Table 3.8 Brownfields in Montenegro

Landuse	Number	Area [ha]
Industrial	201	1,442
Landfill	16	193
Quarry	104	972
Total	**321**	**2,607**

It should be emphasised that the currently available information does not include data on which degraded areas are still in use or how long they will continue to be used. Consequently, the areas presented in the tables should be considered only as indicative information on the overall potential, and not as an indication of the scale that can be realised under the current conditions.

Table 3.9 Brownfields in zones with medium and high potential for SPP development – transmission grid

Landuse	Medium potential [ha]	High potential [ha]
Industrial	11	0
Landfill	56	21
Quarry	189	8
Total	**256**	**29**

Total solar potential is estimated to be 285 MW.

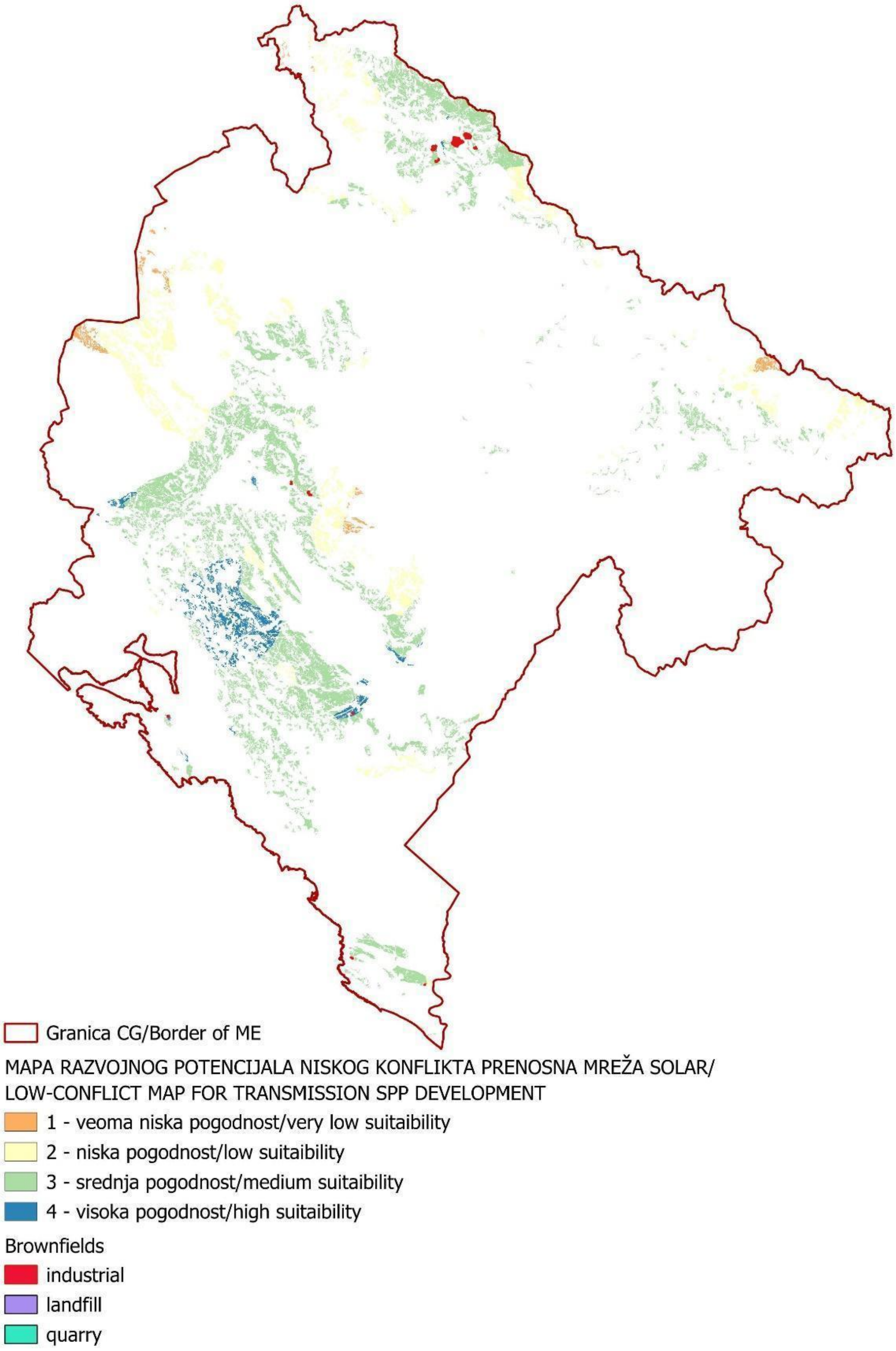

Figure 3.33 Low conflict map for transmission SPP development

Table 3.10 Brownfields in zones with medium and high potential for SPP development – distribution grid

Landuse	Medium potential [ha]	High potential [ha]
Industrial	25	26
Landfill	66	11
Quarry	193	14
Total	**284**	**51**

Total solar potential is estimated to be 335 MW. The combined potential for distribution and transmission solar power plants is not a simple sum (620MW), but 346 MW due to overlap (274 MW).

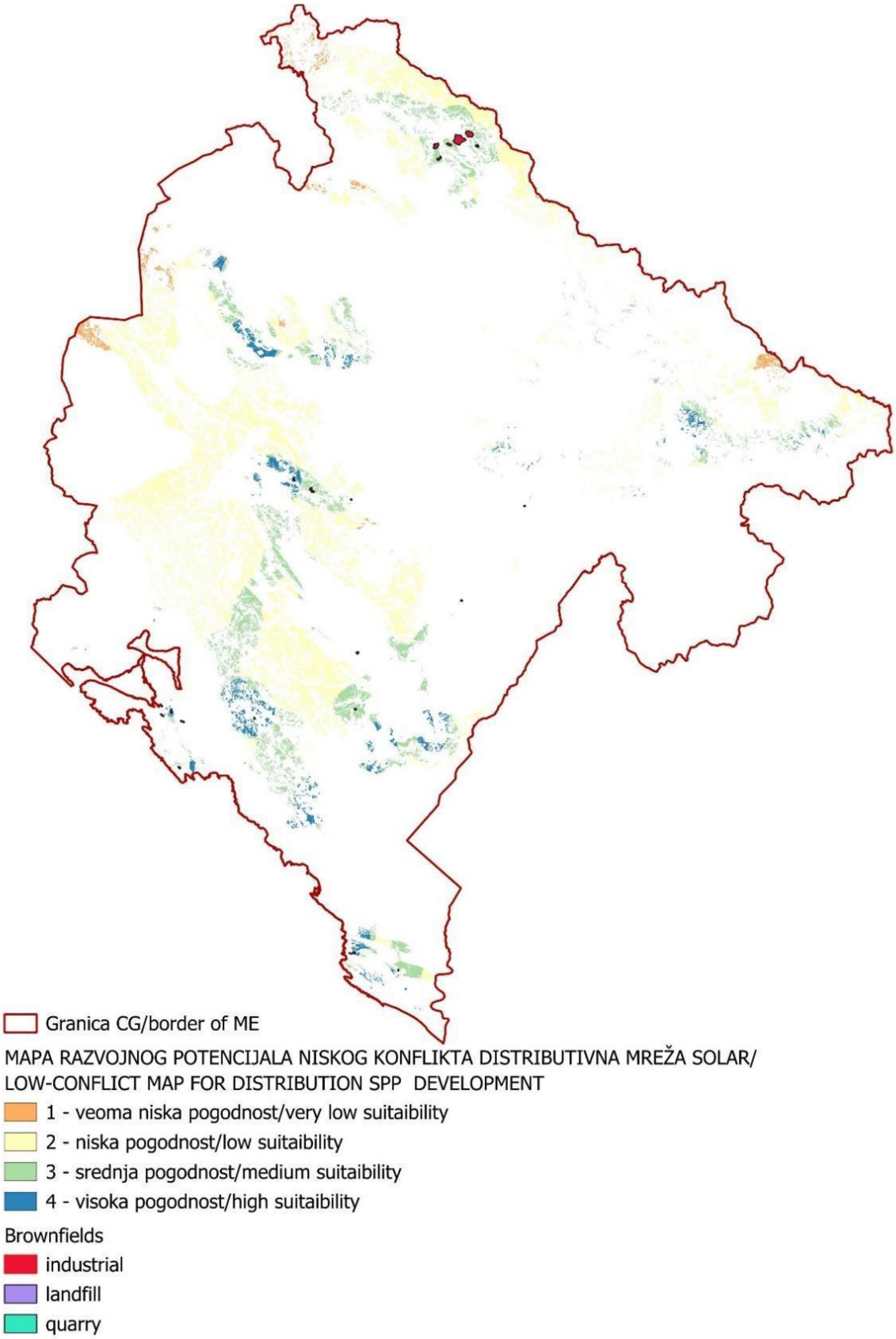

Figure 3.34 Low conflict map for distribution SPP development

Table 3.11 Brownfields in zones with medium and high GHI

Landuse	Medium potential [ha]	High potential [ha]
Industrial	1404	1062
Landfill	193	92
Quarry	949	429
Total	**2532**	**1567**

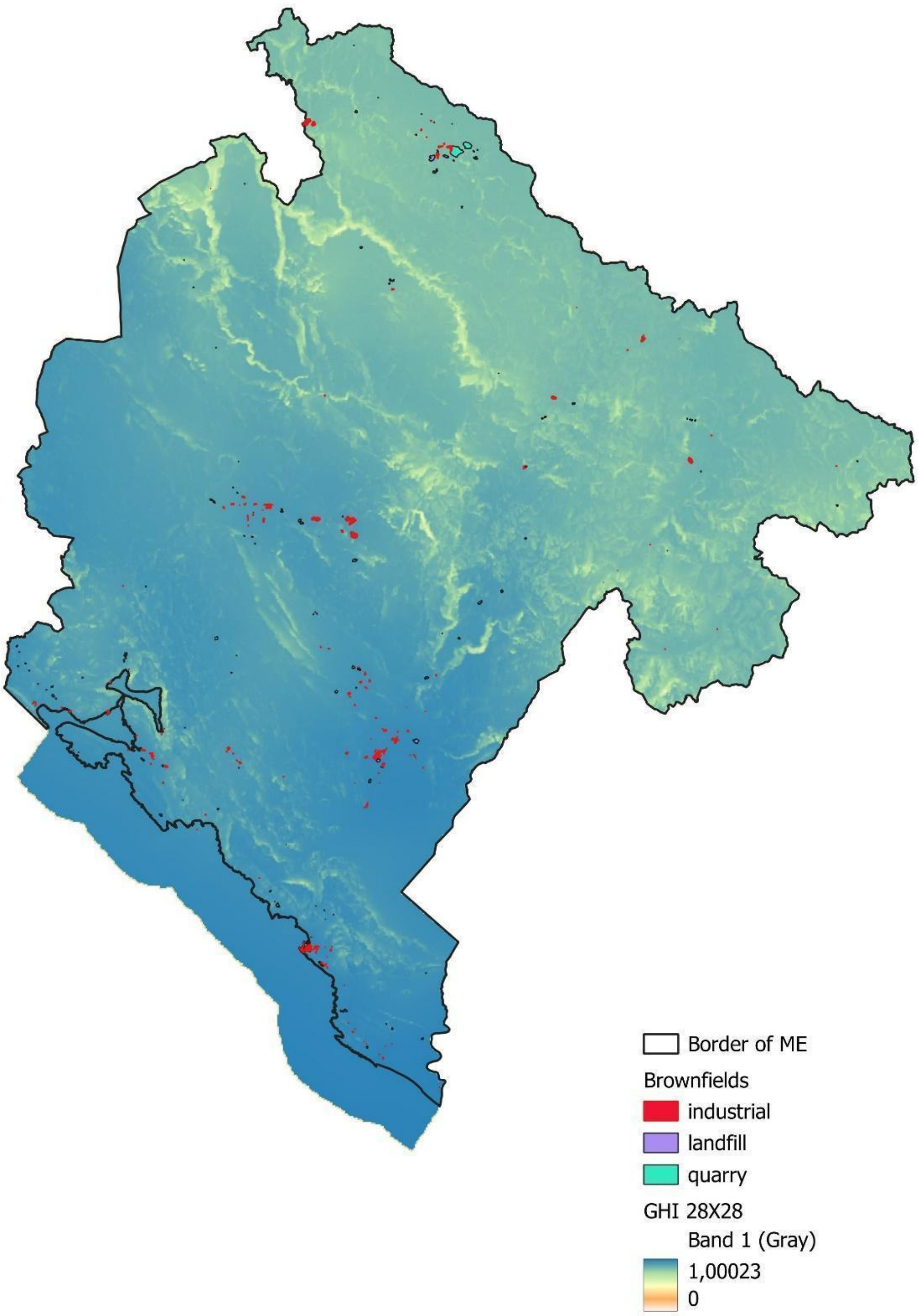

Figure 3.35 Normalised gross solar potential (Global Horizontal Irradiation)

4. Conclusion

The primary means of achieving national decarbonisation goals is the development of renewable energy sources. This is reflected in the increase of the share of renewables in total final energy consumption, as well as in the reduction of greenhouse gas emissions through the substitution of fossil fuels. Montenegro's energy policy and its National Energy and Climate Plan recognise the expansion of renewable energy sources as the most effective measure.

The potential for utilising solar and wind energy in Montenegro has been examined in numerous studies, and a substantial gross potential has been confirmed. This is further supported by the strong interest of investors in developing solar and wind power projects. On the other hand, it should be emphasised that previous studies did not consider conflicts between renewable energy development and environmental protection, cultural heritage or the socio-economic purposes of land use. Additionally, in recent years no strategic document, guidelines or similar instrument has been available to steer the development of renewable energy in an optimal manner, aligned with the needs of the energy system and the sustainable use of space.

The methodology for planning locations for the development of solar and wind power plants with low land-use conflict is proposed in this document. Conceptually, it has already been tested through applications in the regions of Zadar and Nikšić but has been adapted and improved for implementation across the entire territory of Montenegro. The improvements include the use and processing of a significantly larger volume of georeferenced data of various types and formats. Furthermore, the inclusion of grid capacity as a key criterion for determining the technically usable potential has directly contributed to enhancing the quality of the results. It is also important to highlight the inclusion of a new algorithm for evaluating landscape values, representing an upgrade compared to the previous methodological framework.

The aim of the methodology is to conduct a comprehensive analysis of all factors (for which reliable georeferenced data were available) relevant for selecting optimal locations for new solar power plants and wind farms. In the end, the estimates of potential that have been provided, which were derived on the basis of common practical experience, are indicative. A precise assessment of energy potential is an integral part of feasibility studies and the preparation of technical documentation prescribed by law, which are essential steps in the development of such projects. Within these documents, a micro-location analysis is also carried out, as it is the only way to fully assess all details relevant to the feasibility of a project at a given site, particularly taking into account the uncertainty surrounding the development dynamics of the necessary infrastructure, market conditions and regulatory developments in areas that influence the development of renewable energy sources.

It should also be emphasised that the construction of new grid infrastructure for connecting new renewable energy sources will have an impact on the future price of electricity. As a high level of renewable integration is expected, it is reasonable to assume that electricity prices may increase. On the other hand, the availability of energy will also increase, which may offset the aforementioned negative effect on prices. In any case, it is clear that without the development of new renewable energy sources, it will not be possible to achieve the national decarbonisation targets.

Conceptually, the methodology is based on three main steps in the processing of georeferenced data: identifying legal and biophysical constraints, evaluating the technically usable potential and evaluating land-use conflicts between solar and wind plants and other spatial purposes. Finally, as the concluding step, the maps generated through these three processes are overlaid to produce a resulting map showing the level of technical potential in areas identified as low-conflict zones (Table 3.7 - Table 3.10).

The results are encouraging. In locations characterised by minimal conflict and high development potential, a combined capacity of 15,630 MW[19], or nearly 16 GW, for smaller and larger solar power plants has been identified. These zones span an area of 156 square kilometers – roughly one and a half times the area of the city of Podgorica. For wind farms, the identified capacity is around 650 MW across approximately 65 square kilometers – an area comparable in size to Petnjica, one of Montenegro's smallest municipalities.

This capacity translates to an annual electricity production of nearly 20 TWh for solar and 1,200 GWh for wind, which would surpass Montenegro's current annual electricity production by a factor of five to six. Given that Montenegro's current renewable energy share of gross final energy consumption is 45.5% and 850 MW of installed capacity, the potential identified in this study is fit to meet and exceed the country's 2030 renewable energy targets without compromising natural or socio-economic values.

Significant renewable energy potential also exists on brownfield sites (industrial areas, landfills and quarries). Data available to the project team indicate that around 346 MW of combined solar distribution and transmission capacity can be developed in low-conflict areas with medium to high development potential. Energy produced on just these brownfield locations could replace one third of the current generation from the Pljevlja coal plant.

The maps created in this report are prepared in formats commonly used in GIS tools, enabling straightforward micro-location analysis. These results provide a reliable basis for the preparation of conceptual designs, environmental impact assessment studies and other fundamental project development documents. It should be emphasised that the results of this study do not define final project locations, rather, they indicate where an optimal combination of technically usable potential and minimal conflict with other land uses exists. Each project must undergo the standard legally defined development procedure.

The purpose of this study is to serve decision-makers and investors as a tool for the optimal planning of solar and wind power plant development. More specifically, it aims to guide projects toward areas that not only offer favorable technical potential but also exhibit minimal conflict with environmental protection, cultural values and socio-economic land-use factors. The development of new renewable energy projects affects the operation of the power system and consequently influences the potential for integrating new sources, making regular updates of this study's results necessary.

[19]Out of total installed capacity identified for smaller power plants on low-conflict locations with high development potential (8,435 MW), the distribution grid can currently accommodate 235 MW.

5. Appendix

- Methodology for grid modelling
- PPGIS Analysis
- Conflict maps combined with constraint maps

- High-resolution downloadable maps [External link]

5.1 Methodology for grid modelling

5.1.1 Introduction

This document outlines a detailed methodology and model for analysing the capacity of Montenegro's existing transmission grid as well as planned expansions. The aim is to ensure the grid's ability to reliably accommodate current demands, integrate renewable energy sources and meet projected growth requirements. Special attention is given to the unique characteristics of Montenegro's energy mix, geographic conditions, and strategic goals for renewable energy integration and cross-border energy exchange.

The broader methodology, of which the grid model methodology is a part, maps renewable energy potential across the entire territory of Montenegro. The focus is primarily on the spatial distribution of potential, while the aspect of connection to the transmission network is only one of many parameters that influence the assessment of land suitability.

For this reason, a simplified methodology was selected for the purposes of this type of spatial analysis, one that enables the production of sufficiently reliable and spatially applicable results. More advanced models – which would take into account the dynamic behavior of the system, regional grid interconnections and more detailed input/output parameters – would undoubtedly deliver more precise results from the perspective of the power grid, but would significantly increase the cost, preparation time and complexity of the study, without meaningfully improving the spatial representation of potential, which was the primary objective.

It should be emphasised that the aim of this study is not to provide all the technical answers needed for connecting specific facilities, but rather to serve as an indicative guideline for investors and institutions in selecting potential locations. Detailed analysis of the technical connection conditions for particular power plants still would need to be carried out afterwards. This is done for each individual site by specialised institutions using accurate data on capacity, configuration and the dynamic characteristics of the system.

5.1.2 Scope

The scope of this analysis includes:

- **Power Flow Analysis:** Evaluation of steady-state power flows under normal and contingency conditions within Montenegro's grid.
- **Renewable Integration:** Modelling the impact of wind, solar and hydro generation on grid capacity.
- **Future Demand Scenarios:** Analysis of capacity requirements under forecasted load growth and generation expansion aligned with Montenegro's energy strategy, in current grid conditions (2025) and future grid development conditions (2032). The scenario for 2032 will contain planned generation plants according to the moderate scenario, which serves as the basis for other planning documents and aligns with grid development strategies.
- The moderate scenario, as defined in the study Managing Large-Scale RES Integration and Energy Storage in Montenegro, represents a balanced approach to renewable energy integration. It is based on projections from Montenegro's National Generation Development Plans, further refined by CGES through consultations with developers and financial institutions. This scenario assumes a reasonable expansion of wind and solar capacities, considering projects that are most likely to be realised by 2032. It provides a pragmatic outlook on variable renewable energy (VRE) deployment while ensuring alignment with transmission system development and grid stability objectives. It includes:

Solar Power Plants – aggregated 750 MW planned

Distribution production by nodes:

- RP 400 kV Čevo – 40%
- TS 400/110/35 kV Brezna - 15%
- TS 220/110/35 kV kV Vilusi - 30%
- TS 400/110 kV Podgorica 2 – 7.5%
- TS 400/110/35 kV Ribarevine – 7.5%

Wind Farms – aggregated 294 MW planned

Distribution of the planned production by nodes:

- TS 400/110/35 kV Brezna – 50%, 147 MW
- TS 400/110 kV Ribarevine – 50%, 147 MW

5.1.3 Modelling components

5.1.3.1 Grid Topology

The transmission grid of Montenegro is represented using a nodal model:

- **Nodes (Buses):** Substations, load centres and major generation sites, including key hydro plants such as Piva and Perućica.
- **Branches:** Transmission lines (400 kV, 220 kV and 110 kV), submarine cable to Italy, transformers, and interconnectors with Serbia, Bosnia and Herzegovina, Kosovo and Albania.

New grid projects to be considered in the 2032 scenario:

- 400 kV OHL Čevo – Pljevlja
- 400 kV OHL Pljevlja – Bajina Bašta (RS)
- 400 kV OHL Brezna – Sarajevo (BA) with 400/220 kV SS Crkv.polje
- 400/110 kV SS Brezna (II phase)
- 400 kV RP Čevo
- 400/110 kV SS Trubjela
- 400/110 kV SS Kolašin
- 400/110 kV SS Korita
- 220/110 kV SS Vilusi
- VSR Shant reactor 250 MVA Lastva
- 220 kV OHLs Trebinje (BA) – Koplik (AL) ampacity increase
- 220/110 kV SS Perućica reconstruction/enlargement
- 110 kV UCL Ulcinj – Velipoje (AL) with 110/35 kV SS V.Plaža
- 110 kV OHL Lastva – Kotor
- 110 kV OHLs Budva-Lastva-Tivat ampacity increase
- 110 kV OHL Vilusi – H.Novi
- 110 kV OHL Virpazar – Ulcinj
- 110/35 kV Luštica with 2x110 UCL
- 110/10 kV SS Bečići
- 110/35 kV SS Buljarica
- 110/10 kV Podgorica 7

- 110/10 kV Podgorica 9

5.1.3.2 Input Data

Key data inputs for the model include:

- **Grid Parameters:** Impedance, thermal ratings and voltage levels for all lines and transformers.
- **Load Profiles:** Load data for industrial, commercial and residential sectors.
- **Generation Profiles:** Output from hydro, solar and wind plants, including variability in renewable sources.
- **Interconnection Data:** Import/export capabilities and historical cross-border flows.
- **Contingency Scenarios:** N-1 outages based on historical faults and maintenance schedules.

5.1.3.3 Tools and Software

The analysis is conducted using advanced tools, including:

- **PSS®E** for load flow and contingency analysis,
- **GIS Software** for mapping and spatial analysis of transmission infrastructure.

5.1.4 Methodology

This methodology defines the calculation of the maximum available connection power at existing connection points of the electrical transmission system, ensuring no additional system development is required while permanently maintaining the guaranteed transmission parameters.

5.1.4.1 Initial Assumptions

Two models of the Montenegrin transmission system will be considered:

- 2025 – actual grid model
- 2032 – model according to the updated Grid Development Plan 2023-2032

For the actual grid model, the calculation utilises a representative model of the Montenegrin power system, prepared for day-ahead congestion forecasts and combined with other models of the synchronous area of continental Europe. The following assumptions are taken into account:

- The model reflects the system's state from March-April of the last year, on a work day.
- It incorporates the usual topology and switching state of Montenegrin system elements.
- Initial engagement of Montenegrin hydroelectric power plants enables necessary adjustments for potential capacity increases (ΔC) as outlined in Article 4.4.

The calculation is conducted individually for all existing buses in the transmission system.

The 2032 model assumes grid upgrades according to the updated Grid Development Plan 2023-2032 as well as the distribution of new renewable plants according to the moderate scenario. The main projects are listed in Article 3.1. and the distribution of new renewables is explained in Article 2.

5.1.4.2 Initial Scenario

The exchange power at the connection point in the base case (BC) is determined in both directions individually:

Production Power (BCG) – Base case generation power

Consumption Power (BCL) – Base case load power

These values correspond to forces included in the model defined in Article 4.1.

5.1.4.3 Previously Occupied Capacity

Previously occupied capacity at the connection point is determined individually for generation (AACG) and load (AACL) for both maximum and minimum exchange modes:

AACGmax – Maximum previously occupied generation capacity, based on the highest average hourly production in the last 12 months.

AACGmin – Minimum previously occupied generation capacity, based on the lowest average hourly production in the last 12 months.

AACLmax – Maximum previously occupied load capacity, based on the highest average hourly consumption in the last 12 months.

AACLmin – Minimum previously occupied load capacity, based on the lowest average hourly consumption in the last 12 months.

5.1.4.4 Possible Capacity Increase

The potential increase in capacity at the connection point (ΔC) is calculated for both generation (ΔCG) and load (ΔCL).

Generation (ΔCG):

A virtual power plant with large installed capacity is modelled at the connection point.

The plant's production starts at 10 MW, with the nearest hydroelectric power plant's output reduced by 10 MW.

Power flow calculations and N-1 system safety analyses are conducted.

If no system element overload occurs, the virtual plant's power increases by 10 MW, and the nearest hydroelectric plant's output is reduced by the same amount.

This iterative process continues until an overload is detected.

ΔCG is defined as the virtual power plant's capacity in the penultimate iteration.

Load (ΔCL):

A virtual consumer is modelled at the connection point.

The consumer's load starts at 10 MW, with the nearest hydroelectric plant's output increased by 10 MW.

Power flow calculations and N-1 safety analyses are performed.

If no system element overload occurs, the virtual consumer's load increases by 10 MW, and the nearest hydroelectric plant's output is increased by the same amount.

This process repeats until an overload is detected.

ΔCL is defined as the virtual consumer's load in the penultimate iteration. All other short terms (BCG, BCL, AACG, AACL, etc.) represent input variables that are predefined based on historical data and system conditions. The potential capacity increase (ΔC) is then determined through grid model simulations.

5.1.4.5 Maximum Theoretical Connection Power

The maximum theoretical connection power for generation (GTCG) and load (GTCL) is calculated as follows:

GTCG = BCG - BCL + ΔCG

GTCL = BCL - BCG + ΔCL

5.1.4.6 Confidence Margin

The reliability margin accounts for model deviations, measurement errors, system interdependencies and other factors. It is determined by a separate procedure. For this model, 10 MW is used as the margin.

5.1.4.7 Remaining Free Capacity

Generation

Remaining Transmission Capacity for Generation (RTCG) is calculated as:

RTCG = GTCG - TRMG - AACGmax + AACLmin

Where,

GTCG – Maximum available generation connection power

TRMG – Reliability margin for generation power flow calculations

AACGmax: –Reserved connection power for generation

AACLmin – Minimum recorded load at the connection point under normal conditions in the last 36 months

Load

Remaining Transmission Capacity for Load (RTCL) is calculated as:

RTCL = GTCL - TRML - AACLmax + AACGmin

Where,

GTCL – Maximum available load connection power

TRML – Reliability margin for load power flow calculations

AACLmax – Reserved connection power for load

AACGmin – Minimum recorded generation at the connection point under normal conditions in the last 36 months

5.1.4.8 Maximum Available Connection Power

The maximum available connection power (MACP) accounts for other constraints, including:

- Approved or planned facilities at the connection point,
- Spatial and technical limitations of substations or line connections,
- Availability and limitations of planning documentation,
- Social, environmental and other relevant factors.

The MACP is determined as a value below the remaining theoretical free capacity (RTC) after considering these constraints.

This approach to assessing connection constraints reflects the specific practices applied in the Montenegrin transmission system rather than a universal or standardised methodology. When evaluating the capacity for connecting new generation or load, several practical considerations are taken into account, including the availability of spare bays in substations, the spatial feasibility of substation expansion to accommodate new feeders and whether the transmission line configuration allows for the straightforward addition of new connections.

Legal issues related to private property often arise in this process, as well as environmental concerns, particularly in ecologically sensitive areas. These factors are diverse and difficult to quantify with a precise numerical value. Therefore, in practice, their impact is incorporated by adjusting the theoretically derived maximum capacity downward, typically rounding to the nearest lower multiple of 10 MW.

5.1.5 Methodology for distribution network

The allocation of renewable energy potential is closely linked to the possibility of connection to the available and future network infrastructure. Since there is a difference in voltage levels and the purpose of transmission and distribution networks, it is important to highlight the differences in the capacity to connect new energy sources and the way in which this capacity is defined. Unlike the transmission network, whose primary legally defined obligation is to ensure the secure operation of the power system, the distribution network, due to its close interaction with consumers, is primarily tasked with ensuring the quality of supply to connected users. This supply quality is defined more narrowly as the quality of the voltage profile, which is influenced by new distributed energy sources. Accordingly, a set of connection criteria is defined and checked during the planning phase of new distributed energy sources. These criteria are defined within the Technical Recommendation for Connecting Distributed Energy Sources in Montenegro and the Rules for the Operation of the

Electricity Distribution System, verified by the Energy and Utility Regulatory Agency. Given the recent adoption of the Energy Law and the Law on the Use of Energy from Renewable Sources, the update of the Distribution System Operation Rules is expected.

It is important to note that the distribution network in Montenegro is comprised of 35 kV, 10 kV and 0.4 kV levels (there are also 20 kV and 6 kV networks, but to a negligible extent). This analysis covers only the 35 kV network due to the availability of geo-referenced data. Analogous data for other voltage levels are being prepared and are not expected to be available for several years due to the number of elements they cover. Considering the technical characteristics of the 35 kV network in Montenegro (types, cross-sections, line lengths and configurations), the maximum installed power of interest per connection point does not exceed 5 MW. The 35 kV network is radial and can be significantly extended in areas of Montenegro with sparse consumption. The supply points of the 35 kV network are the 110/35 kV substations, which, except for Podgorica and Nikšić (which have two or more such substations), also serve as supply points for all towns in Montenegro.

To ensure the connection and safe parallel operation of distributed energy sources with the distribution system, the following criteria must be met:

- Allowed voltage deviation (change, variation),
- Short-circuit power,
- Flicker,
- Allowed higher harmonic currents,
- Allowed higher harmonic voltage,
- Safe synchronisation,
- Maximum allowed DC injection,
- Voltage unbalance,
- Reactive power.

The short-circuit power criterion is only checked for distributed sources with installed capacity over 1 MVA.

Although all the above criteria are checked for any distributed energy source, it is important to note that for photovoltaic plants, which are the subject of the Study, only the voltage deviation criterion is checked before preparing technical documentation. All other criteria are addressed in the project and measured during the trial operation and are therefore not covered here.

The maximum relative voltage change during the switching on/off of the largest generator unit must not exceed 2% Un, i.e., 0.7 kV in absolute terms for the observed network. Also, if several distributed energy sources are connected to the distribution network of the observed voltage level, the maximum allowed relative voltage change during their simultaneous switching on/off must not exceed 5% Un, i.e., 1.75 kV.

The formula for a quick assessment of this criterion is,

$$\Delta U = S_n / S_{SC}$$

Where,

S_n – nominal power of the distributed energy source

S_{SC} – short-circuit power at the connection point

According to this formula, it can be concluded that the required short-circuit power at the connection point should be 250 MVA for an installed power of 5 MW. If such a plant were connected via two transformers, then a short-circuit power of 125 MVA would be sufficient (since the criterion considers the switching on/off of the largest unit).

In addition to this voltage deviation condition, it is important to emphasise that the voltage values in the network in steady-state must be between 33.25 kV and 38 kV.

Apart from the simple formula, the impact of the plant connection on the network can be assessed by performing a load flow calculation for a specific switching state of the network and the planned connection point. However, the mentioned voltage limits must be respected. The procedure is iterative, testing each potential connection point (in this case, a 35 kV network node represented by a 35/X kV substation) to determine whether a 5 MW photovoltaic plant causes voltage deviations beyond the prescribed limits (in steady-state or during switching). Each node is considered separately. It should be noted that any changes to the normal network configuration or the addition of new energy sources require a new calculation. This procedure provides only an indicative assessment of connection feasibility, while regulations require a personalised study for each new connection, reflecting the current network conditions.

Below is an overview of the state of the 35 kV network in terms of voltage conditions and load for all seven regions.

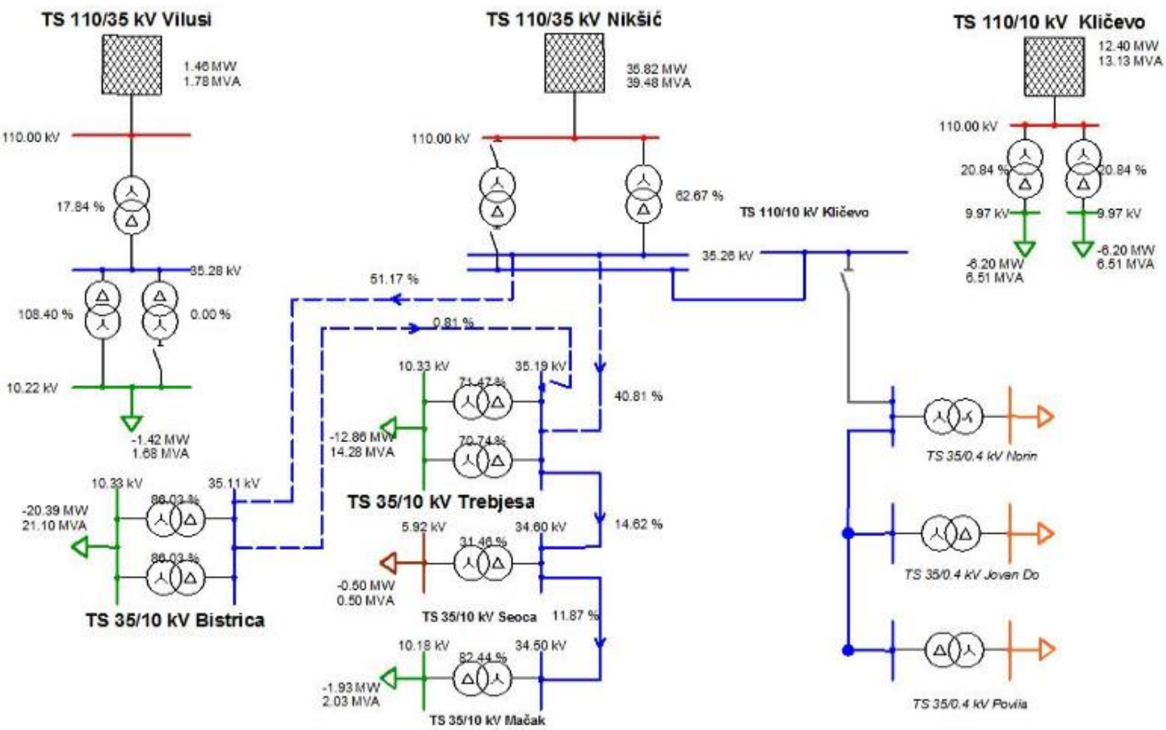

Figure 5.1 Voltage profile and loading for 35 kV grid supplied in Nikšić

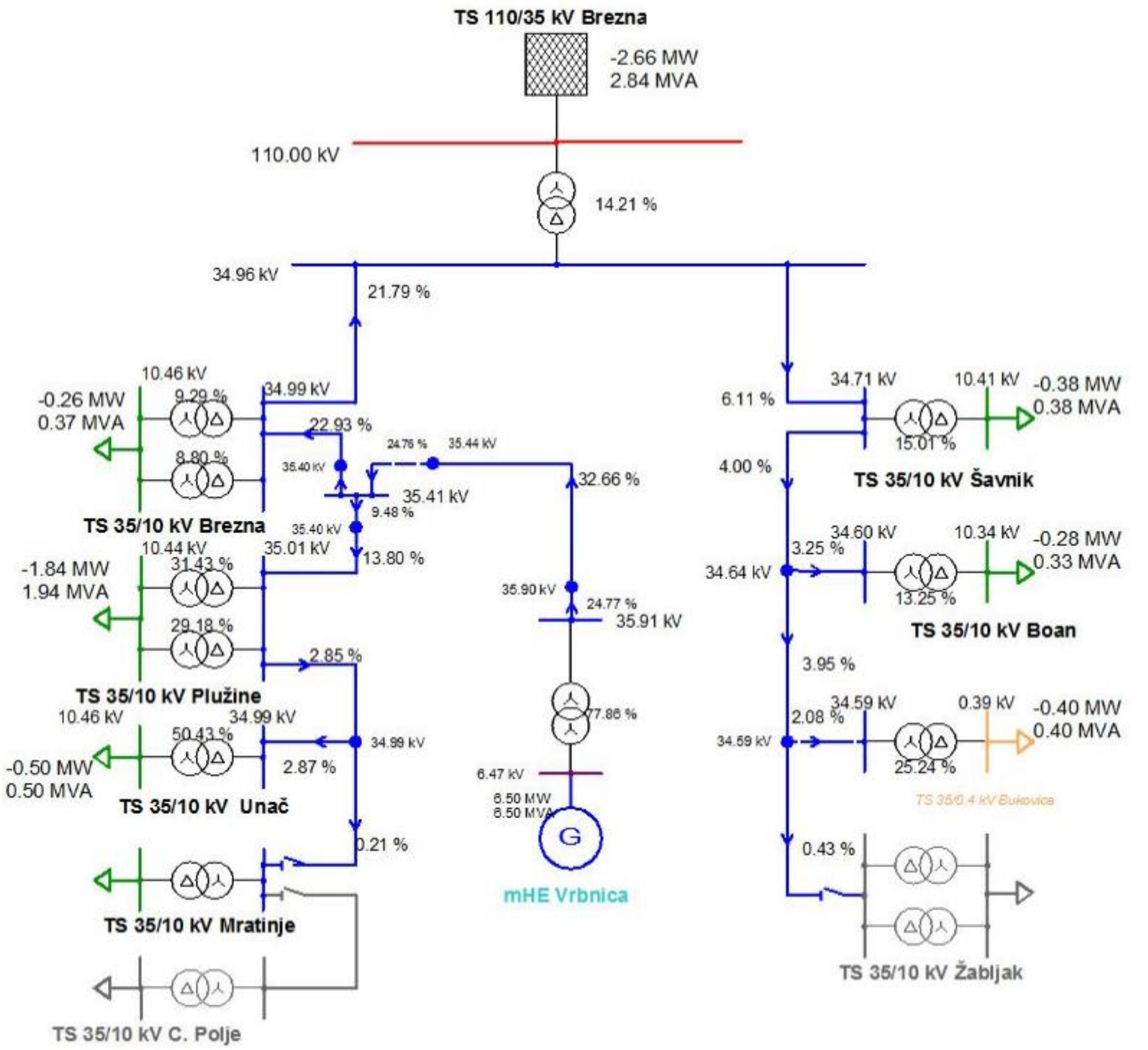

Figure 5.2 Voltage profile and loading for 35 kV grid supplied from TS Brezna

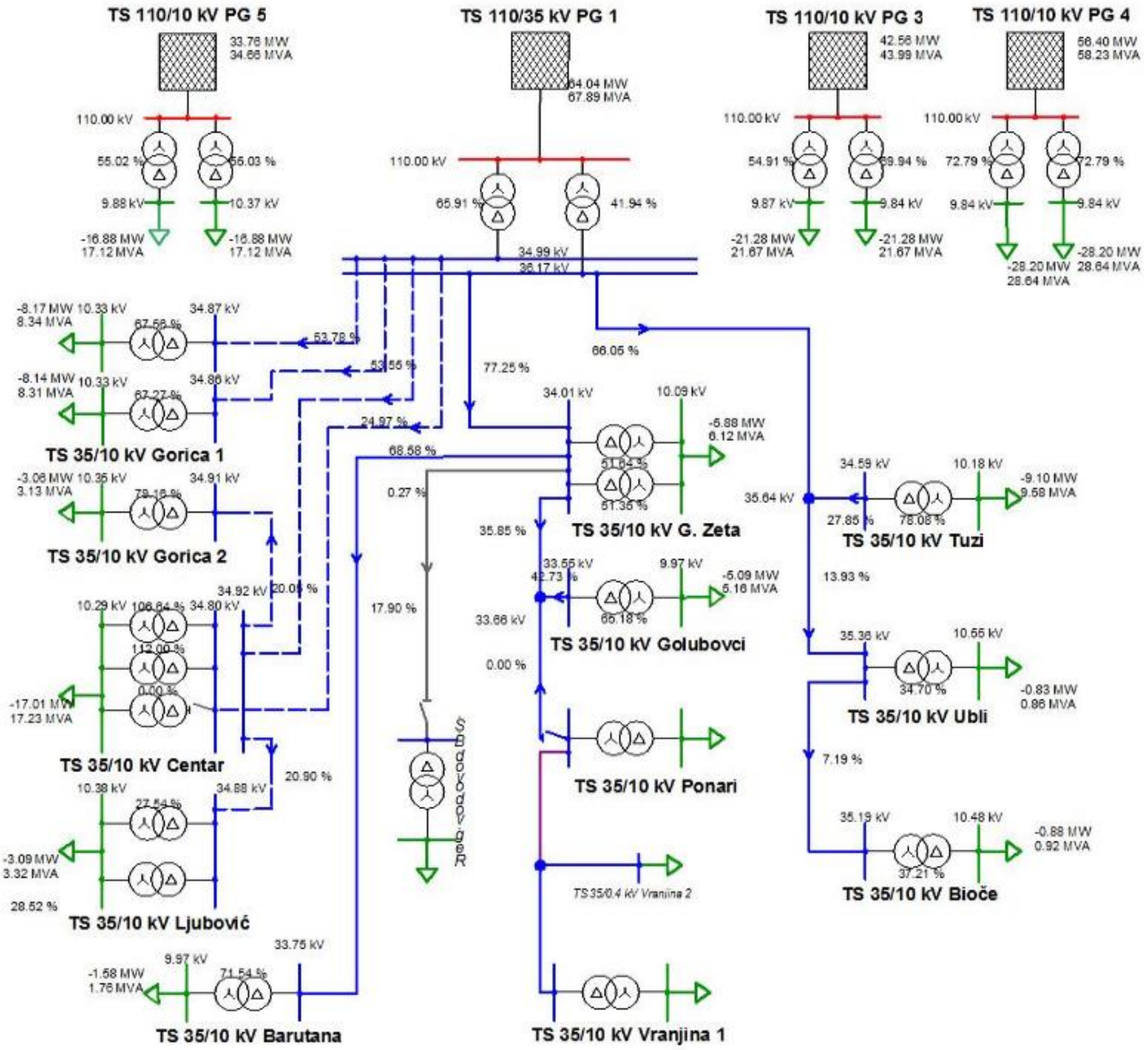

Figure 5.3 Voltage profile and loading for 35 kV grid supplied from TS PG1

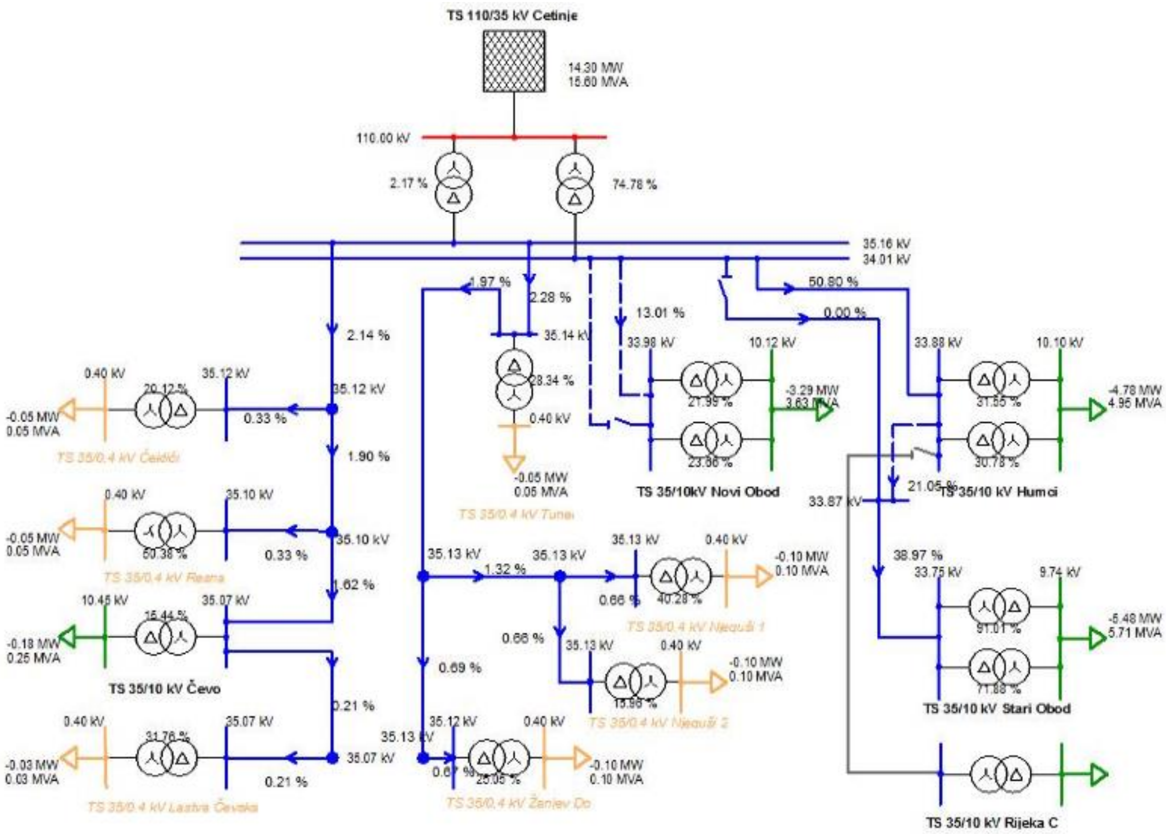

Figure 5.4 Voltage profile and loading for 35 kV grid supplied from TS Cetinje

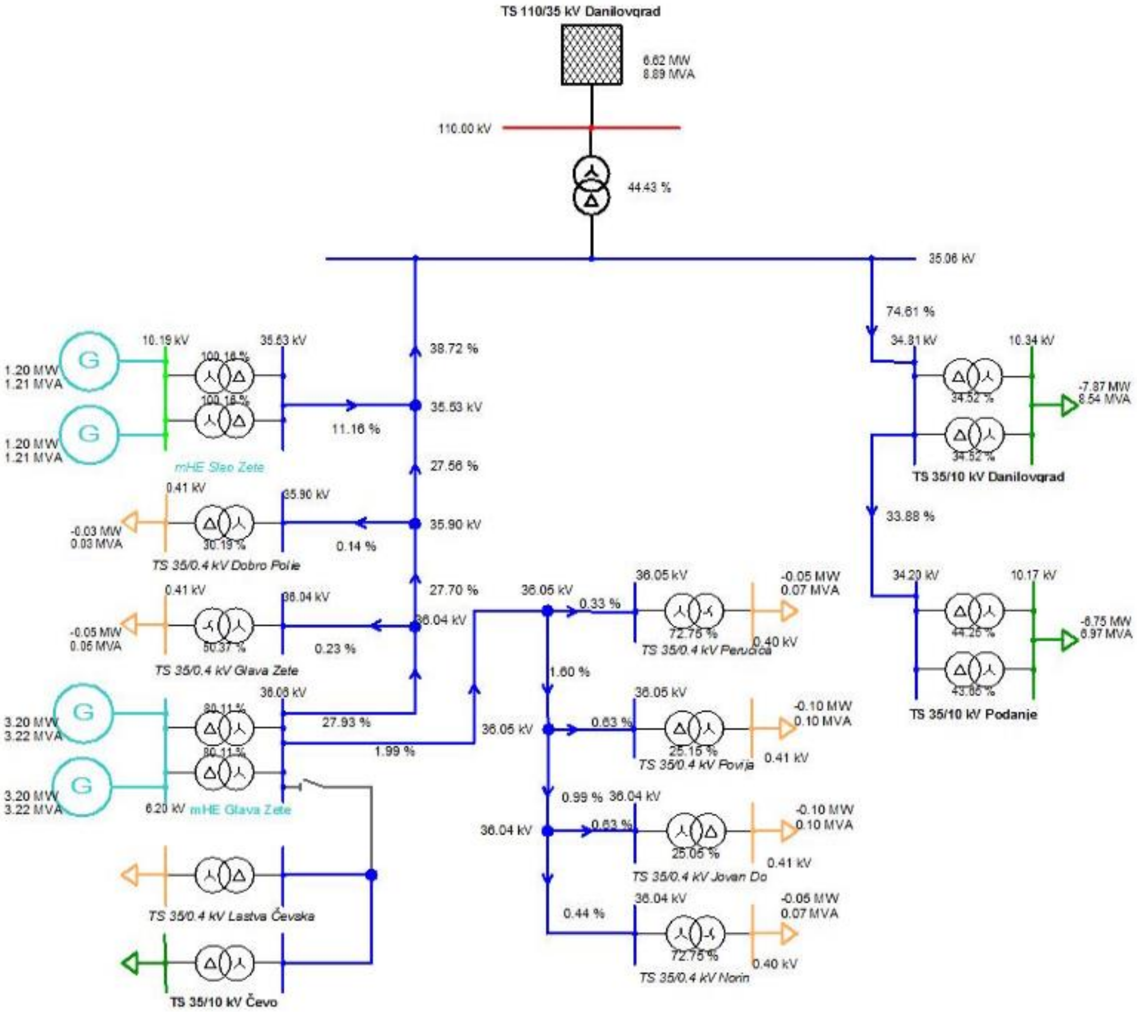

Figure 5.5 Voltage profile and loading for 35 kV grid supplied from TS Danilovgrad

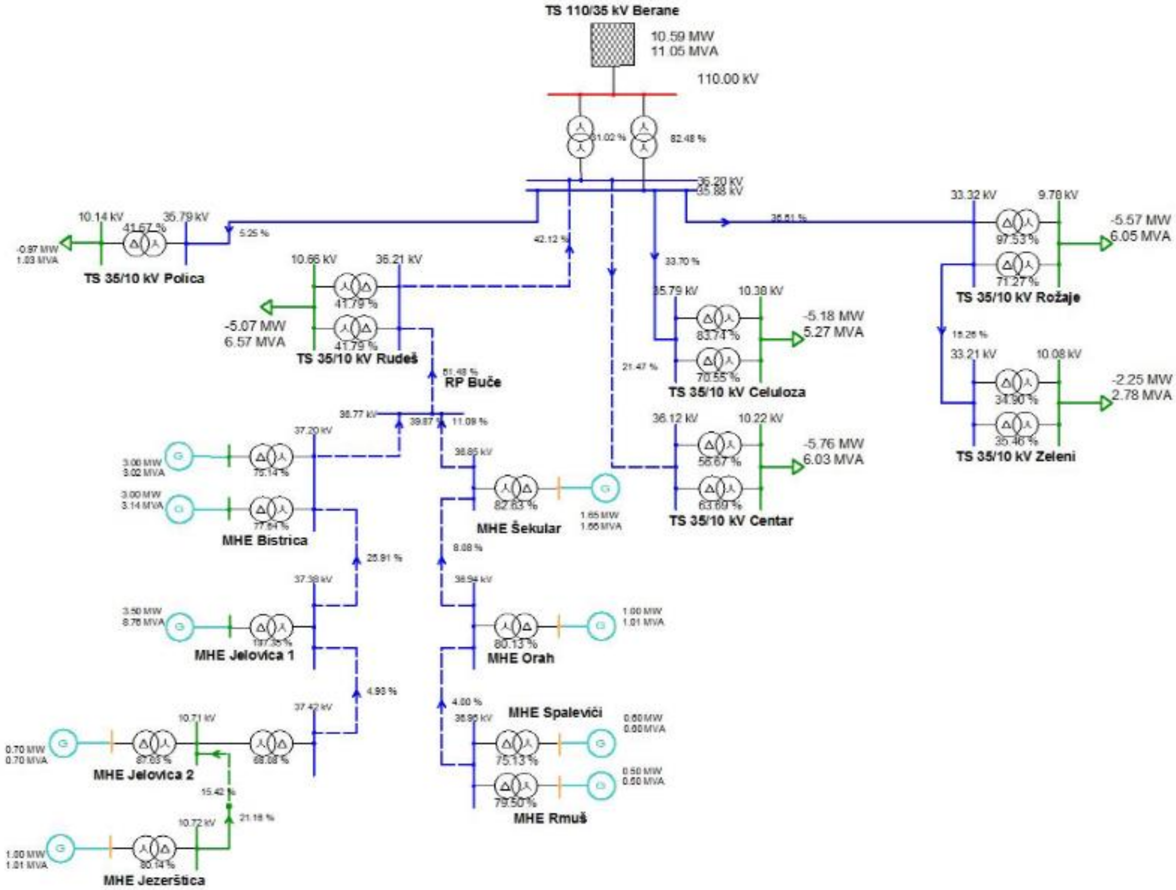

Figure 5.6 Voltage profile and loading for 35 kV grid supplied from TS Berane

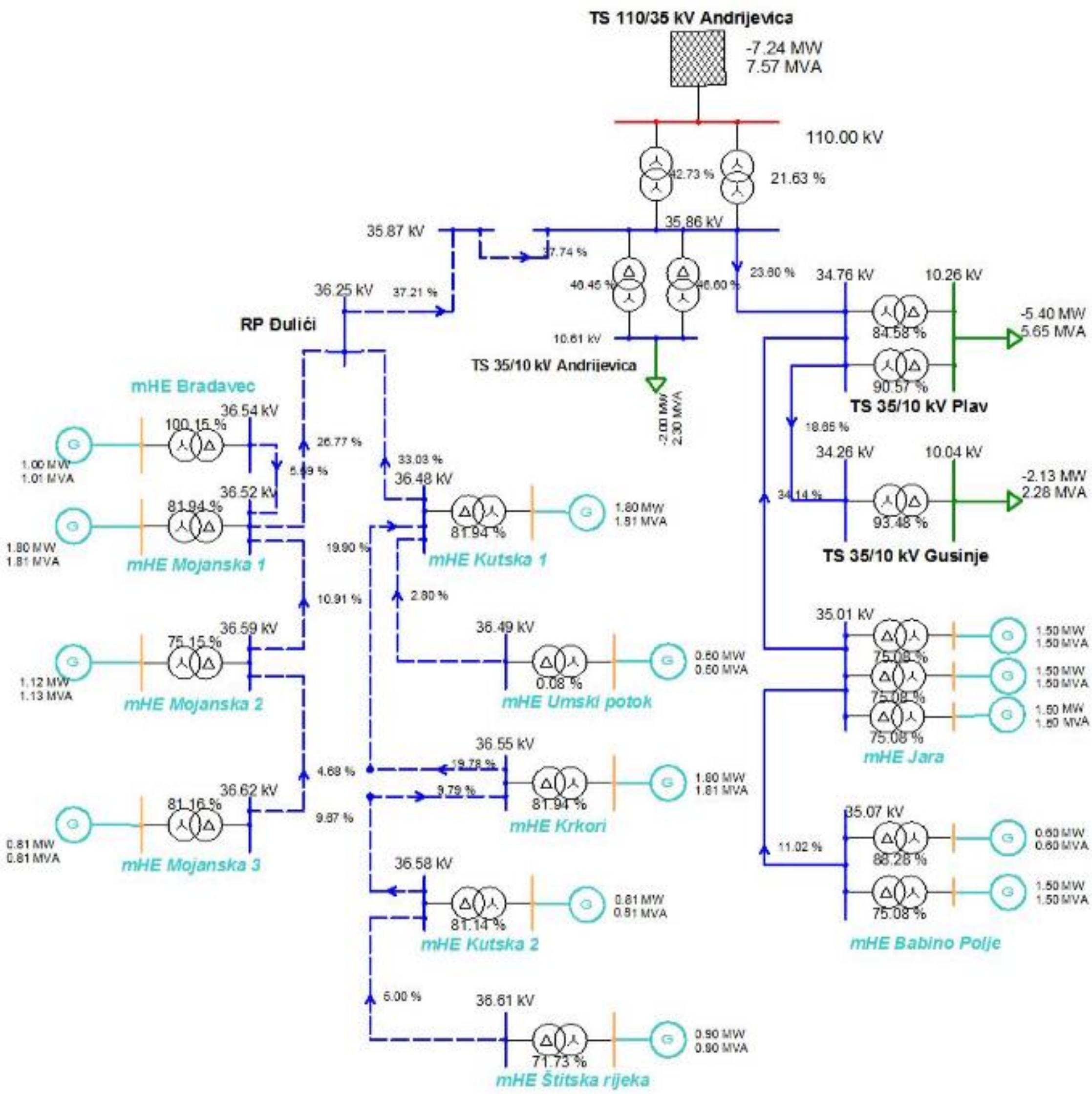

Figure 5.7 Voltage profile and loading for 35 kV grid supplied from TS Andrijevica

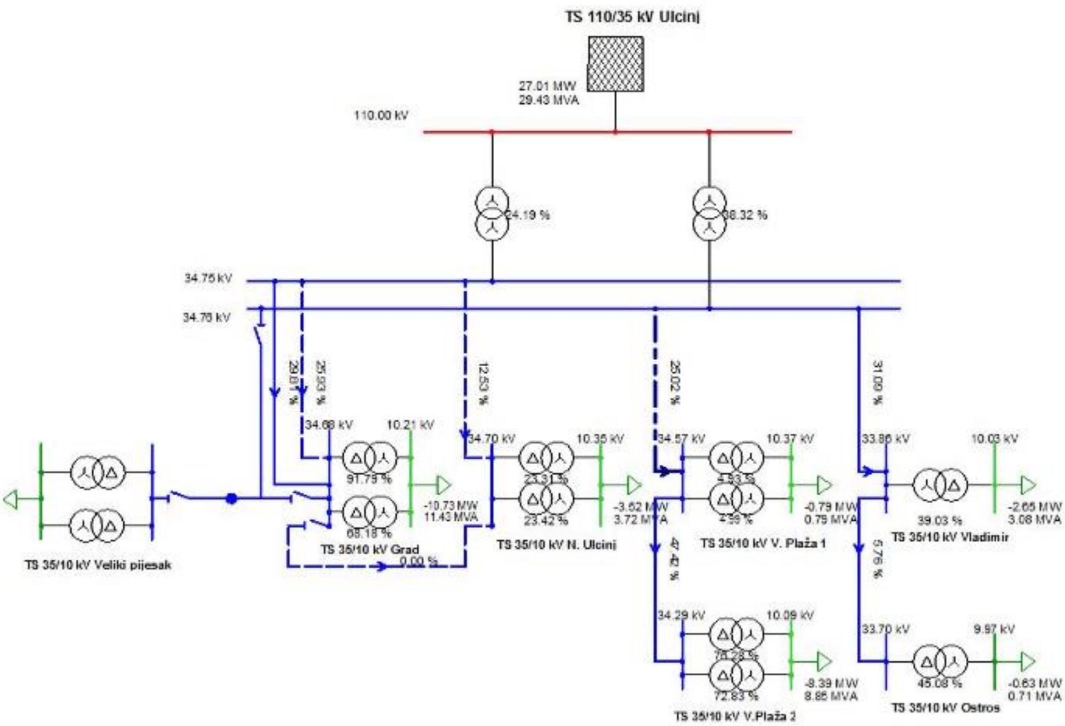

Figure 5.8 Voltage profile and loading for 35 kV grid supplied from TS Ulcinj

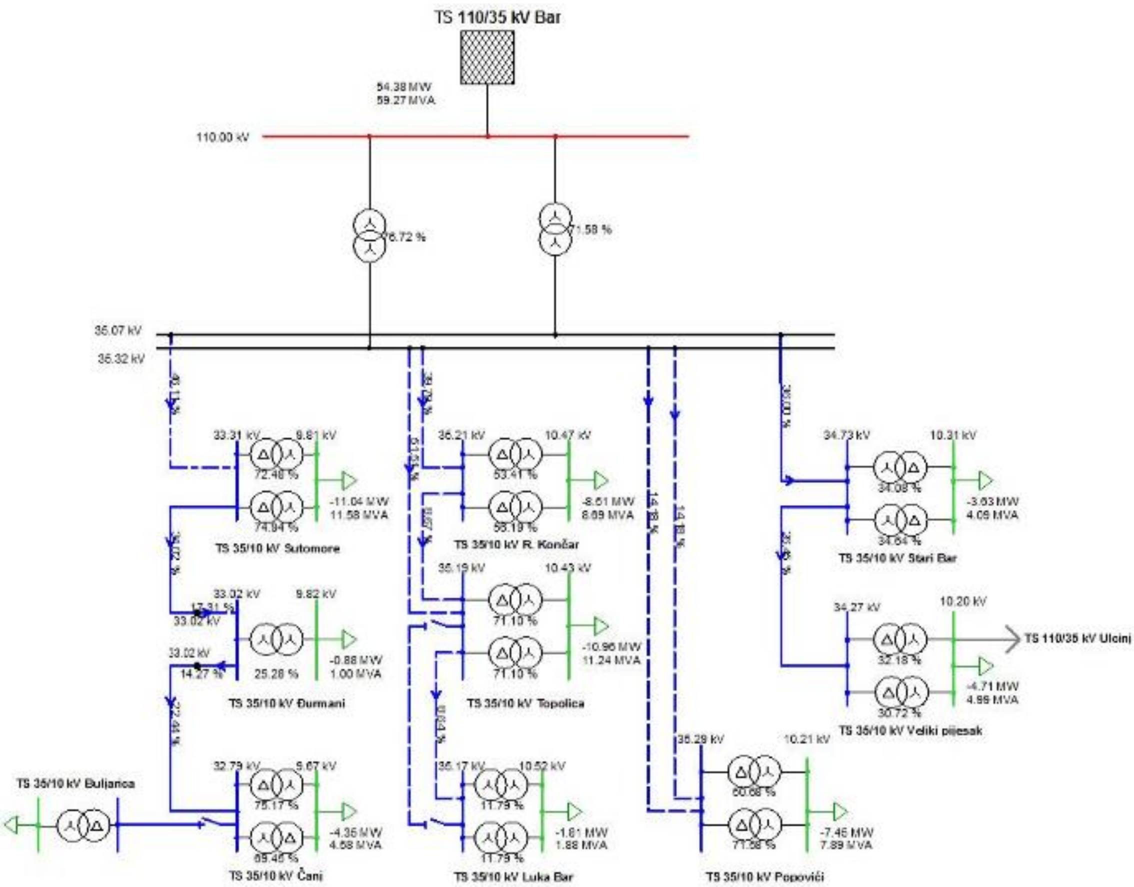

Figure 5.9 Voltage profile and loading for 35 kV grid supplied from TS Bar

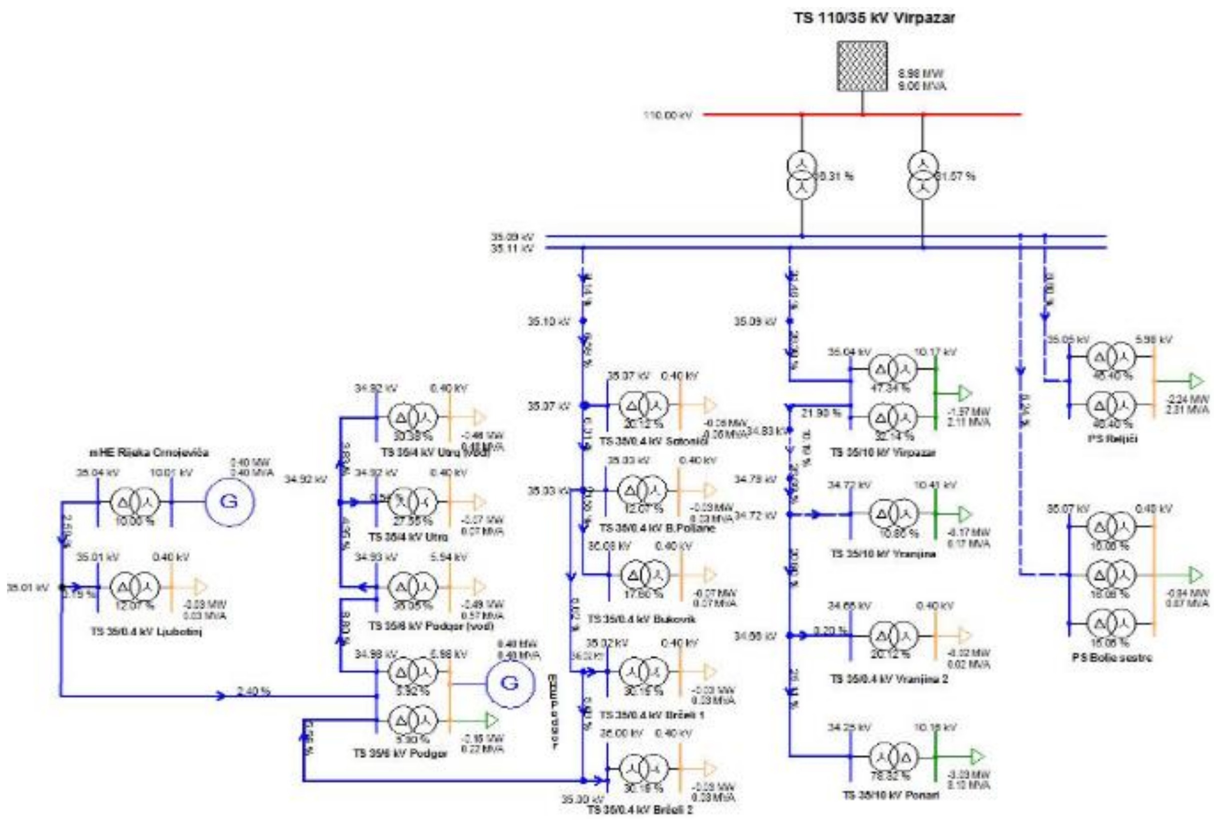

Figure 5.10 Voltage profile and loading for 35 kV grid supplied from TS Virpazar

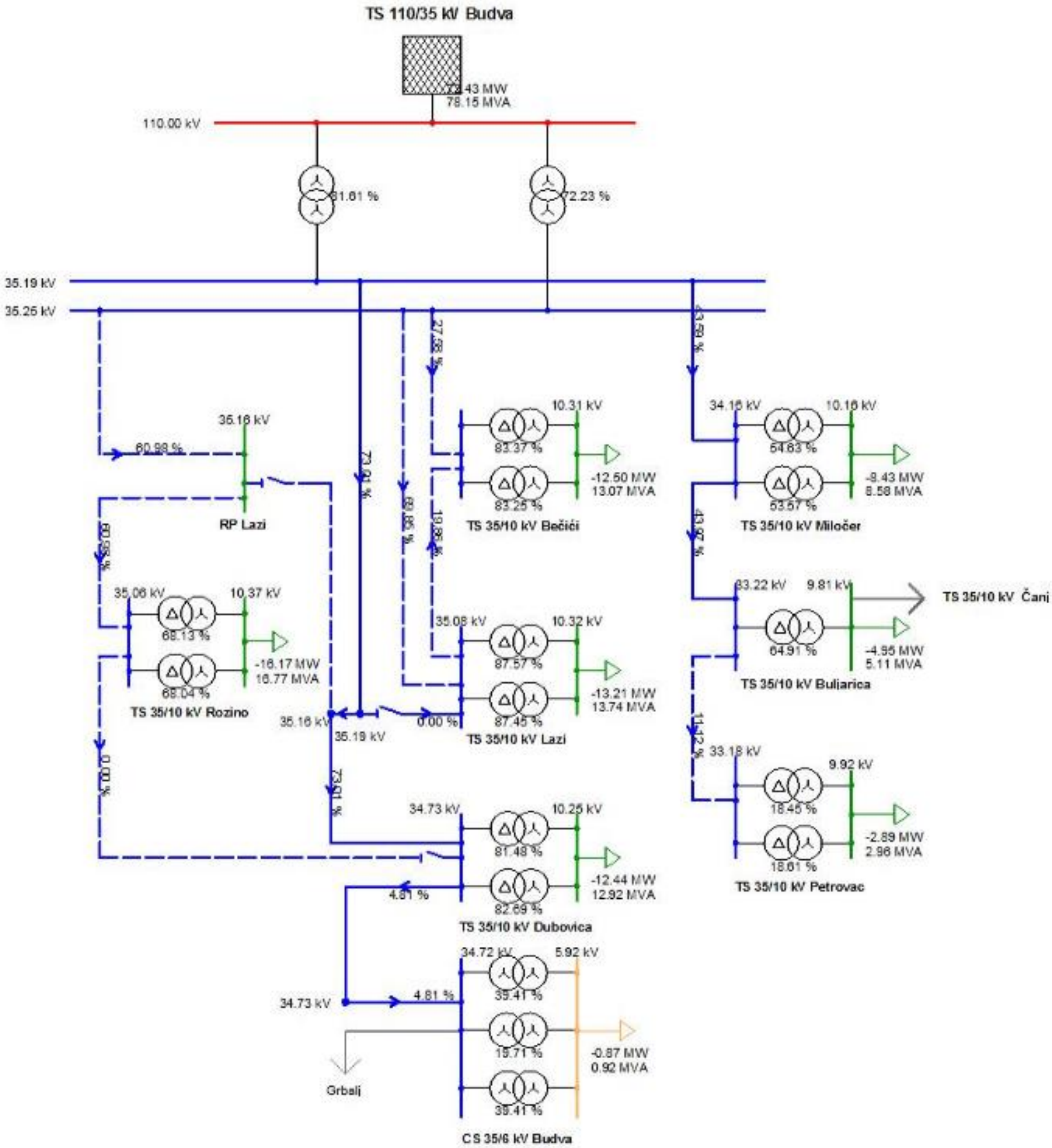

Figure 5.11 Voltage profile and loading for 35 kV grid supplied from TS Budva

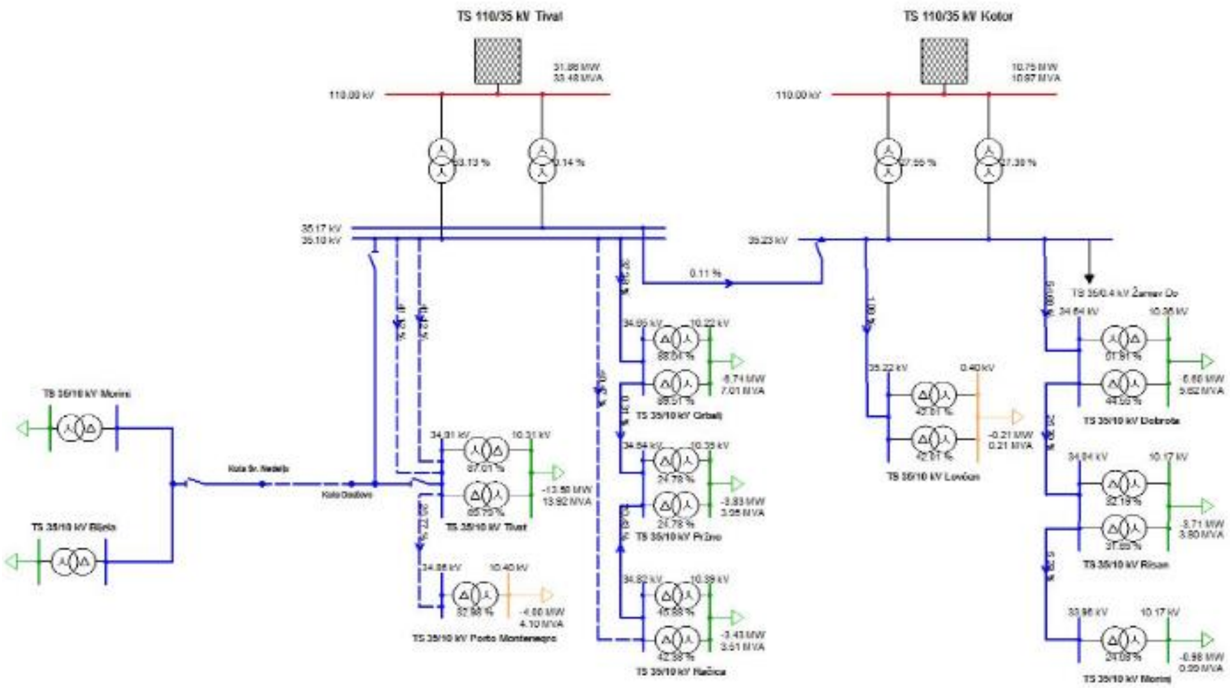

Figure 5.12 Voltage profile and loading for 35 kV grid supplied from TS Tivat and TS Kotor

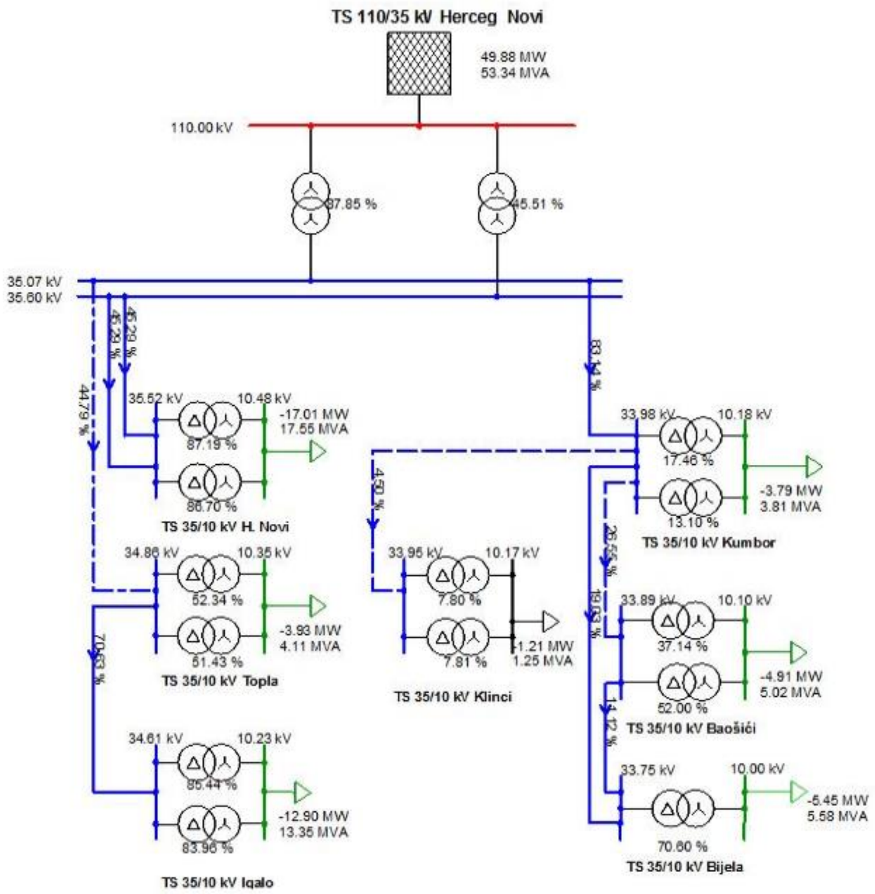

Figure 5.13 Voltage profile and loading for 35 kV grid supplied from TS Herceg Novi

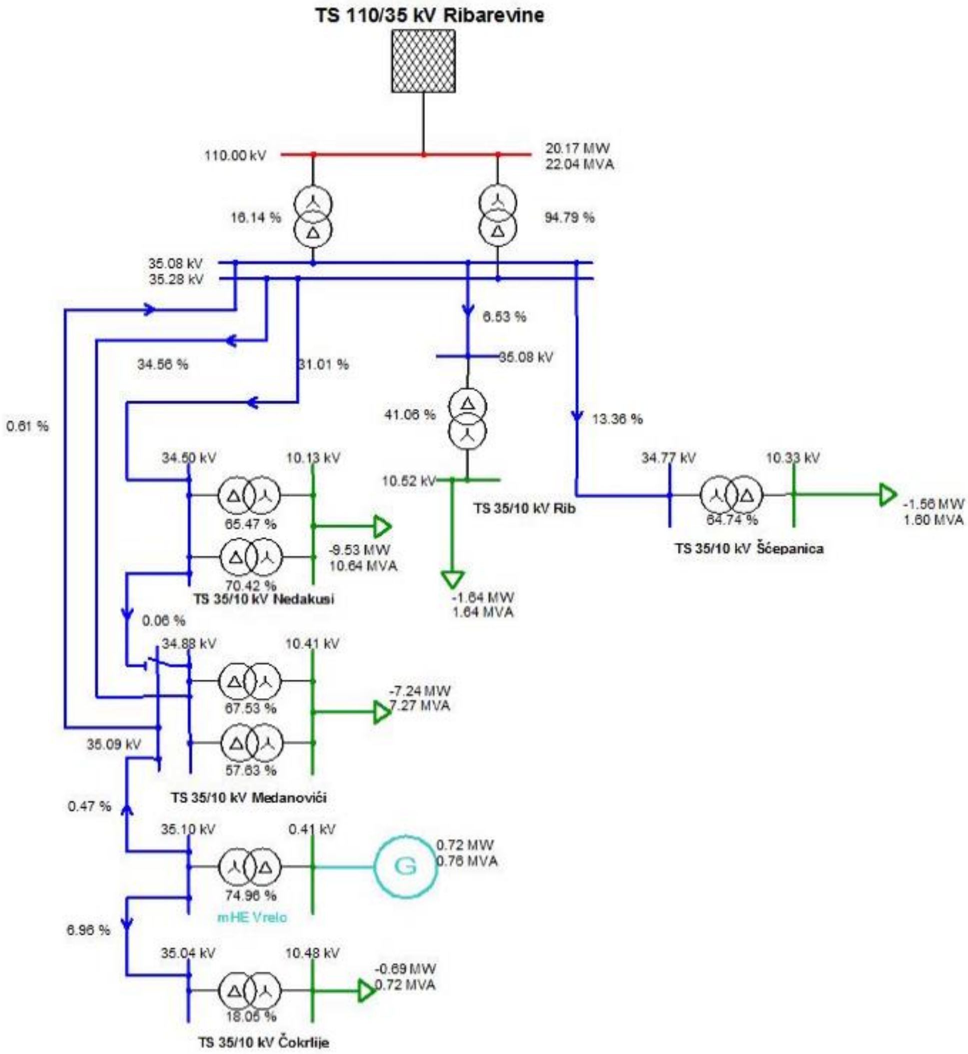

Figure 5.14 Voltage profile and loading for 35 kV grid supplied from TS Ribarevine

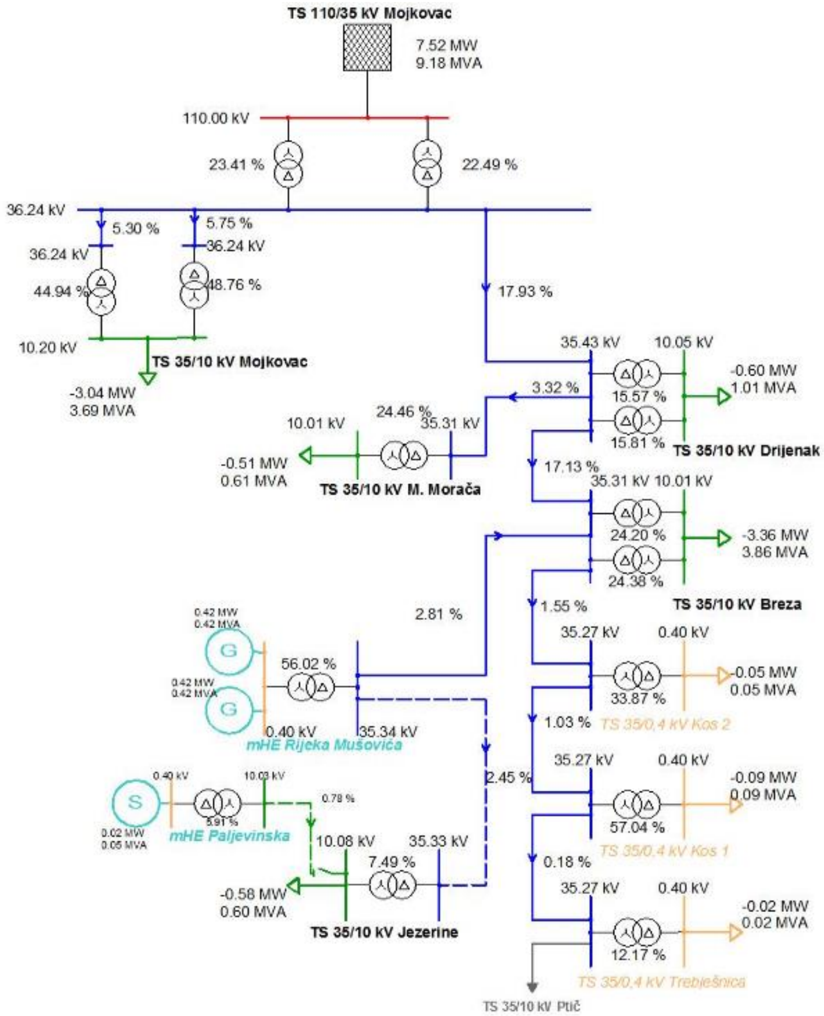

Figure 5.15 Voltage profile and loading for 35 kV grid supplied from TS Mojkovac

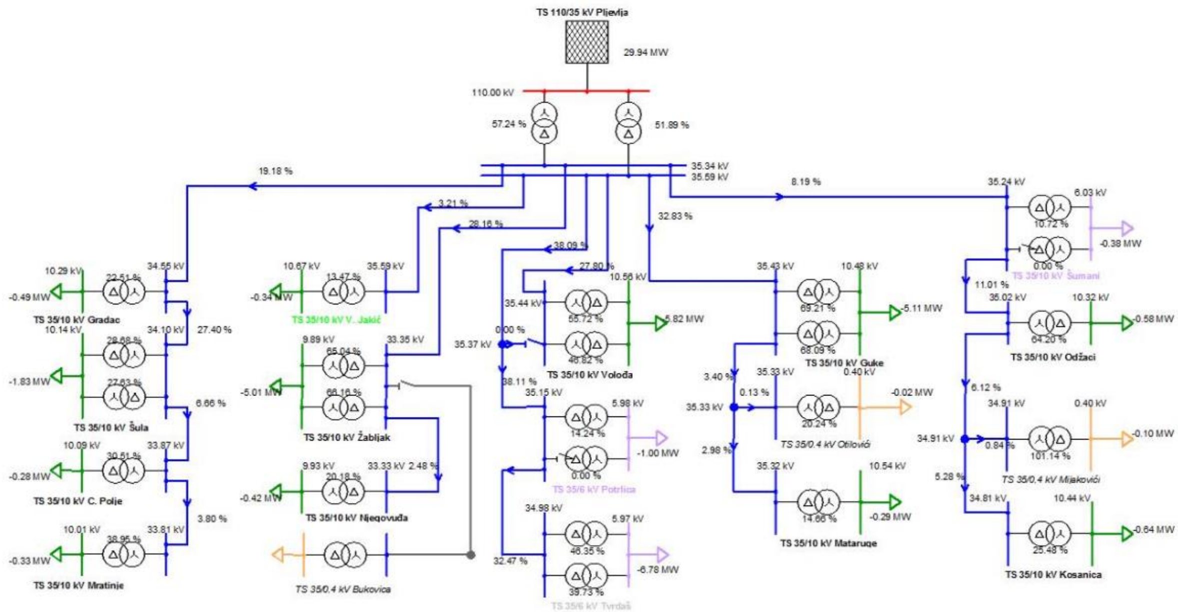

Figure 5.16 Voltage profile and loading for 35 kV grid supplied from TS Pljevlja

Table 5.1 Overview of 35 kV grid nodes

Substation	Connection capacity [MW]
TS 35/10 kV Rudeš	5
TS 35/10 kV Centar Berane	5
TS 35/10 kV Velimir Jakić	0
TS 35/10 kV Šavnik	5
TS 35/10 kV Žabljak	5
TS 35/10 kV Barutana	0
TS 35/10 kV Njegovuđa	5
TS 35/10 kV Lazi	5
TS 35/10 kV Odžaci	0
TS 35/10 kV Bečići	5
TS 35/10 kV Ljubović	0
TS 35/10 kV Gornja Zeta	0
TS 35/10 kV Rožaje	0
TS 35/10 kV Plav	5
TS 35/10 kV Gusinje	5
TS 35/10 kV Medanovići	0
TS 35/10 kV Čokrlije	0
TS 35/10 kV Ptič	0
TS 35/10 kV Nedakusi	0
TS 35/10 kV Šćepanica	0
TS 35/10 kV Andrijevica	5
TS 35/10 kV Drijenak	5
TS 35/10 kV Kolašin (Breza)	5
TS 35/10 kV Šule	0
TS 35/10 kV Bioče	0
TS 35/10 kV Ubli	0
TS 35/10 kV Tuzi	5
TS 35/10 kV Police	0
TS 35/10 kV Brezna	5
TS 35/10 kV Crkvičko Polje	0
TS 35/10 kV Zeleni	5
TS 35/6 kV Celuloza	0
TS 35/10 kV Podanje	0
TS 35/10 kV Čevo	0
TS 35/10 kV Rijeka Crnojevica	0
TS 35/10 kV Humci	5
TS 35/10 kV Boan	0

Substation	Connection capacity [MW]
TS 35/10 kV Plužine	5
TS 35/10 kV Gradac	0
TS 35/10 kV Poddubovica	0
TS 35/10 kV Grbalj	0
TS 35/10 kV Račica	0
TS 35/6 kV Podgor	0
TS 35/10 kV Pržno	5
TS 35/10 kV Guke	0
TS 35/10 kV Šumani	0
TS 35/10 kV Morinj	0
TS 35/10 kV Risan	5
TS 35/10 kV Dobrota	5
TS 35/10 kV Volođa	0
TS 35/10 kV Mataruge	0
TS 35/10 kV Klicevo	0
TS 35/10 kV Škaljari	5
TS 35/10 kV Kosanica	0
TS 35/10 kV Manastir Morača	0
TS 35/10 kV Virpazar	5
TS 35/10 kV Vladimir	0
TS 35/10 kV Ostros	0
TS 35/10 kV Grad	5
TS 35/10 kV Velika Plaža 1	5
TS 35/10 kV Velika Plaža 2	5
TS 35/10 kV Veliki Pijesak	5
TS 35/10 kV Stari Bar	5
TS 35/10 kV Sutomore	5
TS 35/10 kV Đurmani	5
TS 35/10 kV Čanj	5
TS 35/10 kV Buljarica	5
TS 35/10 kV Miločer	5
TS 35/10 kV Tivat	5
TS 35/10 kV Bijela	5
TS 35/10 kV Kumbor	5
TS 35/10 kV Topla	5
TS 35/10 kV Igalo	5
TS 35/10 kV Herceg Novi	5
TS 35/10 kV Ponari	0

Substation	Connection capacity [MW]
TS 35/10 kV Trebjesa	5
TS 35/10 kV Danilovgrad	5
TS 35/10 kV Seoca	0
TS 35/10 kV Mačak	0
TS 35/10 kV Rudnik Tvrdas	0
TS 35/10 kV Golubovci	5
TS 35/6 kV Bolje sestre	0
TS 35/10 kV Mratinje	0
TS 35/10 kV Novi Obod	5
TS 35/10 kV Unač	0
TS 35/10 kV Stari Obod	5
TS 35/10 kV Topolica	5
TS 35/10 kV Gorica A	0
TS 35/10 kV Gorica B	0
TS 35/10 kV Centar Podgorica	0
TS 35/10 kV Bistrica	0
TS 35/10 kV Rade Končar	0
TS 35/10 kV Luka Bar	0
TS 35/10 kV Arsenal Porto Montenegro	0

It is important to point out that a certain number of connection requirements have already been issued, which have priority over future requests.

Table 5.2 Overview of planned distribution power plants

Investor	Power [MW]	Minicipality
"KIPS" d.o.o Podgorica	0.90	Bar
Danilović Marija	0.60	Bar
"Solar Sing" d.o.o Bijelo Polje	4.80	Bijelo Polje
"BP Energy" d.o.o Bijelo Polje	4.25	Bijelo Polje
Slobodan Šćekić	4.50	Bijelo Polje
"Čevo solar" d.o.o Cetinje	3.25	Cetinje
Dejan Marinović	1.00	Cetinje
Vukčević Ana i Marković Vladimir	1.00	Cetinje
Predrag Mirjanić	3.06	Danilovgrad
Zeković Milija	1.50	Danilovgrad
Šaranović Boban, Milosav i Đorđija	1.60	Danilovgrad
Top dizajn d.o.o. Podgorica	0.30	Danilovgrad
Žarko Pajović	2.50	Kolašin
Igor Ercegović	2.03	Kotor
"KIPS" d.o.o Podgorica	1.35	Kotor
Gobović Tihomir i Lazar	2.00	Kotor
"Internorma" d.o.o Podgorica	5.00	Nikšić

"R-SOLAR" d.o.o. Nikšić	4.00	Nikšić
"Župa solar" d.o.o. Podgorica	3.00	Nikšić
"MWP" d.o.o Podgorica	4.00	Nikšić
"Solar elektro" d.o.o. Nikšić	1.00	Nikšić
Elektroprivredna Crne Gore	4.80	Nikšić
Elektroprivredna Crne Gore	4.80	Nikšić
Elektroprivredna Crne Gore	9.60	Nikšić
Vanja Maksimović	0.70	Nikšić
Krešeljević Vojin	2.00	Nikšić
"EnergoFinanzza" d.o.o. Podgorica	5.00	Podgorica
Internorma d.o.o Podgorica	3.13	Podgorica
Stojanović Lado	4.00	Podgorica
"MK Energy" d.o.o. Podgorica	5.00	Podgorica
"ZT Energy" d.o.o. Podgorica	4.50	Podgorica
"Voli trade" d.o.o Podgorica	2.00	Podgorica
"KIPS" d.o.o Podgorica	2.40	Podgorica
Vujošević Zoran	4.80	Podgorica
"MK Energy" d.o.o. Podgorica	5.00	Rožaje
"TZ Energy" d.o.o Tuzi	2.25	Tuzi
"Phyllon" d.o.o. Tuzi	10.00	Tuzi
E.C."Auto trade" d.o.o. Tuzi	1.00	Tuzi
Dedić Bajo	0.70	Ulcinj
Vukčević Žarko i Drano	5.00	Ulcinj
Vukčević Žarko i Drano	1.00	Ulcinj
Enver Lika	4.00	Ulcinj
Enver Lika	3.00	Ulcinj
"Agrolife Montenegro" d.o.o. Podgorica	5.00	Ulcinj
Herceg Novi - SE Ćukoš	3.60	Herceg Novi
Herceg Novi - SE Sasovići	5.00	Herceg Novi
Zoran Dedeić	3.00	Žabljak
Total [MW]	**152.92**	

5.2 Approach to public consultations in the MEGA project

In parallel with the technical work of identifying optimal locations for the development of solar and wind power projects, a public participation process was designed and implemented over the period June – October 2025.

The Public Participation Geographic Information System (PPGIS) tool was used for the consultations with the general public and local communities in six municipalities: Bijelo Polje, Cetinje, Kotor, Nikšić, Pljevlja and Podgorica. They were selected for having significant energy development potential and low environmental and social conflict. The use of the PPGIS allowed the public to identify locations that may not be suitable for solar and wind projects due to high social values[20].

[20] The list of social values (such as biodiversity, natural resources, landscape and aesthetic values, economic activities, quality of life, traditional use of space and others) integrated in the PPGIS was determined through the analysis of responses to the survey designed primarily to solicit stakeholders' opinions on the relative significance of different criteria for the vulnerability analysis and calculation of weight factors for the development of conflict maps. The responses to the survey were provided by 25 professionals from a range of national and local-level institutions and organizations.

The PPGIS tool was implemented in workshops and online. In addition to the mapping exercise, the workshops included a discussion on the attitudes towards renewable energy development and related concerns. The overall objectives of the MEGA public consultation process were to:

- Ensure early public participation in renewable energy development planning;
- Enable local residents to map areas reflecting key environmental, economic, cultural and other social values attributed to landscape (without binary questions);
- Validate the coarse-filter data collected for the PPGIS test sites;
- Supplement coarse-filter data with PPGIS data from the test sites;
- Collect information on additional social value classes that may have been overlooked in the smart siting process;
- Identify root causes of conflicts and conditions for public acceptance;
- Highlight to decision-makers and developers potential resistance risks, reasons, approaches to mitigate risks and benefit schemes.

5.2.1 Consultation process and data collection

Online consultations

Over four weeks (from 1 September to 3 October), the use of the PPGIS tool was made available online for three municipalities with high solar and wind development potential: Bijelo Polje, Kotor and Podgorica. Bijelo Polje and Podgorica have a low environmental and social conflict and Kotor has a high density of cultural and historical values. Therefore, Kotor was selected for the PPGIS application to assess the importance of cultural and historical sites to local communities and to ensure that development doesn’t harm its rich heritage.

In-person workshops

Three **workshops** were held to gather local knowledge, preferences and concerns in the process of identification of optimal locations for wind and solar energy development. The goal was to provide timely information and involve citizens in the planning process while revealing the areas that hold different values for local communities. To this end, the participants were invited to identify valuable sites using the PPGIS mapping tool and to discuss the future of wind and solar energy development in Montenegro.

The **workshops were co-organised** by The Nature Conservancy and Eco-team (the local partner) in the three municipalities, which were selected for the high wind and solar development potential and low environmental and social conflict (based on the preliminary data assessment). The respective municipalities and the workshop dates were:

- Nikšić, 9 September 2025
- Cetinje, 11 September 2025
- Pljevlja, 18 September 2025

Invitations were sent to a range of local stakeholders identified by Eco-team. The events were also announced by national-level electronic and printed media[21], by the Nikšić TV station, various web portals (Nikšić, Pljevlja and Podgorica) and newspapers (Cetinje, Pljevlja, and others). Social media and media appearances were also used to disseminate information on the workshops and the use of the PPGIS tool.

A total of **54 people[22] participated** in the workshops: 19 in Nikšić, 14 in Cetinje and 21 in Pljevlja. Participants came from diverse backgrounds (e.g., biologists, historians, entrepreneurs, farmers,

[21] Daily newspaper Pobjeda, CdM and Aktuelno portals, business portals eKapija and Bankar.me, Mina Agency.
[22] Not counting the organisers and MEGA team members.

engineers, teachers, architects, landscape architects) and spanned ages 18 to 80. Most of the participants were representatives of local self-governments (municipal authorities) and specifically of Local Communities[23]. Representatives of educational institutions, cultural organisations, national park managers, utility companies, tourist organisations, energy companies and civil society were also present.

Based on responses from the workshop evaluation forms, it can be concluded that most participants learnt about the workshop through direct invitations, while a number of them were informed through social networks and media.

The workshops comprised **two sessions**:

1. Presentation of the PPGIS tool followed by the registration of participants and actual mapping of locations that the participants considered significant for their communities;
2. Discussion on the future of solar and wind energy development within the territory of the respective municipality, focusing on:
    a. the impact of renewable energy sources on the values and areas significant for the local communities,
    b. attitudes towards RE projects and conditions for their acceptance, and
    c. previous experiences with public participation processes.

The sessions were facilitated by members of the MEGA project team.

The main findings and points discussed are presented below.

In all three workshops, during the discussions participants focused on the suitable sites for solar and wind energy development rather than on the values and spaces that should be protected from such developments. Participants were technically assisted to map the values and areas that should be preserved. They were instructed on how to use the tool individually, but some of them preferred to perform mapping in pairs. This approach reduced the number of input locations, as entries were interpreted as originating from a single account. After the exercise, they were invited to share the information with their families, neighbours and acquaintances to obtain feedback from a larger number of people.

Most of the participants expressed their appreciation of the effort made under the MEGA project. There was acknowledgment of the potential the PPGIS tool has in helping to identify values that should be preserved and conflicts related to future solar and wind energy development. There was also interest expressed (Pljevlja workshop) for a possible use of the tool in other planning processes.

Nevertheless, several concerns were expressed, most notably on the usefulness and effectiveness of the exercise for the decisions on the future development of RES. Negative experiences with previous public participation processes and development of energy projects were mentioned to this end. It was also pointed out (Nikšić, Pljevlja) that these types of consultations should be led by relevant institutions and not civil society.

While early involvement of the public in the planning process was recognised as very important and an example of a good practice, participants mentioned examples of energy projects being developed without citizens being informed and consulted (e.g., wind park in Pljevlja). The planning process for solar power plants in Čevo (Cetinje municipality) with a total capacity of more than 1,500 MW was also mentioned in a negative context, as the initial stages of the projects led to large land sales to

[23] The Local Community (*Mjesna zajednica*) is a part of the local self-government system, the purpose of which is to allow for direct participation of citizens in public affairs. Through the Local Communities, citizens can participate in decision making on issues such as arrangement of settlements, housing, consumer protection, sports and culture, environmental protection and others.

investors, causing significant social changes in this underdeveloped rural area. Even though public participation was enabled through the environmental impact assessment, the participants had the opinion that these were not meaningful and that in this specific case (Čevo solar development), MEGA consultations came too late.

Despite different public participation opportunities, the participants assessed that citizens are not likely to participate in the public debates unless they feel their personal interests are affected. The same stands for the organisation and implementation of actions that are of wider public interest. Citizen activism and voluntarism are low and the efforts to do something good for the community are often met with suspicion. It is necessary to work on changing this situation, primarily through the educational system and activities involving children.

Some participants expressed apprehension regarding the use of the PPGIS. They felt uncomfortable indicating suitable or unsuitable locations for RE development on behalf of the others (despite the organisers explaining they should do the mapping based on their personal knowledge and preferences). In all the workshops, suggestions were made to visit all the Local Communities and/or to organise citizens' assemblies, collecting opinions directly from all those concerned. It was indicated that such a practice would be inclusive towards people without access to social networks and news, or those living in distant rural areas who might not be able to join the workshops. At the same time, assistance could be provided to those who might not be familiar with modern technologies. After the workshops, the PPGIS tool was still accessible for about two weeks. Participants flagged that this time was short, especially if they needed to share the tool with other community members. Consequently, the project team agreed to extend the originally planned deadline by one week.

The attitudes towards development of solar and wind projects differed widely depending on the municipality and/or individual views. In Nikšić, several participants pointed out areas that were seen as highly favourable for RE development (e.g., Bogetići, Banjani, Grahovo, Golija) while in Cetinje, the opinion was that not a single shrub should be removed for wind and solar development and that rural space should be preserved for future generations.

The participants assessed that the acceptability of RE projects to the local population depended largely on the type and ownership of the project. In that regard, state-owned projects were preferred over those initiated by private investors. Widespread mistrust within society[24], as well as a lack of transparency in some projects and past cases of corruption also affect the acceptability of RES projects in a negative way.

Solar and wind projects are seen as economically profitable, but the question raised was: Who benefits from them? Solar power plants can be developed in many areas, but it is not clear what will be the benefits for the village where it is constructed. Some participants pointed out that negative impacts on local communities certainly existed and that acceptability could only be discussed for specific projects (and not in general). Overall, it was emphasised that new employment opportunities for the local communities, together with improvements in local infrastructure and lowered electricity prices were some of the ways to reduce resistance of local communities.

Other important views expressed during the workshops included:

- It is necessary to first use degraded areas (open mines, waste disposal sites, old industrial zones and similar) for the development of RES;

[24] One of the messages heard during the Pljevlja workshop, for example, was that people were deceived many times and no longer believed in changes.

- Information on additional sources (studies, projects) that could be used to map valuable areas for Nikšić municipality was shared with the organisers;
- The necessity of strengthening of collaboration between citizens, civil society and public administration/the state was highlighted;
- MEGA project results can be taken into account for the preparation of local spatial plans.

A large number of differing views were expressed and useful information shared during the three workshops, whereas the following can be singled out as the most important **conclusions**:

- There is a low level of trust in public consultation processes in Montenegro and there is scepticism that citizens' opinions will be taken into account in decision making processes.
- The participants had difficulty mapping the valuable locations that should be spared from RES development and were more inclined to discuss the areas suitable for such development.
- Additional efforts should be made by the project team (and responsible institutions) to reach more citizens and collect their opinions directly, as some of those taking part in the workshops felt uncomfortable with what they perceived as "deciding on behalf of the others" through the use of PPGIS.
- Nevertheless, it was agreed that participants would make an effort to inform other members of local communities on the possibility of using the PPGIS tool in order to solicit opinions from a larger number of people.
- Despite expressed concerns, the potential of the PPGIS tool was recognised and the effort of the MEGA project team to allow for early public participation in the planning of solar and wind energy development was met with appreciation.
- The need for meaningful public participation processes was highlighted alongside with the need for improved cooperation between state and local authorities, citizens and civil society.

Based on experiences in the Nikšić, Cetinje and Pljevlja workshops, the following **lessons learned and recommendations for future PPGIS uses** can be drawn:

- The purpose of the PPGIS exercise should be clearly communicated;
- Sufficient time should be allocated for the public participation process;
- The public participation toolkit should include both the mapping activity and focus group discussions;
- Trusted local partner's lead in the process is key;
- In order to ensure engagement for online collection, the user experience should be improved further;
- A simple step-by-step video should be produced in the local language to guide tool usage;
- Multiple communication channels should be used to promote the tool;
- Whenever possible, online tool application should be combined with physical workshops.

5.2.2 Spatial analysis of collected data

Methods

A total of 43 participants and 183 mapped points were collected for Cetinje, Nikšić and Pljevlja municipalities across eight social value categories (Natural resource value (including agriculture, forests and water resources), Settlements and quality of life, Landscape/visual aesthetics, Biodiversity importance, Traditional way of life and use of space, Cultural value, Economic or tourism value, Geological diversity). All of the spatial data was collected at in-person workshops. Online data collection in Kotor, Bijelo Polje and Podgorica unfortunately yielded no data for further analysis (see recommendations for future PPGIS application above).

This analysis follows the purpose and methodology of a similar analysis previously performed by TNC in Silves, Portugal. All spatial analyses were performed in the WGS84 / UTM zone 34N projection (EPSG:32634), ensuring alignment with our study's national-scale datasets. The analysis window was defined as the municipal boundaries of Cetinje, Nikšić and Pljevlja (source: geoBoundaries), supplemented with a small (300 m) buffer around any mapped points that fell outside of the administrative polygon that still displayed on the PPGIS application. This 'practical boundary' ensured that all community-mapped values were retained within a valid analysis domain, while remaining geographically realistic for the analysis.

We applied a kernel density estimation (KDE) approach to generate continuous spatial surfaces representing the relative intensity of mapped social value points across the study area. We used an automatic bandwidth selection method, Diggle and Berman's mean square error cross-validation method (bw.diggle), from the R package 'spatstat.explore', an approach well suited for tight clustered point distributions[25]. For visualisation and interpretability, the selected bandwidth was scaled by a factor of 1.25 ($\sigma \times 1.25$). KDE surfaces were computed at a 100 m resolution, and a minimum patch size of 16 grid cells (~0.16 km^2) that filtered out spurious small clusters.

Hotspot extraction was performed by retaining ~70% of mapped points within the highest-density KDE cells (the 'retention threshold'). This threshold is somewhat lower than the 80% used in Pocewicz et al. (2013[26]), but was selected to balance inclusivity with interpretability given the pilot nature of our dataset (n = 183). Sensitivity checks at 65% and 75% retention confirmed that the main clusters were stable across thresholds. Through this analysis, we produced polygons representing social value hotspots suitable for visualisation, comparison with our other conflict mapping outputs and planning insights.

We analysed both pooled hotspots (all values combined) and per-category hotspots. Our report primarily presents patterns from the pooled hotspots. In addition, we tested sensitivity to the hotspot retention threshold (65%, 70%, 75%). Finally, we compared the identified local-scale hotspots with our study's national combined conflict raster to assess how community-mapped values aligned or diverged from a pre-screening approach of coarse-filter siting. Any corresponding results for per-category hotspots represent a much smaller sample size and can be found in the technical annex.

Results

As part of this exercise, citizens in Cetinje, Nikšić and Pljevlja municipalities mapped 183 points (118, 32 and 33 points respectively in each municipality) of social value across eight categories: Natural resource value (including agriculture, forests and water resources) (48), Settlements and quality of life (43), Landscape/visual aesthetics (27), Biodiversity importance (27), Traditional way of life and use of space (19), Cultural value (12), Economic or tourism value (6), Geological diversity (1). Across our results, in line with The Nature Conservancy's Human Subject Research guidelines, we present figures with aggregated data on important social value areas (i.e., hotspot polygons) and withheld individual participant mapped points to protect their exact locations. Contact the project team to inquire about accessing figures with participant points, which may be made available upon reasonable request and with appropriate measures taken to ensure participant anonymity.

[25] Baddeley A, Rubak E, Turner R (2016). Spatial Point Patterns. Methodology and Applications with R (Chapman&Hall/CRC Interdisciplinary Statistics Series).

[26] Pocewicz, A., & Nielsen-Pincus, M. (2013). Preferences of Wyoming residents for siting of energy and residential development. *Applied Geography*, *43*, 45-55.

Taking into account all mapped points sourced from the public participation, pooled across the social value categories, our KDE identified hotspot clusters that cover about 56.72 km², while capturing 48.3-71.9% of all mapped points (Figures 1-3). These patch sizes ranged from 0.379 km² to over 33 km², depending on the municipality. Median sizes of hotspots were 0.57, 5.34 and 1.58 km² for Cetinje, Nikšić and Pljevlja respectively (Table 1). Therefore, one notable difference between the municipalities is the smaller size of the clusters in Cetinje municipality (which also had the largest sample size with 118 points) compared to the others, which suggests an extremely tight clustering within the identified hotspots in that municipality. Our overall results indicate that participants mapped several values in a concentrated manner, suggesting some key value areas, but at least some valued areas were spread across each of the municipalities.

Table 5.3 Summary metrics for hotspots at a 70% retention threshold (pooled across all mapped points)

Metric	***Cetinje***	***Nikšić***	***Pljevlja***
# Patches	3	4	4
Area (km²)	1.864	44.739	10.103
% of Window Area	0.2	2.2	0.7
% Points Inside	48.3	71.9	67.6
Median Patch Size (km²)	0.568	5.34	1.584
Mean Patch Size (km²)	0.621	11.185	2.526
IQR Patch Size (km²)	0.269	14.339	2.466
Min Patch Size (km²)	0.379	0.749	0.799
Max Patch Size (km²)	0.917	33.309	6.136

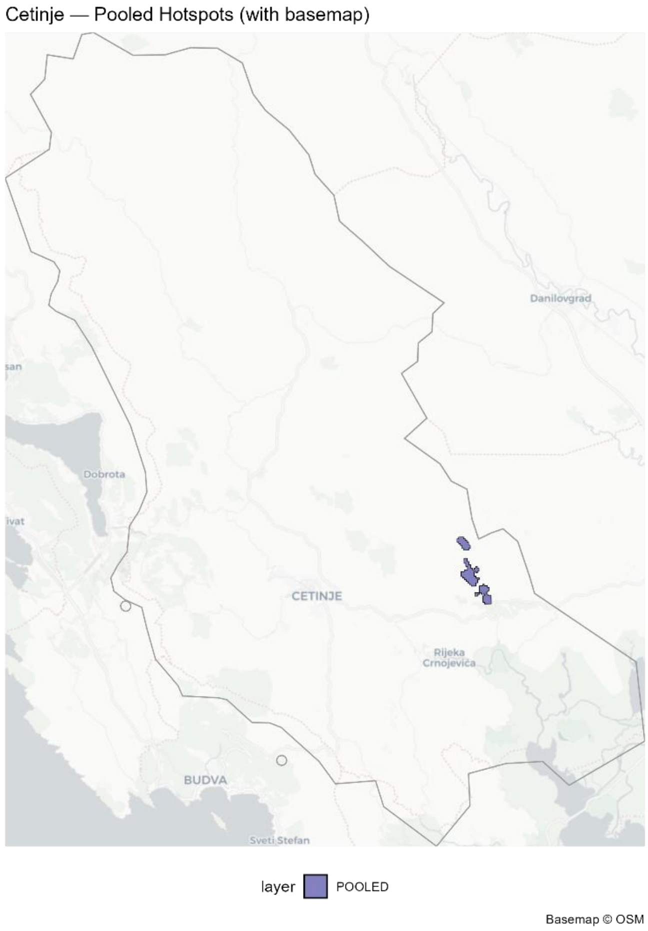

Figure 5.17: Pooled social value hotspots in Cetinje (blue). Participant points are masked to protect exact locations.

Niksic — Pooled Hotspots (with basemap)

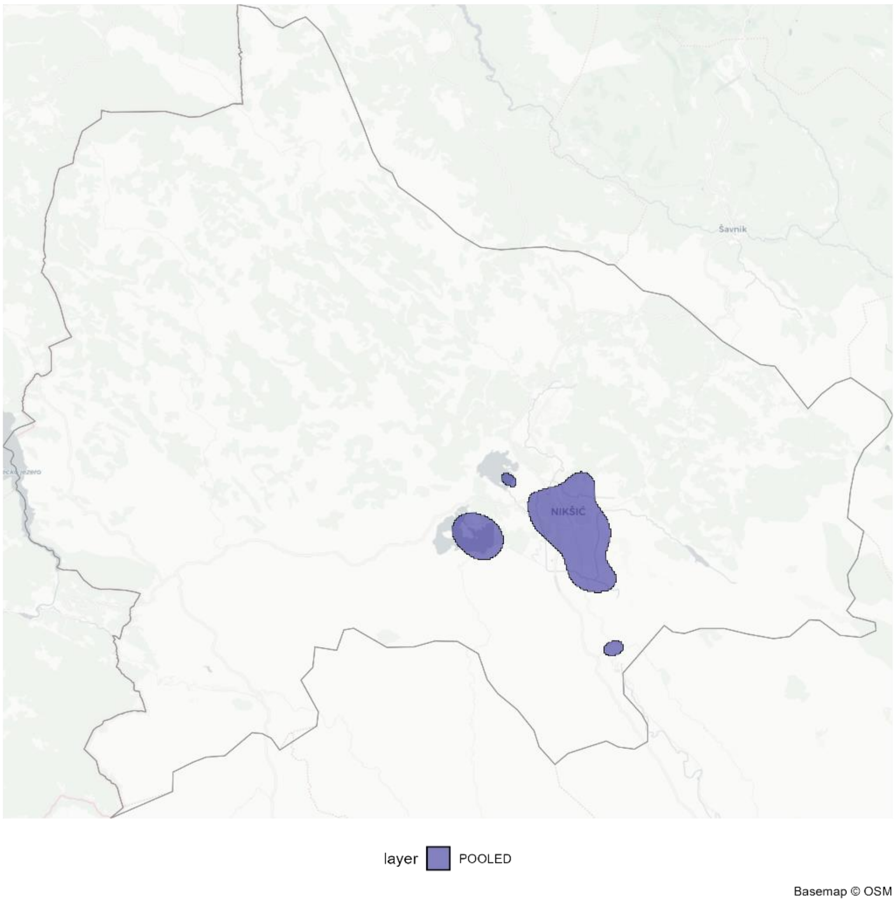

Figure 5.18: Pooled social value hotspots in Nikšić (blue). Participant points are masked to protect exact locations.

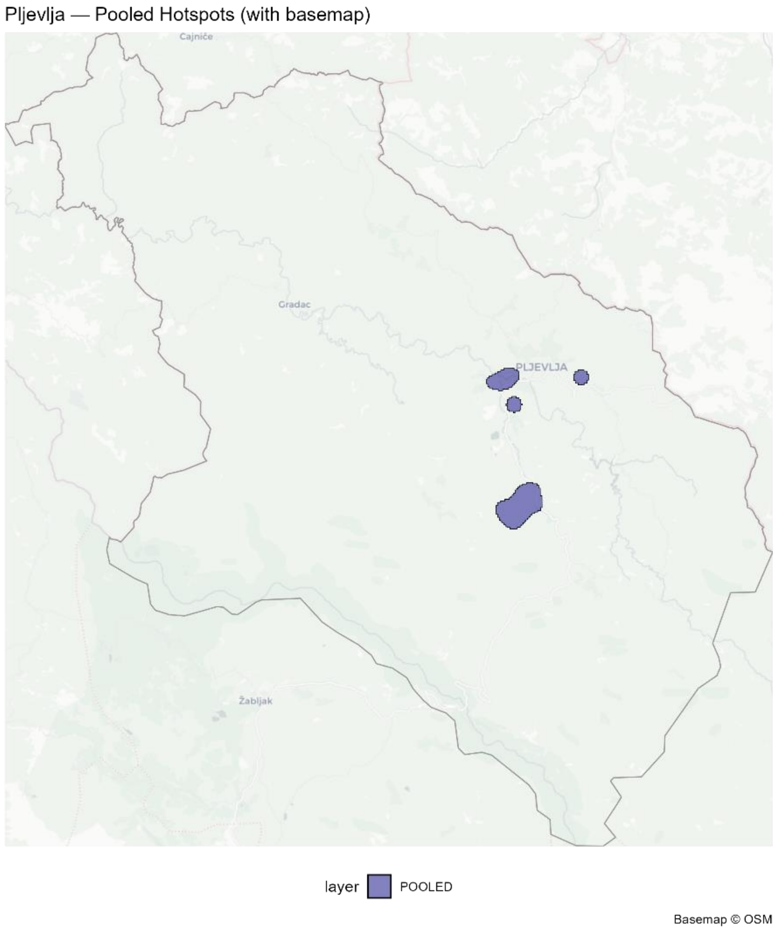

Figure 5.19: Pooled social value hotspots in Pljevlja (blue). Participant points are masked to protect exact locations.

A central purpose of this public participatory mapping exercise was to understand how local-scale, community values attributed to the landscape may differ or correspond with the spatial conflict data our study has developed through a more general spatial conflict mapping approach.

When we compared our identified clusters (for the pooled participant data) with the national conflict raster (combining both social and environmental layers), results varied by municipality, with Cetinje having the least overlap between hotspot area and high-conflict land (~34 %), and Nikšić and Pljevlja having higher overlaps (50% and ~78% respectively) (Figures 4-6). This result is not unexpected given the extremely tight clustering in a comparatively small area designated as high conflict in Cetinje municipality compared to the others. When considering hotspots for different value groups separately, the largest overlap was with the "natural resources" value group in Nikšić and Pljevlja municipalities, with 91.5% and 90.7% overlap with high conflict areas inside these municipalities. This can be explained by forests and agricultural areas, which are part of the natural resources value group, having a strong impact on conflict score, which could indicate the suitability of this method to identify hotspots for this value group, but basing any decision-making on this method would certainly require a more robust sample size.

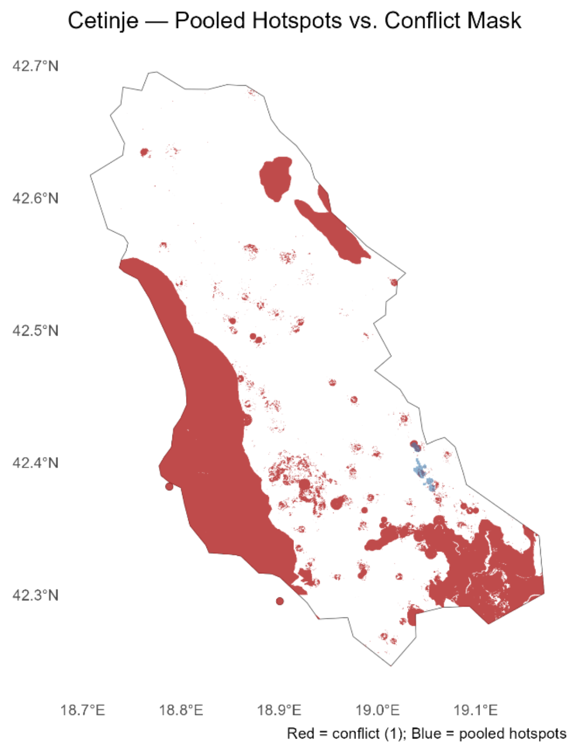

Figure 5.20: Hotspot polygons for pooled social value points (blue) overlaid with lands classified as "conflict" per coarse-filter environmental and social data (red) in Cetinje municipality.

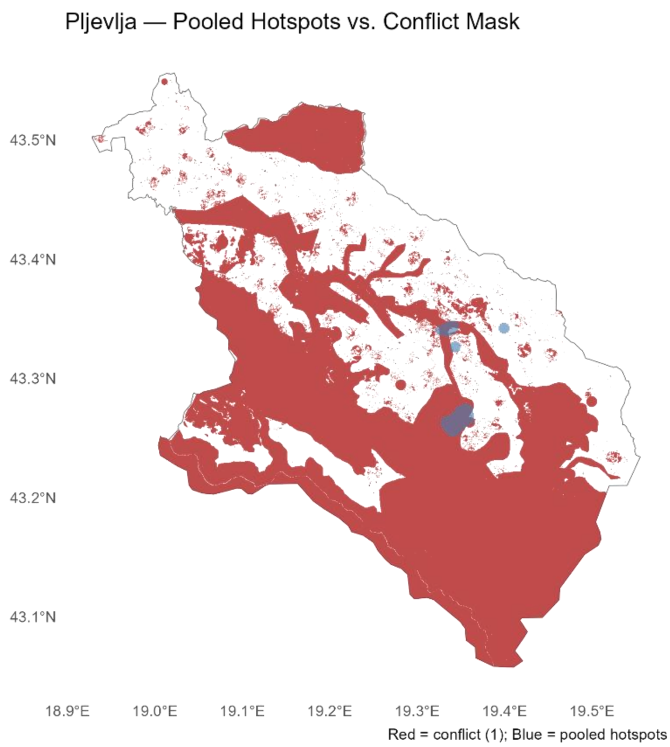

Figure 5.21: Hotspot polygons for pooled social value points (blue) overlaid with lands classified as "conflict" per coarse-filter environmental and social data (red) in Pljevlja municipality.

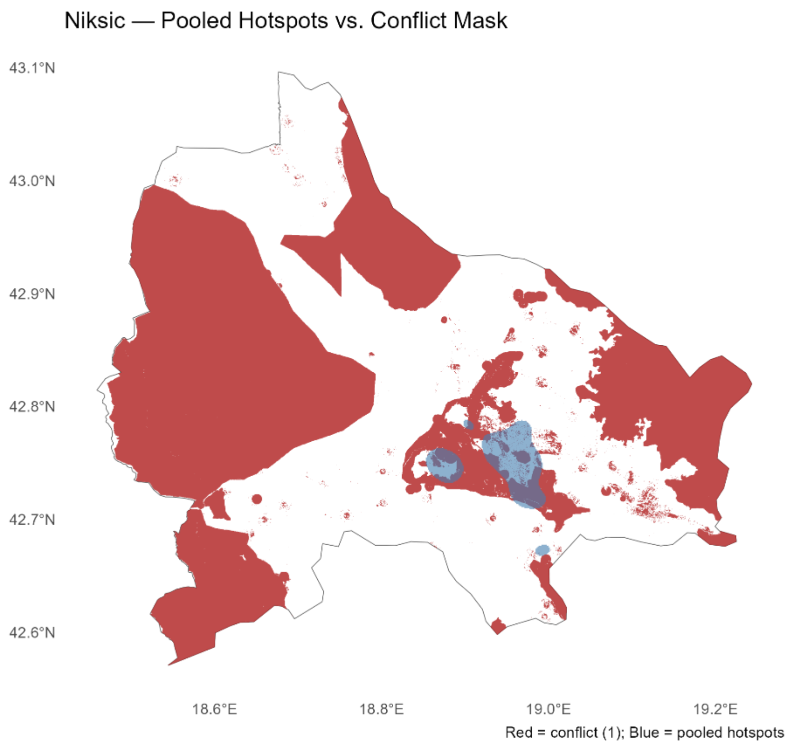

Figure 5.22: Hotspot polygons for pooled social value points (blue) overlaid with lands classified as "conflict" per coarse-filter environmental and social data (red) in Nikšić municipality.

Despite the limited geographic and temporal scope of this participatory component of the project, we tested for the degree of clustering using the Clark-Evans nearest-neighbour test and confirmed significant clustering present across value attributes in our sample. Additional details can be found in the annex.

Additional technical information

Summary of identified hotspots categorised by social value type

While our main analysis focused on pooled hotspots across all values (n=183), for exploratory purposes, and in Cetinje municipality where the sample size was largest (n=106), we also generated per-category clusters to examine any differences in spatial expression of social values (Table 5.4). As a caveat, these results should be treated as preliminary insights due to the relatively small sample sizes of mapped points for each category. Nonetheless, we can highlight distinct patterns within this constrained sample (Figure 5.23).

Table 5.4: Summary of hotspot metrics by social value categories in Cetinje Municipality, Montenegro.

Category	**# Patches**	**Area (km²)**	**% of Window Area**	**% Points Inside**	**Median Patch Size (km²)**	**Mean Patch Size (km²)**	**IQR Patch Size (km²)**	**Min Patch Size (km²)**	**Max Patch Size (km²)**
Biodiversity (habitats and species)	2	7.687	0.8	73.7	3.844	3.844	3.574	0.269	7.418
Cultural assets	2	17.508	1.9	72.7	8.754	8.754	5.424	3.33	14.178
Landscape and aesthetic values	2	53.042	5.8	73.3	26.521	26.521	1.685	24.836	28.206
Natural resources	1	0.369	0	38.9	0.369	0.369	0	0.369	0.369
Settlements and quality of life	2	2.273	0.2	72	1.137	1.137	0.708	0.429	1.845

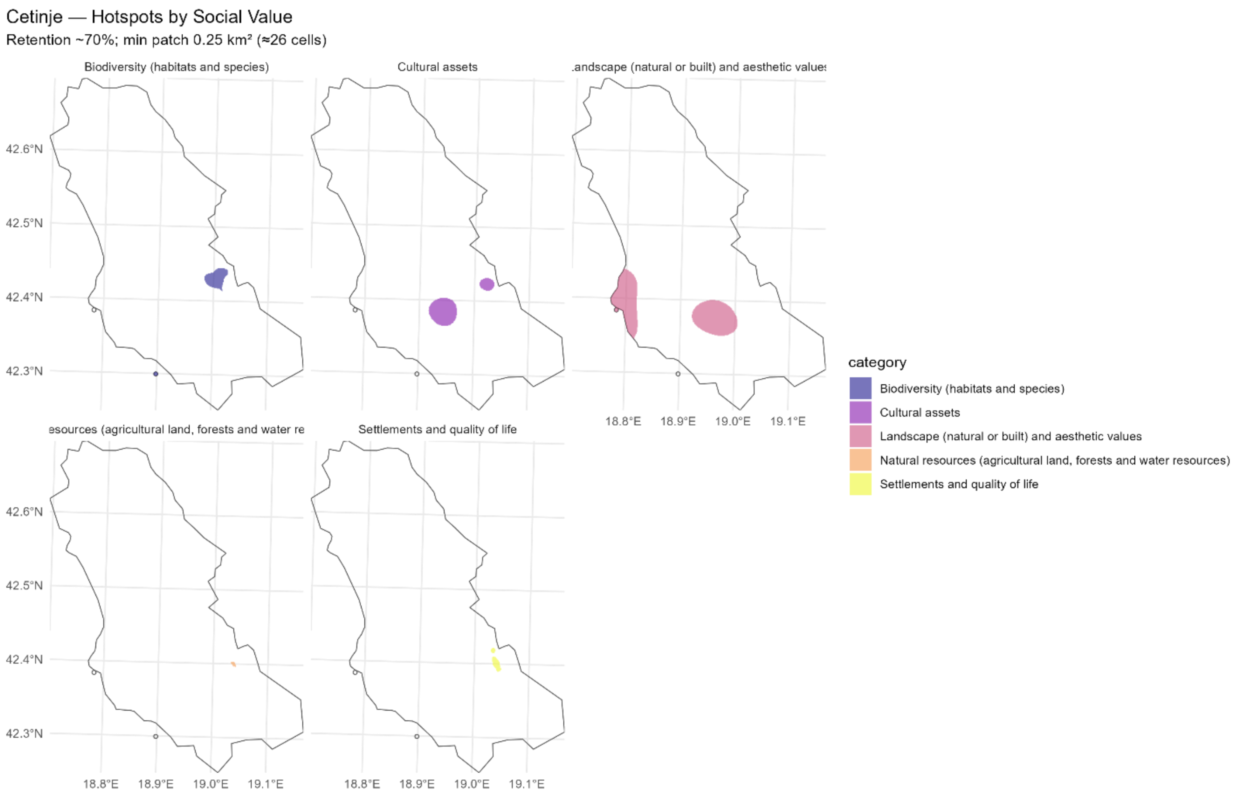

Figure 5.23: Hotspot polygons shown separately for each social value category.

We find the largest footprints of a social value hotspot for landscape/visual aesthetic values, covering approximately 53 km² in total (5.8% of the analysis boundary, i.e., Cetinje municipality) in two roughly equal-sized patches. This indicates that landscape aesthetic values were mapped in a dispersed area compared to other value groups but still covering a relatively modest proportion of the whole municipality.

In contrast, the value category for natural resources (including agriculture, forests and water resources), was extremely compact despite having the largest sample size (n = 36 points), with the only patch measuring only 0.369 km². This suggests an extremely tight spatial grouping for this particular value category that also affects the overall pooled clusters in Cetinje municipality. If inferences or spatially explicit decisions were to be made from these results, a detailed consideration of reasons for this result would be warranted. While it is possible that the identified cluster does represent a restricted area that is extremely valuable in terms of natural resources, it is also possible that a biased sample of participants, or discussion among participants during the data collection workshop, led to an overrepresentation of points in this particular area.

Spatial distribution diagnostics

Finally, following the Pocewicz & Nielsen-Pincus et. al., 2013 methodological approach of considering a preliminary spatial clustering test, we applied a Clark–Evans nearest-neighbour diagnostic to the pooled datasets for each municipality. The results confirmed that participant points were non-random and significantly clustered, with Clark–Evans R values of 0.394 (z = -6.44) for Cetinje, 0.331 (z = -3.70) for Nikšić and 0.658 (z = -1.95) for Pljevlja municipality. The observed mean nearest-neighbour distances (549, 1316 and 2088 m) were substantially smaller than the expectation under complete spatial randomness (1393, 3975 and 3172 m) in all municipalities. This diagnostic test provides a preliminary validation that the mapped points considered in this analysis (specifically for the pooled hotspots identified) were not random noise, but represent meaningful clusters of perceived value among this sample of participant data.

5.3 Conflict maps combined with constraint maps

In accordance with the presented methodology for allocating optimal zones for the development of renewable energy projects that use solar and wind energy, conflicts that the development of such projects may have in relation to the environment, society, and other land uses are of particular importance. In this regard, maps were created in order to identify zones with a low level of conflict, so that these zones could then be further analyzed in terms of development potential, i.e., the techno-economically available energy potential. It should be emphasized that, within this methodology, the presented conflict-level maps represent only an intermediate result and are not intended for independent use (outside of the final resulting maps). However, in order to improve the visibility of zones with a certain level of conflict, these maps were combined with maps of legal exclusions to obtain maps that can also be used independently, and they are presented in the following figures separately for solar and wind energy.

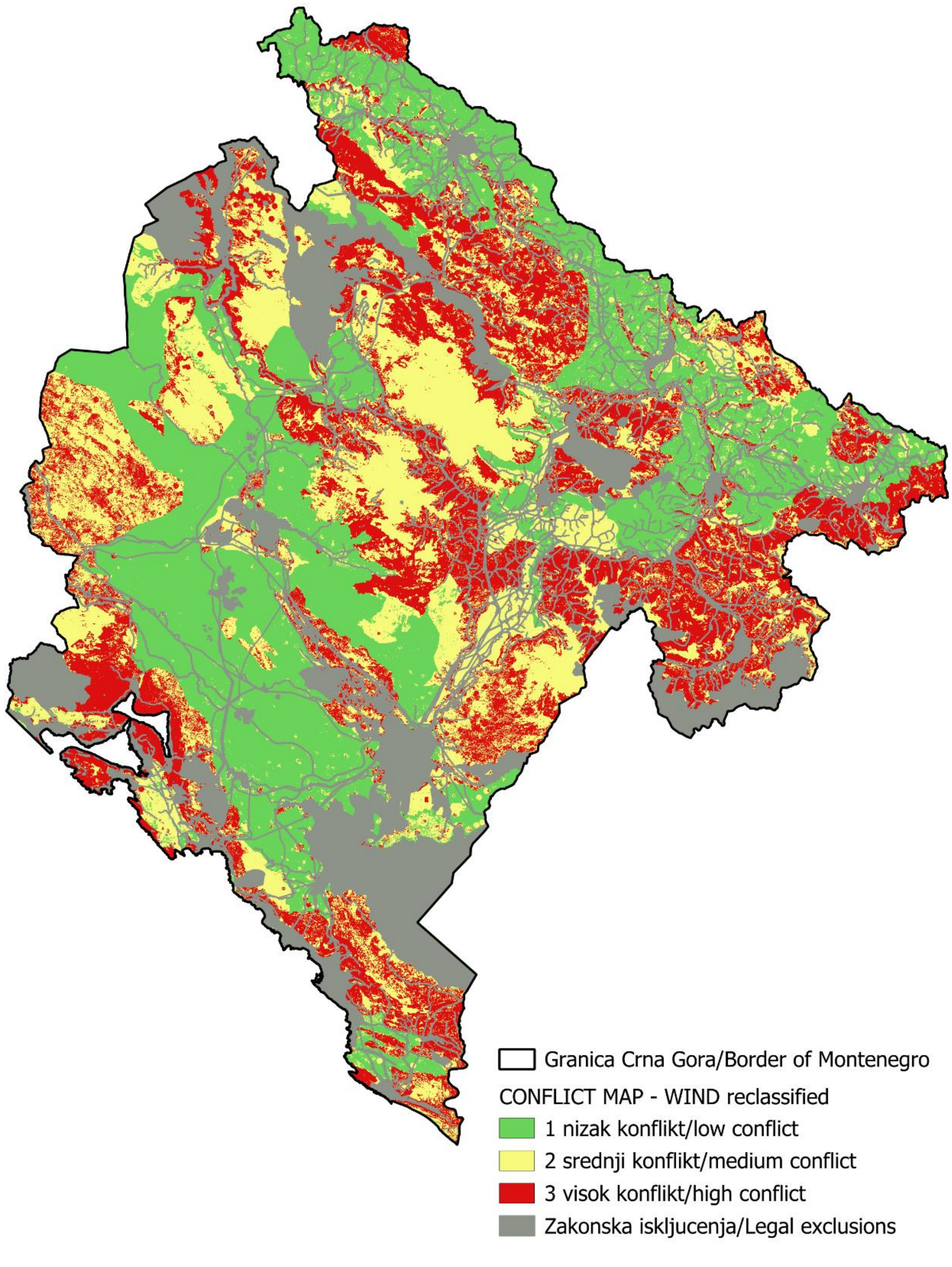

Figure 5.24 Resulting reclassified conflict map for solar power plants with legal exclusions

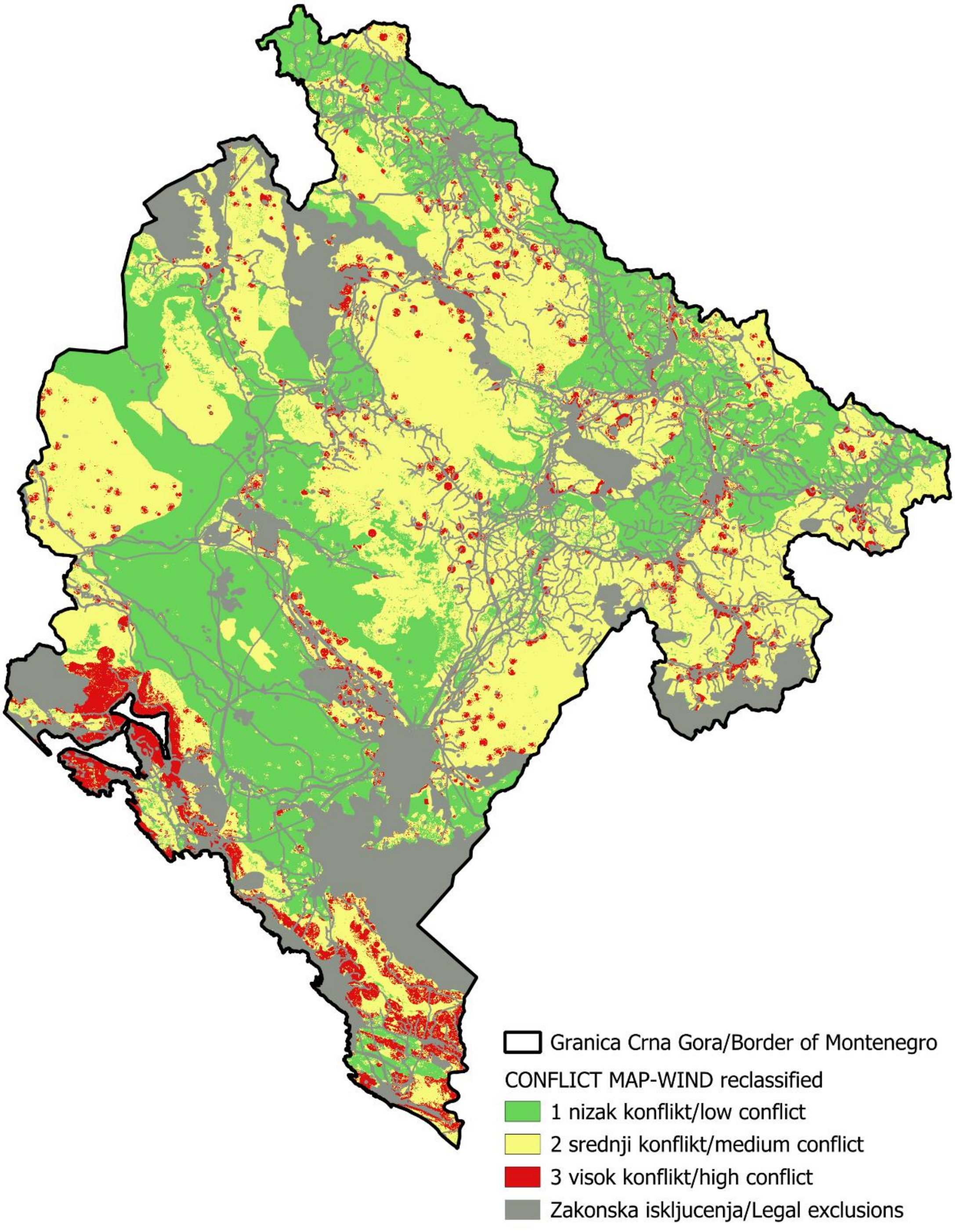

Figure 5.15 Resulting reclassified conflict map for wind power plants with legal exclusions