Mapping Solar and Wind Potential in the Municipality of Nikšić

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Authors: Božidar Pavlović, Irma Muhović, Biljana Medenica, Dražen Karadaglić

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1 INTRODUCTION

With its climate and energy framework, the EU aims to reduce its greenhouse gas emissions by at least 55% from 1990 levels and to increase the share of renewable energy sources in its energy mix to at least 45% by 2030. In line with EU climate and energy policy, in December 2022 the Energy Community adopted the 2030 energy and climate targets. These targets are essential to put the Energy Community Contracting Parties on a path towards achieving climate neutrality by 2050 and decreasing dependence on fossil fuels in the shorter term.

As one of the contracting parties, Montenegro has an obligation to meet its share of the very ambitious EU renewable energy source (RES) targets. Specifically, Montenegro has a new target of having 50% of its gross final energy consumption come from RES by 2030, a significantly higher rate than the previously met 2020 target of 33%. According to data from the national report on the implementation of RES Directive 2009/28/EC for 2021, final energy consumption in Montenegro from RES was 345.26 ktoe, meaning that 39.29% of the gross final consumption came from RES. The RES share for electricity consumption in 2021 was 60.33% (186.50 ktoe).

The National Energy and Climate Plan (NECP), currently under preparation, will provide a strategy for how Montenegro will meet the new 2030 targets. The NECP will define the mix of energy sources (especially solar and wind) that can realistically be expected by 2030 and beyond. In order to achieve these new ambitious RES targets for 2030, construction of new RES capacities is needed.

Increased installation of RES creates significant demand for land. This potentially creates a conflict between energy policies on one side and nature preservation and social acceptance on the other. This could lead to delays or even cancellations of RES projects and cost increases for investors. .In developing RES projects, investors are often guided by spatial plans that are based purely on wind or solar resource potential and which do not take into account environmental or social/cultural aspects. Assessing potential environmental problems or social/cultural conflicts can reduce the risk of long costly delays or even project cancellation.

The Nature Conservancy (TNC) and NGO EKO-Tim have started implementing a project called *Support towards accelerating renewable energy deployment in the Municipality of Nikšić*. The purpose of the project is to develop a low-conflict solar and wind siting scenario for the Municipality of Nikšić by identifying and mapping the highest priority areas for solar and wind development that have the lowest environmental and social conflict. The goal is to contribute to climate change mitigation and limit administrative delays.

The methodology is based on available data and information about the status of natural resources, flora and fauna, cultural heritage and landscape value, taking into consideration existing and planned land use patterns. The aim was to identify sites with high sensitivity where RES should not be built, as well as sites with lower sensitivity where RES development should be stimulated.

The Municipality of Nikšić was selected as a pilot area for the development of low-conflict maps due to its size (it is the largest municipality in Montenegro). As such, it serves as a good case study for analysing potential conflicts and expected trade-offs related to RES developments throughout Montenegro. The aim was to develop a methodology that can be scaled up to the national level or used in any other region of Montenegro.

The developed methodology serves as a tool for spatial planning; it provides guidelines based on defined criteria and thresholds important for the sustainable utilisation of RES. The aim of the project is not to replace existing Strategic Environmental Assessment (SEA) and Environmental

Impact Assessment (EIA) procedures. However, the methodology can serve as a baseline and provide support for future SEAs. Finally, the project informs potential project developers about site sensitivity levels and the potential risks associated with various locations in order to facilitate the development of RES projects.

2 METHODOLOGY

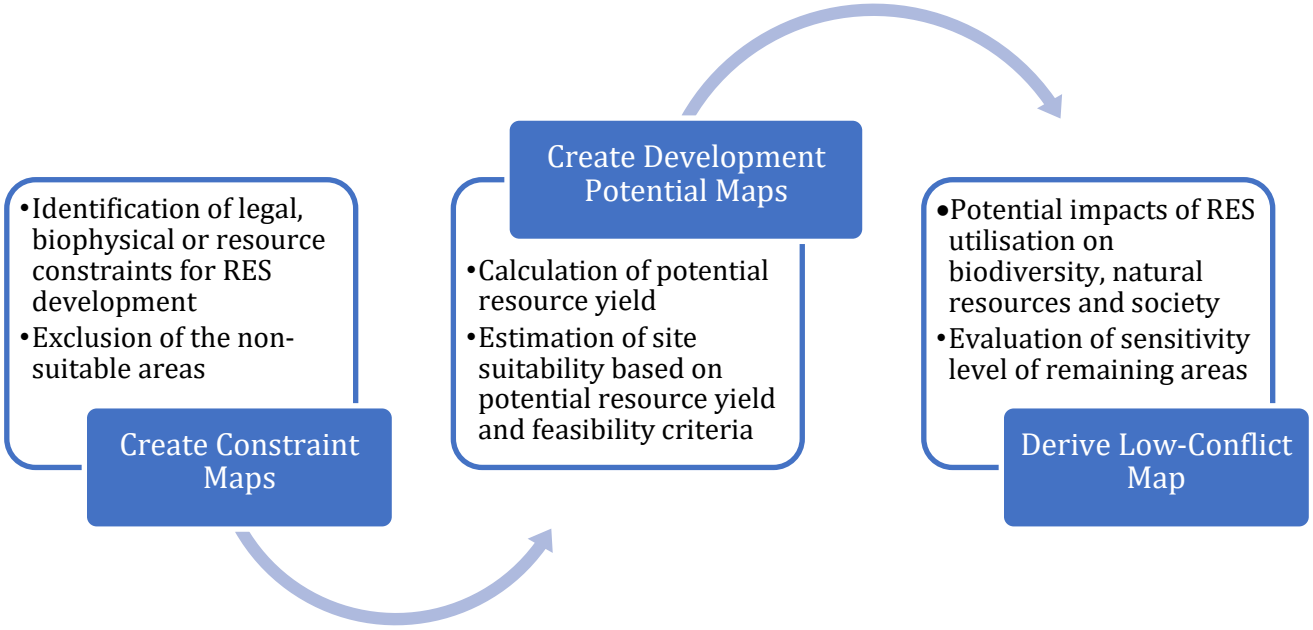
The aim of the project is to develop a low-conflict solar and wind siting scenario for the Municipality of Nikšić by identifying the highest priority areas for solar (specifically, photovoltaic (PV)) and wind development which will also have the lowest environmental and social conflict. In general, the development of a low-conflict RES siting scenario includes:

- Energy mapping, which considers RE spatial database development and site modeling and
- Values mapping, which considers environmental, biodiversity, and social/cultural elements of conservation interest.

Areas with minimal potential social and environmental conflicts are identified by sorting conflict scores from low to high and then by ranking production potential from high to low.

The development of low-conflict solar and wind siting scenarios for the Municipality of Nikšić is based on a three-step approach (also illustrated below):

- Step 1: Create Constraint Maps - identification of areas which are not suitable for wind and solar siting due to legal, biophysical or resource constraints;
- Step 2: Create Development Potential Maps - estimation of potential resource development suitability based on potential resource yield and feasibility criteria (e.g proximity to major roads, railroads, power lines and consumption centers);
- Step 3: Derive Low-Conflict Map - indication of sensitivity level of suitable areas based on evaluation of potential impacts of RES utilisation on biodiversity, natural resources and society.



Each step requires a provision of relevant spatial data, some of which is used as is, some of which must be modified in GIS software prior to use. Global data sets should be supplemented or replaced with data from local sources when possible. An overview of relevant data and data sources used for preparation of this report is given in *Annex 1*.

Step 1 - Create 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. For example, 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 also important for planning future RES projects (steeper slopes affect the complexity of the planned power plant). Also, certain types of land cover and features (e.g. rivers and lakes) are not suitable for RES installation.

An overview of constraints for RES suitability mapping in the Municipality of Nikšić is given in *Table 1* and a detailed explanation of criteria for exclusion is given in *Annex 2*. 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 (zero value for "buffer" size in the *Table 2*).

Also, according to national regulations, there is no defined protection zone around cultural, historic and spiritual sites that would prohibit construction of SPP and WPP in their proximity. Therefore, potential conflict for developing RES projects in those areas are considered under Step 3 (Derive Low-Conflict Map).

When it comes to infrastructure, the suitability of RES development is defined by the buffer zone around certain features measured from their center (e.g. in accordance with the Law on Railways the zone on both sides of the railway, to a width of 25 m, is for the use, maintenance and technological development of railway infrastructure). For infrastructure such as the small sport airport at Kapino Polje and radio/cell towers there is no defined zone prohibiting construction of SPP and WPP, but national regulations specifically require the development of a technical analysis prior to constructing a WPP.

Finally, all water bodies were excluded from further analysis which means that potential floating SPP are not a subject of this study. Also, the existing WPP Krnovo is at the northern border of the Municipality of Nikšić and its impact on future WPP/SPP is not considered in this analysis.

Table 1: Overview of constraints for RES suitability mapping in the Municipality of Nikšić

Constraints (criteria for exclusion)	**Excludes**	**Buffer size**	**Unit**
Legal constraints *Protected areas according to national legislation where construction is prohibited (IUCN categories); Areas designated as cultural heritage sites and archaeological sites; Specially designated areas (military zones, touristic and recreational zones (hotels, touristic settlements, camps, open air sport facilities))*			
Protected areas	feature + buffer	0	m
Recreational areas	feature + buffer	0	m
Touristic zones	feature + buffer	0	m

Constraints (criteria for exclusion)	Excludes	Buffer size	Unit
Military zones	feature + buffer	0	m
Cultural, historic and spiritual sites	feature + buffer	0	m
Current Infrastructure *Settlements (in urban and rural areas) and corridors along or around infrastructure such as power lines, roads and airports*			
Settlements/Buildings			
Urban	feature + buffer	500	m
Rural	feature + buffer	500	m
Roads			
Major	feature + buffer	40	m
Minor	feature + buffer	20	m
Airport (small sport)	feature + buffer	0	m
Railways	feature + buffer	25	m
Power lines			
Transmission	feature + buffer	30	m
Distribution	feature + buffer	15	m
Power plants (wind)	feature + buffer	0	m
Radio/cell towers (wind only)	feature + buffer	0	m
Biophysical constraints *Slope of the terrain, elevation; River networks, borders of basins and sub-basins, water springs and water sanitation zone;*			
Water			
Lakes	feature + buffer	15	m
Rivers	feature + buffer	15	m
Slope of the terrain	**Excludes**	**Value**	**Unit**
Photovoltaic (PV)	values above	10	degrees
Wind	values above	15	degrees
Economic constraints			
Wind speed	values below	5	m/s

Constraints (criteria for exclusion)	Excludes	Buffer size	Unit
Global Horizontal Irradiance (GHI)	values below	3	kWh/m^2 per day

The area suitability evaluation for RES development results in constraint maps for solar and wind which should be developed in GIS for further use in the analysis (example of constraint map is shown in *Figure 1*).

In practical terms, selected constraints are mapped and converted to raster datasets, and then combined to produce a binary dataset identifying RE suitability (i.e., 0-unsuitable and 1-suitable). This RE suitability map is then refined for both solar and wind based on slope and resource requirements (for more detail see Chapter 3 - Energy Mapping).

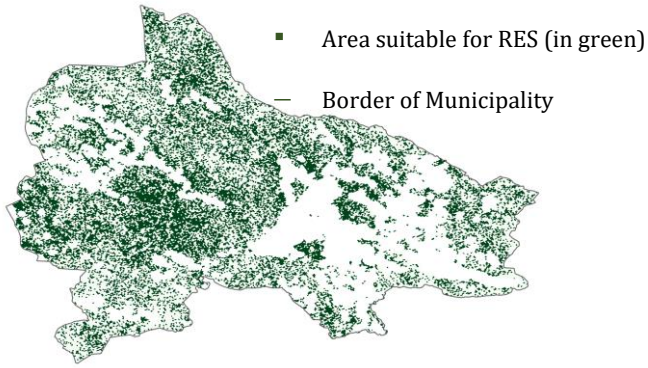


Figure 1: Example of constraint map for the Municipality of Nikšić - suitability for wind and solar siting

Step 2 - Create Development Potential Maps

For the RES development potential assessment, reliable data on solar irradiation and wind speed are needed. Due to the lack of local data sets for the Municipality of Nikšić, global open-source data sets are used as described in *Table 2*.

Table 2. Open-source data used in RE assessments

Source	Potential RE siting data	Data Resolution
Global Wind Atlas	Wind speed at 100m height	250 m
Global Solar Atlas	Global Horizontal Irradiance (GHI)	250 m

To produce a final ranking of RE development potential across the study area, the feasibility criteria must be defined. Feasibility criteria often include measures of resource potential (e.g. wind speed, GHI, and/or capacity factors) and development feasibility (e.g. proximity to major roads, railroads, power lines and consumption centers). The criteria used for RES development ranking potential in the Municipality of Nikšić are given in *Table 3*. Values for weighting factors were defined on the basis of similar experiences in the region (e.g. Serbia, Croatia). Fine tuning

of the weighting factors is done in consultation with energy experts and other stakeholders identified in the workshop that was organised for the presentation of preliminary results.

Table 3: Ranking criteria used in RE siting analysis

Criterion	Highest suitability (outside of constraints)	Weighting factor
Irradiance/Wind speed	highest value	0.45
Distance from consumption centers (i.e. urban areas)	nearest pixel	0.11
Distance from transmission/distribution lines	nearest pixel	0.25
Distance from roads	nearest pixel	0.14
Distance from railroads	nearest pixel	0.05

The next step after defining criteria for the ranking of RES suitability is to map the information across the study area, such as in *Figure 2.*

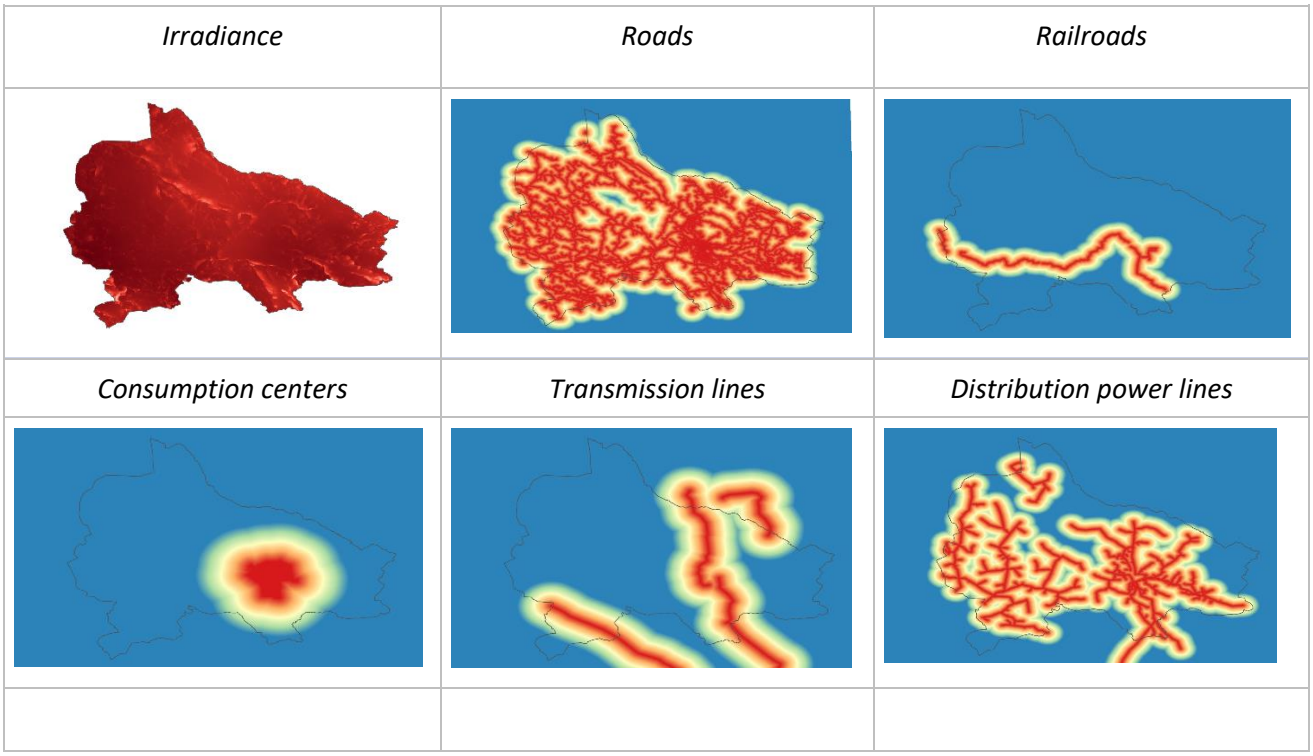


Figure 2: Illustration of mapping of ranking criteria for SPP development

Selected criteria are then limited to non-restricted development areas identified in the constraint mapping and scaled to comparable units (e.g. 0–1). Once the criteria have been selected and scaled, each is assigned a weight based on the siting importance of the individual criterion. All weights are typically between 0 to 1 and add up to 1 (see *Table 3*).

The final step is to combine selected criteria and their assigned weights to produce a ranking of suitability by application of the weighted linear combination (WLC) technique, which is a simple additive method. An important aspect of this method is that all criteria need to be independent

of each other to avoid redundancy. Development potential maps for solar and wind resulting from this process are shown in Chapter 3.

Step 3: Derive Conflict Map

Identifying potential conflicts between RES development and natural (environmental, social, cultural) values is of the highest importance. Conflict maps are created with the purpose of identifying spatial sensitivity to SPP and WPP development, indicating areas where such projects are likely to encounter conflicts with other land uses and nature protection, as well as areas where such conflicts are less likely to occur.

The degree of conflict is evaluated based on the most important potential impacts of solar and wind technology on biodiversity, natural resources and society. These impacts may include potential direct and indirect negative effects arising from land occupation/conversion, turbine rotation and noise generated by wind turbine blades or inverters.

In practical terms, conflict mapping consists of first, defining criteria and sensitivity scoring and second, assessing potential conflict:

1. **Definition of criteria and sensitivity scoring.** The territory of the municipality is analysed against a set of criteria grouped into three categories:
    a. Nature protection and biodiversity including protected areas Special Protection Areas (SPA), Regional parks, Important Bird Areas (IBA), endangered and rare habitats, habitats important for bats and birds;
    b. Natural resources and areas intended for economic and social activities including forests, agricultural land, zones for development of tourism/recreation;
    c. Social and cultural features including cultural goods, extremely valuable natural and semi-natural areas.

    The sensitivity evaluation is performed such that the assessment area is evaluated against each criterion and, based on the prevailing characteristics (degree of protection, distance from the zone/object, land value and etc.) and defined thresholds, given a score 0, 3 or 5. A score of 0 means the area is considered to have low sensitivity to the potential impacts of SPP/WPP. A score of 5 indicates high sensitivity for that specific criterion. *Table 4* provides a detailed overview of the defined criteria as well as sensitivity levels for SPP/WPP.

Table 4: Criteria for the sensitivity analysis for SPP and WPP

Criterion	Description	Relevance	Sensitivity scoring (high - 5)	Sensitivity scoring (medium - 3)	Sensitivity scoring (low - 0)
Protected areas	*Sensitivity based on the level of protection according to nature protection regulations and international agreements.* *Data: sets of locally available data were used for determination of the protected areas.*	SPP and WPP	Emerald, SPA, IBA	Areas proposed for protection	Outside protected areas
Endangered and rare habitats	*Sensitivity to the possibility of the deterioration of habitat quality.* *Data: sets of locally available data on Natura 2000 were used.*	SPP and WPP	Potential Natura 2000 habitats (priority habitats for the EU)	-	Outside priority habitats
Habitats important for bats	*Sensitivity with respect to distance from habitats important for bats (forests, bodies of water).* *Data: a set of local data on waterbodies and a set of global data on forests were used.*	SPP and WPP	< 1000 m	1000 - 2000 m	> 2000 m
Habitats important for birds	*Sensitivity with respect to distance from habitats important for birds (lakes, wetlands)* *Data: sets of local data on lakes and wetlands were used.*	SPP and WPP	< 1000 m	1000 - 5000 m	> 5000 m
Agricultural land	*Sensitivity regarding the importance and maintenance of agricultural land*	SPP	Agricultural land	-	Outside agricultural land

	functions, i.e. the probability of direct or indirect impact on the quality and sustainability of the natural resource. *Data: a set of local data on agricultural land was used*	WPP	-	Agricultural land	Outside agricultural land
Forest	*Sensitivity regarding the importance and maintenance of forest functions, i.e. the probability of direct or indirect impact on the quality and sustainability of the natural resource.* *Data: sets of global data on forests were used – layers of tree cover and shrubland were considered as relevant for sensitivity scoring*	SPP and WPP	High-woods	Shrubland/Degraded forests	Outside forest land
Touristic/ Recreation zones	*Sensitivity regarding possible impairment (type of use, attendance) with regard to visual impacts, noise and flickering in case of SPP and WPP. Distance from the existing tourist/recreation zone.* *Data: a set of local data on touristic zones and recreational areas from the municipal spatial plan was used*	SPP	< 500 m	500 - 1000 m	> 1000 m
		WPP	< 1000 m	1000 - 2500 m	> 2500 m
Distance from cultural goods	*Sensitivity regarding possible impairment (type of use, attendance) with regard to visual/social impacts in the case of SPP/ WPP.* *Data: local data on location of cultural, historical and spiritual sites were used*	SPP and WPP	< 500 m	500 - 1000 m	> 1000 m

Extremely valuable natural and semi-natural areas	*Exceptionally valuable natural and semi-natural areas, cultural areas and protected areas (natural monuments, reserves, areas of exceptional quality).* *Data: a set of data for extremely valuable natural and semi-natural areas from the municipal spatial plan was used*	SPP and WPP	-	Extremely valuable natural and semi-natural areas in accordance with the spatial plan	Outside valuable areas

2. **Assessing potential conflict.** For each criterion a weighting factor is allocated and the level of potential conflict of the assessed area within the respective category is obtained by calculating the products of criteria (x_{crit}) and their associated weighting factors (w_{crit}). The weighted scores obtained this way for each criterion are added together to get the overall conflict score (c_{all}) for SPP and WPP:

$$c_{all} = \sum_{i=1}^{n} x_{crit} \times w_{crit}$$

Table 5 contains proposals for weighting factors for each of the defined criteria for SPP and WPP.

Table 5: Weighting factors for sensitivity analysis for SPP and WPP

Index	Weighting factor for SPP	Weighting factor for WPP
Nature protection		
Protected areas	0.2	0.3
Endangered and rare habitats	0.2	0.2
Habitats important for bats	0.25	0.2
Habitats important for birds	0.25	0.2
Natural resources and development potentials		
Agricultural land	0.2	0.1
Forests	0.25	0.3
Touristic/Recreation zones	0.25	0.3
Human environment (social values)		
Distance from cultural goods	0.15	0.1
Extremely valuable natural and semi-natural areas	0.25	0.2

Finally, assessed areas are divided into three categories by application of a linear scale on the max value of the overall score:

1. *low conflict* – below 30% of max value,
2. *medium conflict* – 30-50% of the max value,
3. *high conflict* – above 50% of the max value.

Values for criteria buffers and weighting factors were defined using similar experiences in the region (e.g. Serbia, Croatia). Fine tuning of the values/factors is done in consultation with experts in the field of energy, environment, agriculture and landscape architecture from the review team and from relevant institutions. In addition, a stakeholder workshop was organised with the aim of familiarising stakeholders with the project and preliminary results.

3 ENERGY MAPPING

As described in the Methodology (Chapter 2), energy mapping for the Municipality of Nikšić entails two steps:

- Identification and exclusion of the areas which are not suitable for wind and solar siting due to legal, biophysical or resource constraints;
- Estimation of site suitability for RES based on potential resource yield and feasibility criteria (e.g. proximity to major roads, railroads, power lines and consumption centers).

Exclusion of the areas that are not suitable for wind and solar siting is done on the basis of the constraints identified in *Table 1*.

In the first step, all legal and infrastructure constraints which preclude a zone from being suitable for SPP or WPP development were mapped, as shown in *Figure 3*, where 311.5 km2 were excluded. The mapping of constraints is done in vector format with final results being rasterized to a resolution of 30x30 m.

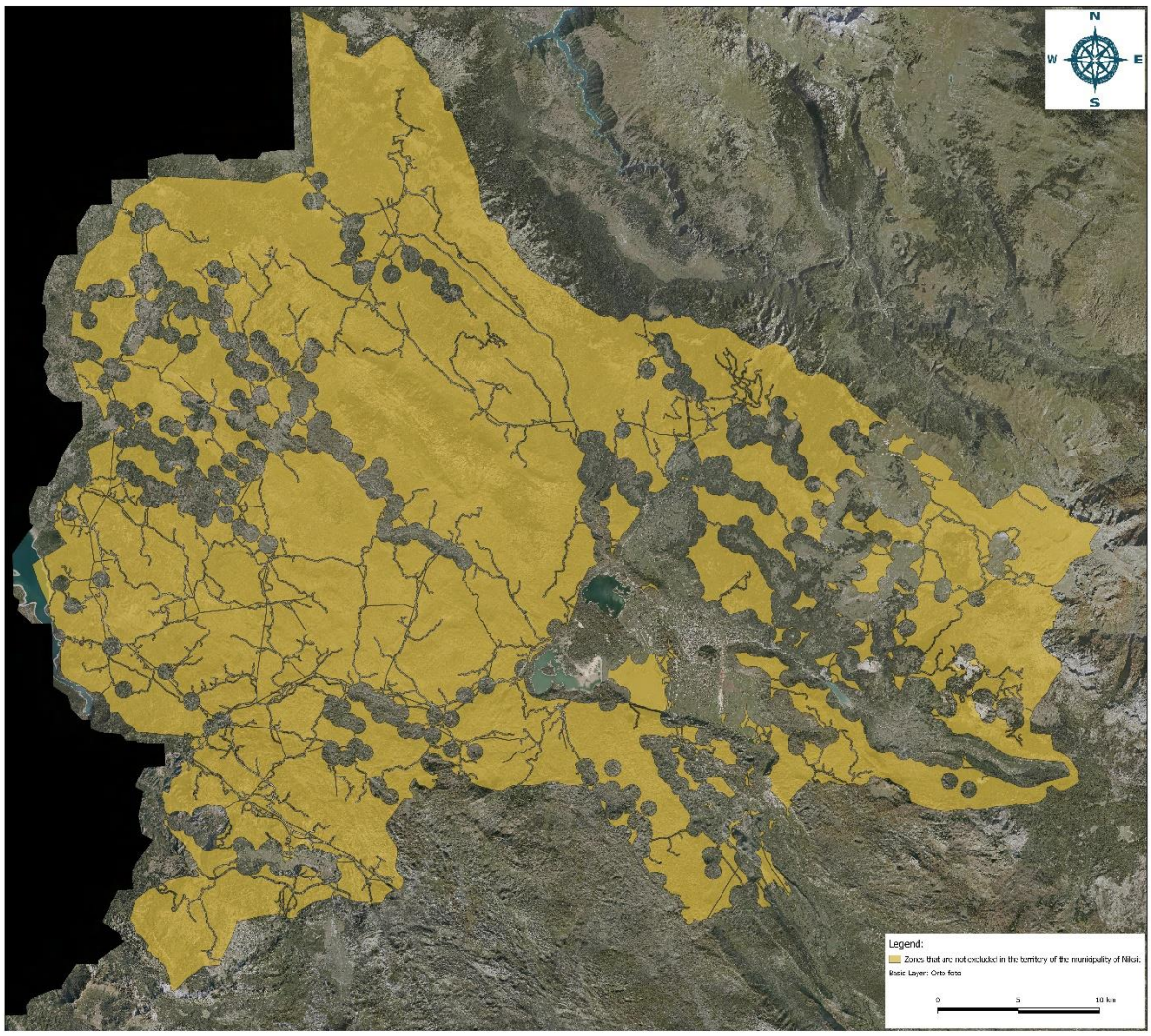


Figure 3: Exclusion of zones with legal and infrastructure constraints for RES siting

Next, due to the impact that steep slopes can have on the utilisation of space and complexity of plant construction, terrains with slopes above certain values were excluded as follows:

- For SPP 10˚,
- For WPP 15˚.

For the evaluation of slope, a digital evaluation model (DEM) with a resolution of 28x28 m was used. The resulting maps for slope evaluation are shown in *Figure 4.*

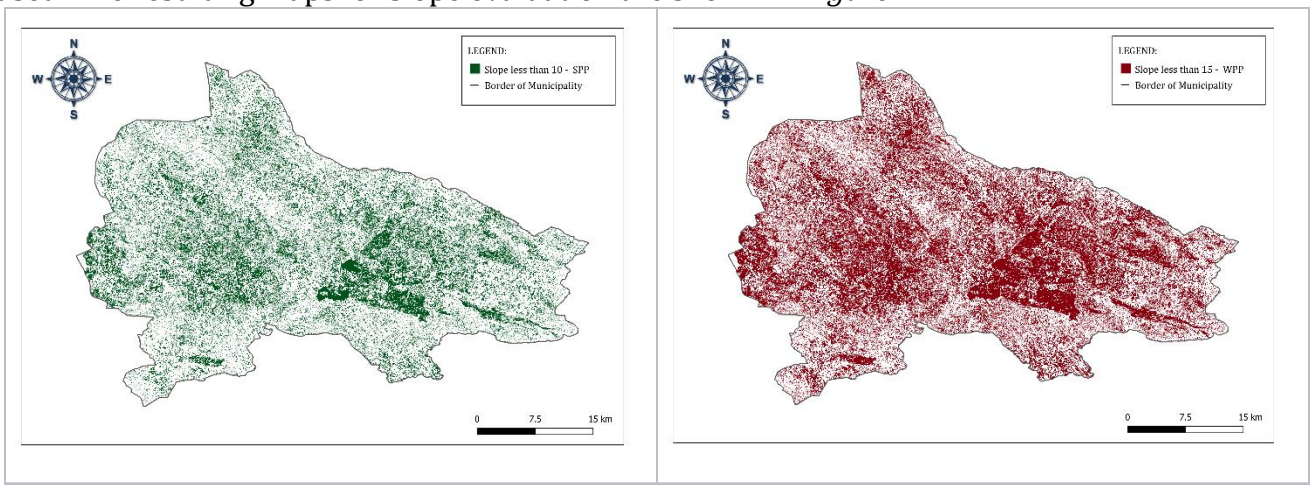


Figure 4: Map of exclusion of areas by slope above 10˚(left) and 15˚ (right) for the Municipality of Nikšić

The final evaluation of area suitability for solar and wind siting, that is, following the exclusion of areas due to legal/infrastructure constraints as well as slope analysis, are shown on constraint maps in *Figure 5*.

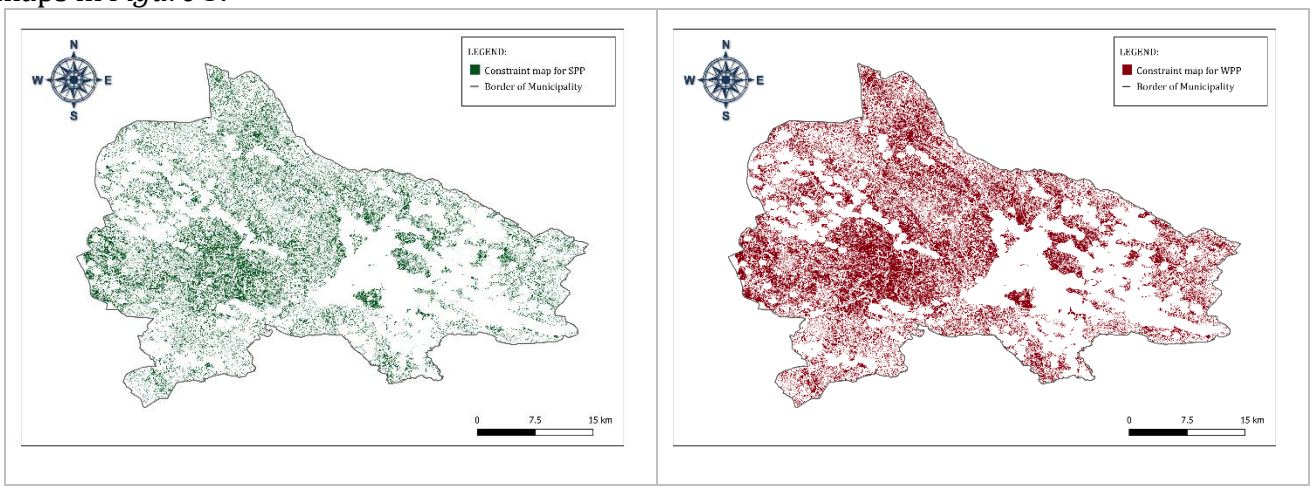


Figure 5: Constraint maps for SPP (left) and WPP (right) for the Municipality of Nikšić

Estimates of potential resource yield site suitability are done separately for solar and wind by using available data on potential resource yield. Data on global solar irradiation (GHI) and wind speed that can be used to estimate RES potential are taken from global sources (in accordance with *Table 2*) and the relevant maps are illustrated in *Figure 6*.

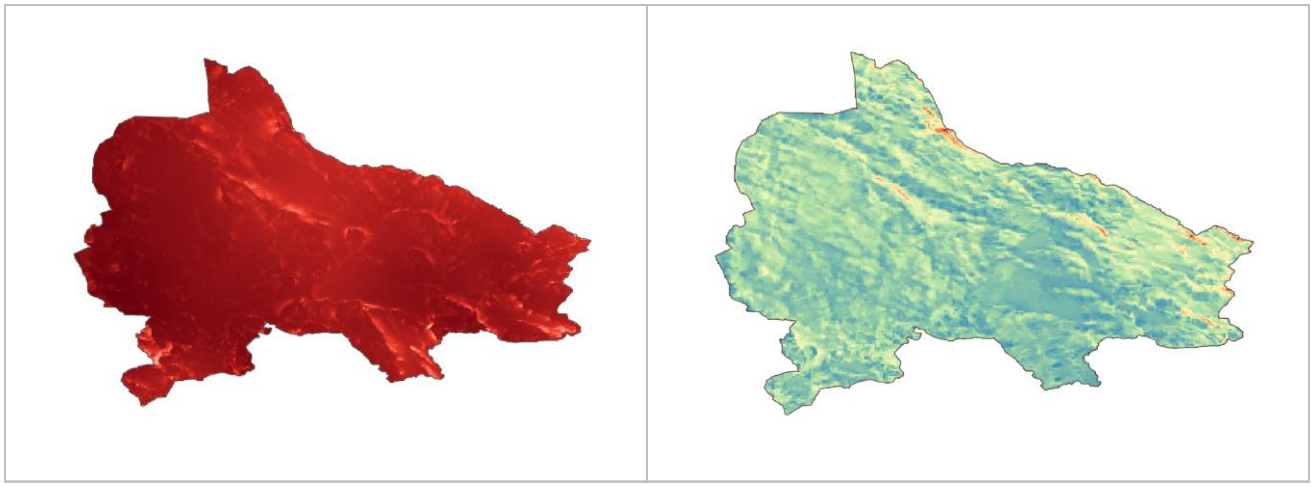


Figure 6: Maps for GHI (left) and wind speeds (right) for the Municipality of Nikšić

3.1 Suitability for solar power plants

In the case of SPP, the parameter used as the indicator of natural potential for solar energy production in a certain area is GHI (expressed in kWh/m^2 per day). Areas with GHI below 3 kWh/m^2 per day were excluded due to the low economic potential for development of solar power plants.

The analysis of GHI data for the Municipality of Nikšić shows (and this can be noticed in *Figure 6*) that on 99% of municipal territory the irradiation level is higher than the minimal threshold.

The subsequent map showing suitable areas for solar development in the Municipality of Nikšić is prepared by overlapping binary datasets of the GHI map and the constraint map (from *Figure 5*) in a resolution of 28x28 m (*Figure 7*). The total area suitable for development of SPP is around 465.4 km^2. Assuming that 2 ha of land are required for 1 MW of solar energy capacity, the total potential capacity of the Municipality of Nikšić amounts to 23.27 GW.

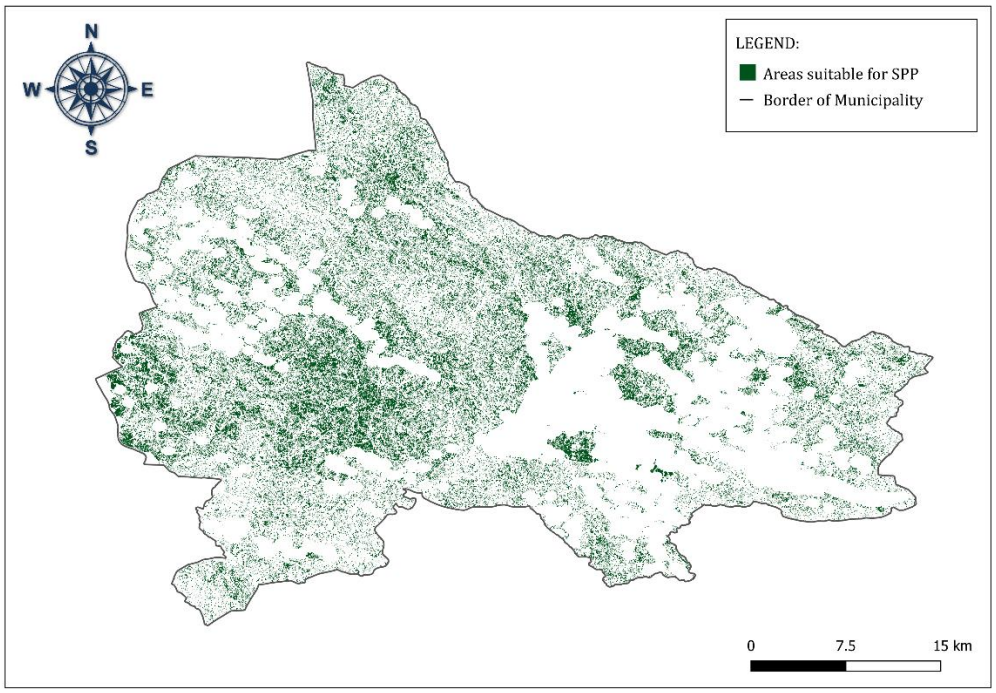


Figure 7: Suitability area for SPP development in the Municipality of Nikšić

If we want to limit the analysis to larger SPP projects, for example those larger than 1MW, it is necessary to apply a filter which will eliminate areas smaller than 2 ha (less than 30 contiguous pixels). The map of suitable areas for developing SPP projects larger than 1 MW is shown in *Figure 8*.

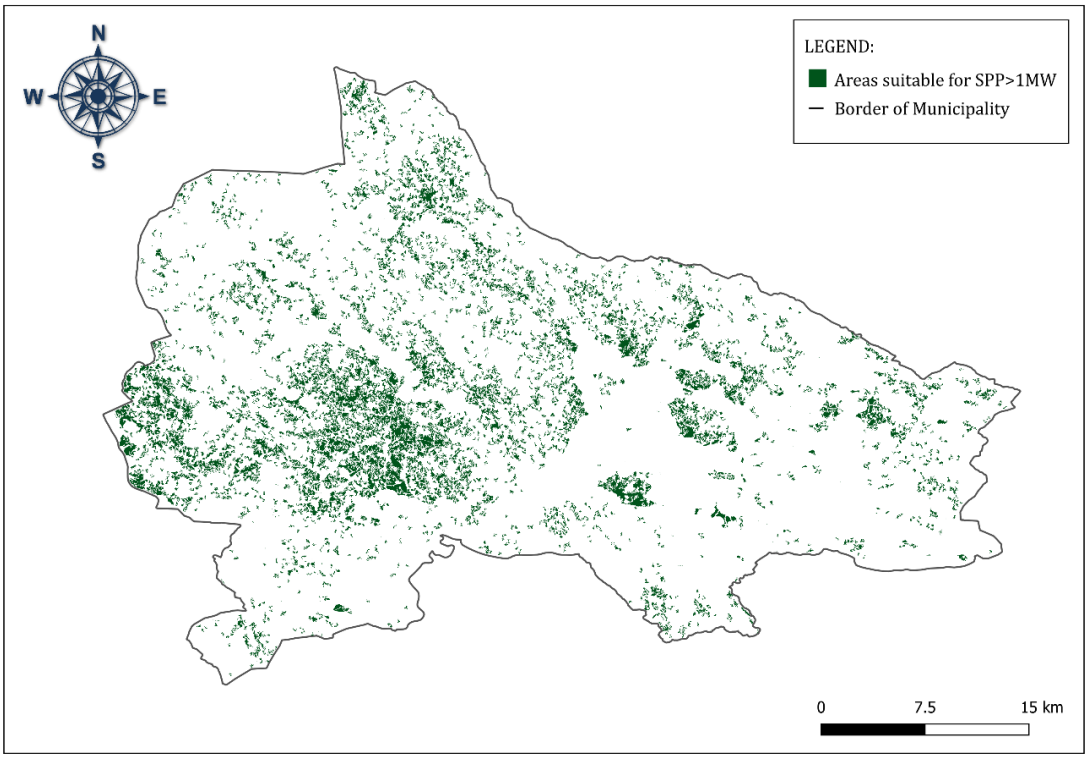


Figure 8: Suitability areas for development of SPP>1 MW in the Municipality of Nikšić

The spatial siting of SPP could also be limited by other factors that impact project costs (e.g. proximity to major roads, railroads, power lines and consumption centers). To produce a final ranking of RE development potential across the study area, the feasibility criteria are applied in accordance with *Table 3*. For SPP, potential developments' distance from distribution and transmission power lines is considered as part of the feasibility criteria.

Final SPP ranking scores are further divided into four categories and assigned to four suitability levels (very low; low; medium; high), as shown in *Figure 9*. Intervals for suitability levels are set against final scores in such a way that the threshold between two lower levels (very low; low*)* and two higher levels (medium; high) is 0.75 (max value 0.97).

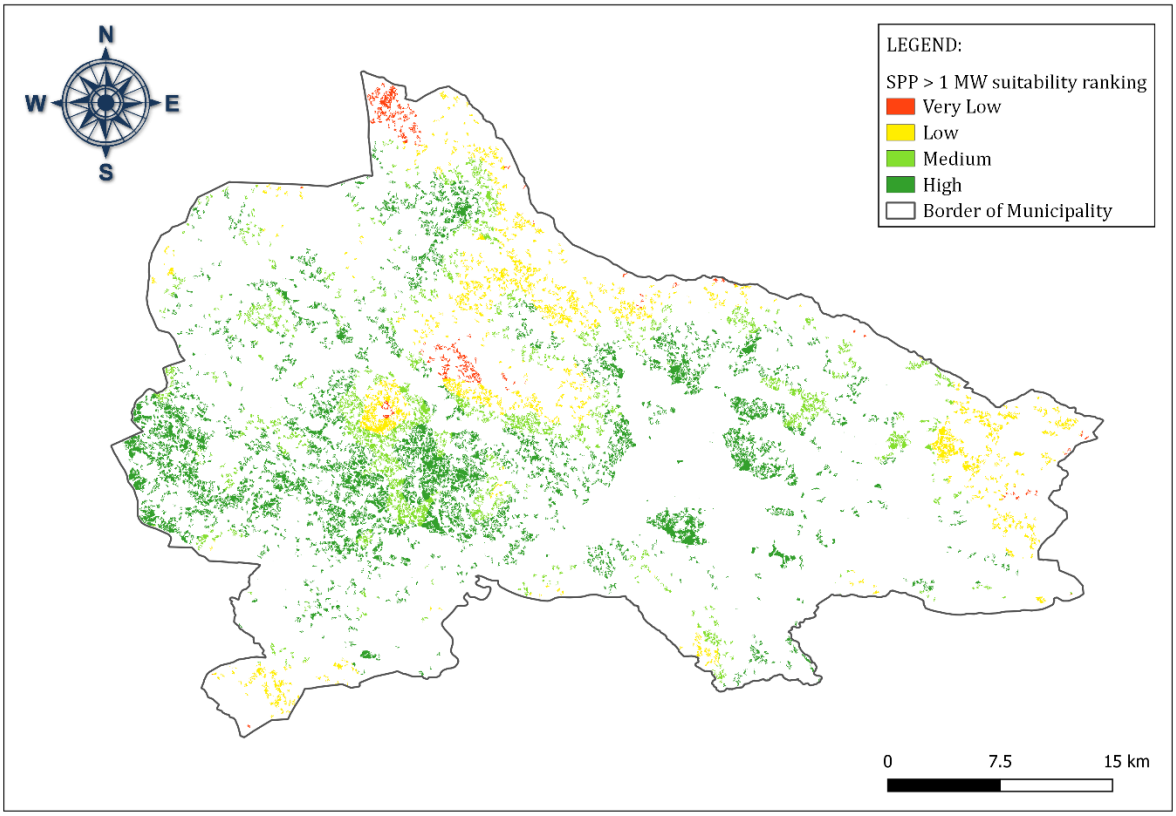


Figure 9: Ranking of suitability areas for development SPP>1MW in the Municipality of Nikšić

3.2 Suitability for wind power plants

In the case of WPP, wind speed (m/s) is used as the indicator of natural potential for wind energy production in a certain area. Areas with a wind speed below 5 m/s were excluded due to the low economic potential for development of wind power plants.

The analysis of wind speed data for the Municipality of Nikšić shows (and this also can be noticed in *Figure 6*) that in 10% of municipal territory wind speeds are above the minimal threshold.

The subsequent map showing suitable areas for wind development in the Municipality of Nikšić is prepared by overlapping binary datasets of the wind speed map and the constraint map (from *Figure 5*) in a resolution of 28x28 m (*Figure 10*).

The total area suitable for development of WPP is around 60.1 km^2. Assuming 10 ha of land is required per 1 MW of wind energy capacity (based on recent WPP built in the region e.g. Croatia, Serbia), the total potential capacity of the Municipality of Nikšić amounts to around 400 MW.

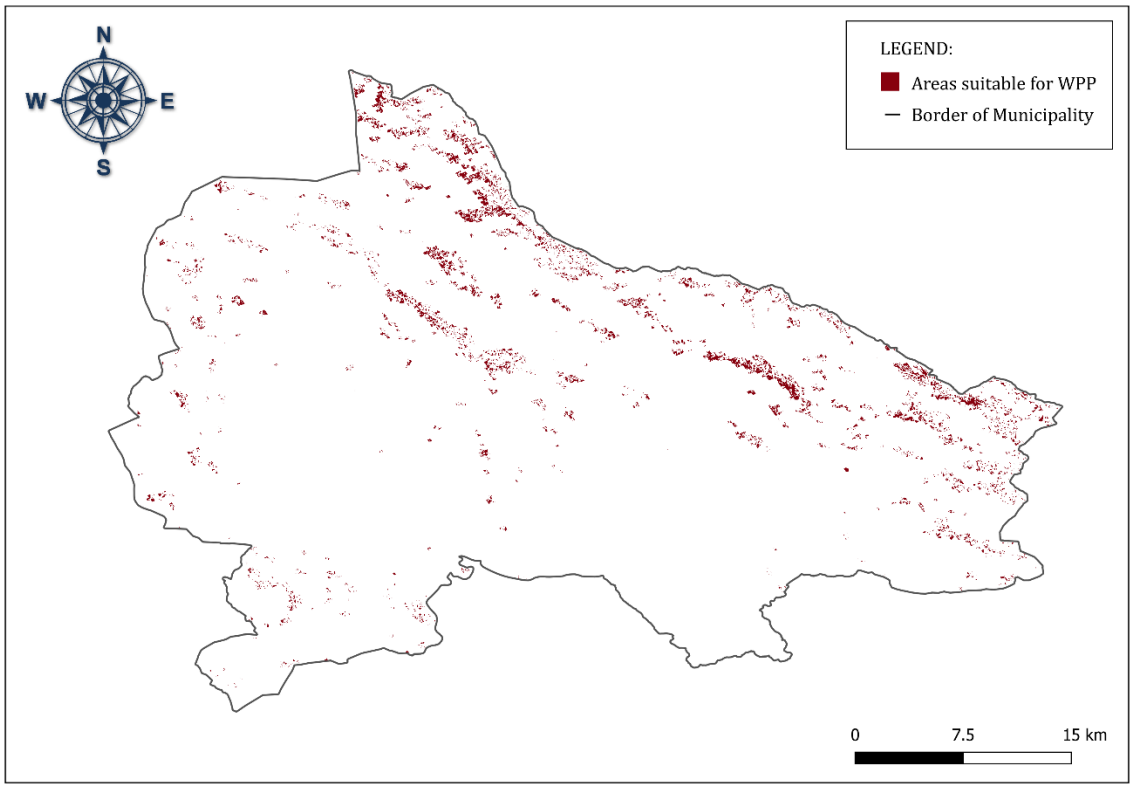


Figure 10: Suitability areas for WPP development in the Municipality of Nikšić

Similar to SPP, WPP project costs depend on other factors (e.g. proximity to major roads, railroads, power lines and consumption centers) and RE development potential is ranked by applying feasibility criteria in accordance with *Table 3*. Criteria used for ranking RE development potential for the Municipality of Nikšić are given in *Table 3*. For WPP development only distance from transmission power lines is considered as a feasibility criterion due to the larger installed capacities. Distribution power lines were not considered as relevant for connection points for future WPP projects.

Final WPP ranking scores are further divided in four categories and assigned to four suitability levels (very low; low; medium; high), as shown in *Figure 11*. Intervals for suitability levels are set against final scores in such a way that the threshold between two lower levels (very low; low) and two higher levels (medium; high) is 0.68 (max value 0.86).

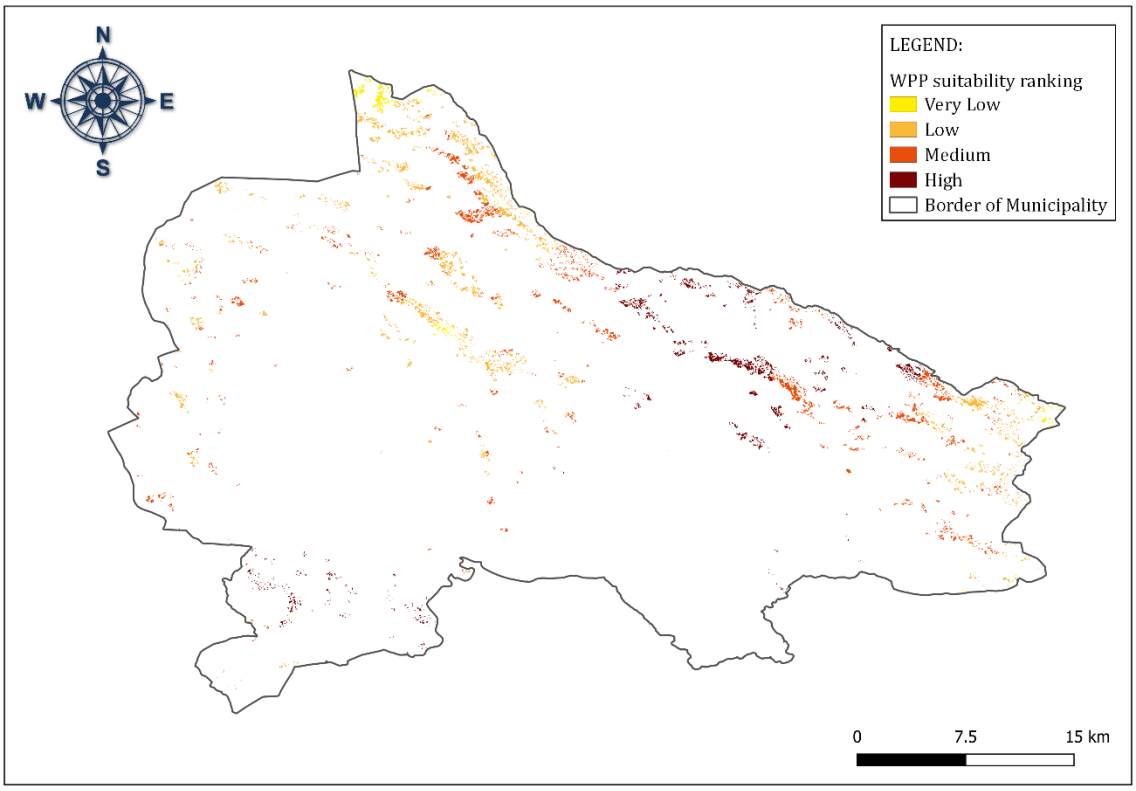


Figure 11: Ranking of suitability areas for WPP development in the Municipality of Nikšić

Finally, it is also interesting to see which areas are suitable for the development of hybrid generation projects which includes SPP and WPP at the same time. This can be done by simply overlapping the layers for suitability of SPP and WPP. An illustration of locations suitable for hybrid RES projects is given in *Figure 12*.

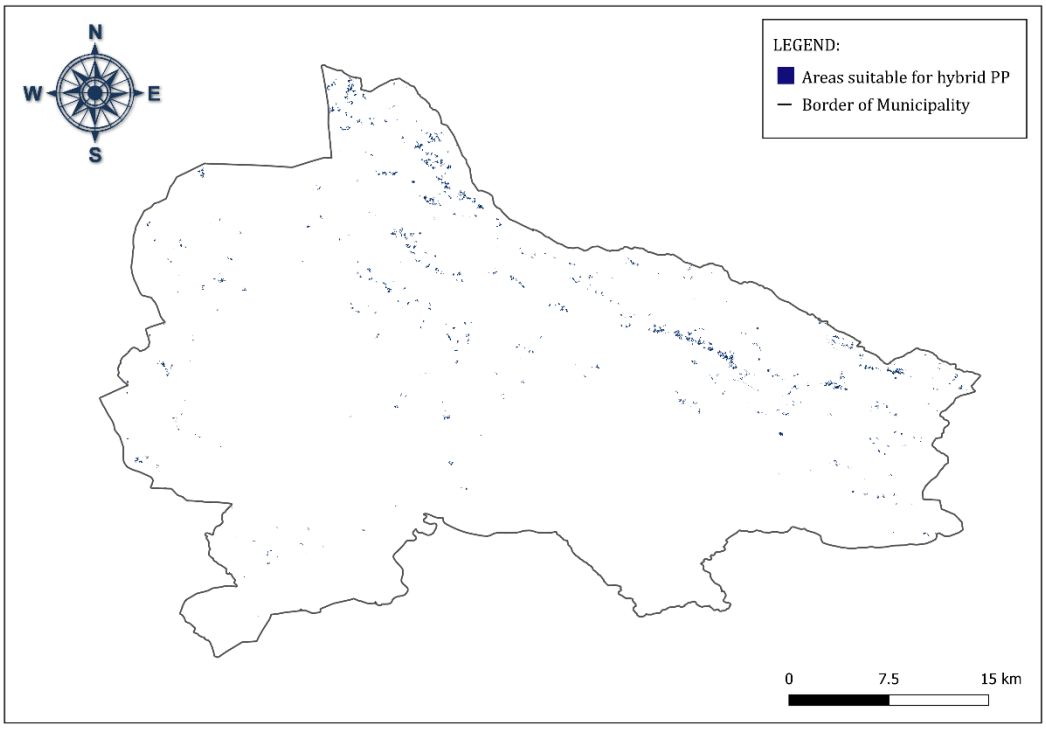


Figure 12: Suitability area for development of hybrid RES projects in tbe Municipality of Nikšić

4 LOW-CONFLICT SOLAR AND WIND MAPPING

The aim of the project is to develop a low-conflict solar and wind siting scenario for the Municipality of Nikšić by identifying and mapping the highest priority areas for solar and wind development that have the lowest environmental and social conflict.

The Methodology (Chapter 2) provides details on the sensitivity analysis of the assessed area based on available data and information about the status of natural resources, flora and fauna, cultural heritage and landscape value, as well as taking into consideration the existing and planned land use patterns. The aim was to identify sites with high sensitivity where RES should not be implemented, but also sites with low-conflict for future SPP/WPP deployment.

As described in the Methodology, for the sensitivity analysis a set of criteria is defined in accordance with *Table 4* with a scoring method based on prevailing characteristics (degree of protection, distance from the zone/object, land value, etc.). An illustration of sensitivity scoring for defined criteria for SPP/WPP development is given in *Figure 13.* The maps of sensitivity scoring contain two shades of green. Dark green corresponds to a sensitivity score of 5 and indicates high sensitivity. Light green corresponds to a sensitivity score of 3 and indicates medium sensitivity (see *Table 4*). White regions correspond to a sensitivity score of 0 and represent areas that are considered to have low sensitivity to the potential impacts of SPP/WPP development.

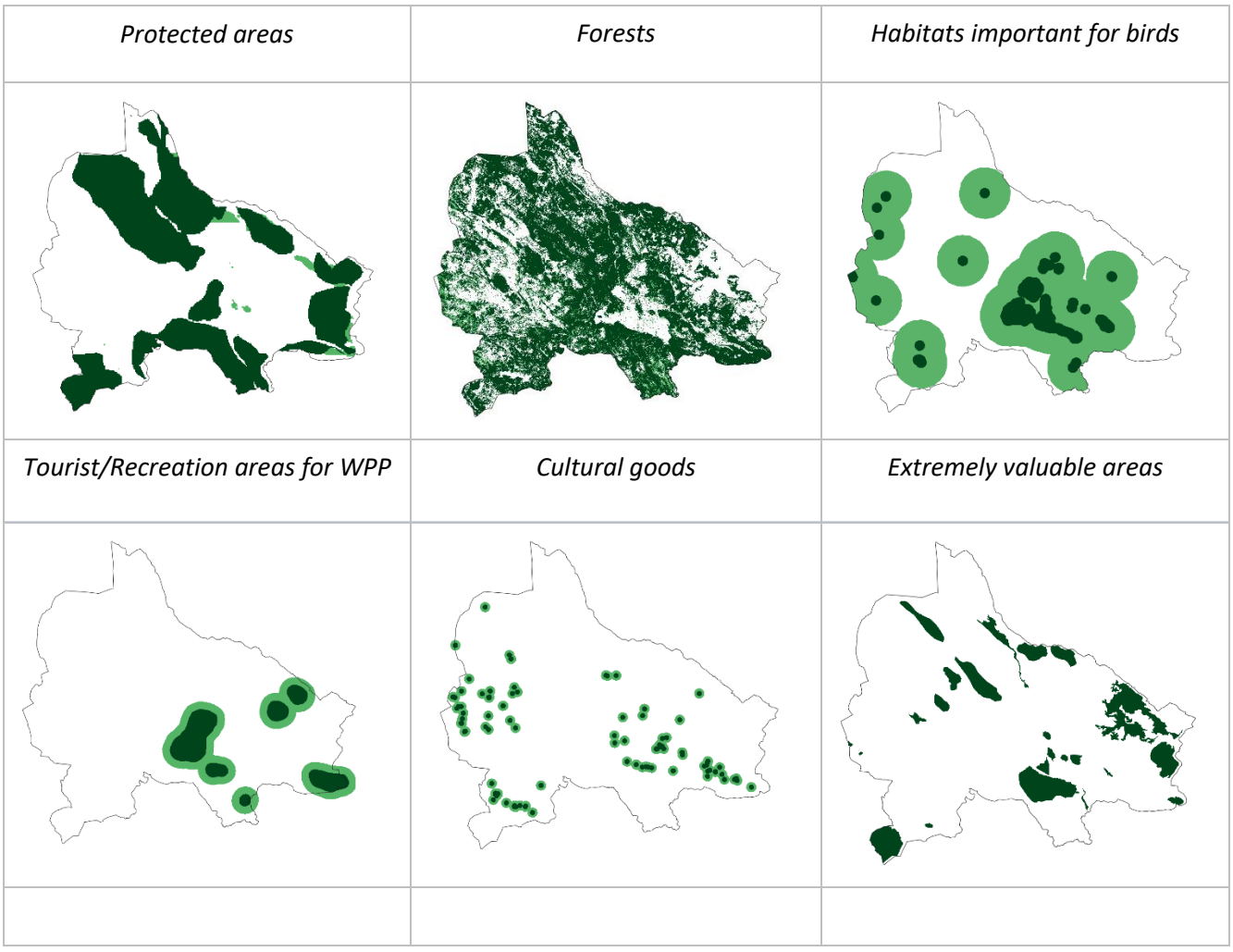


Figure 13: Illustration of sensitivity scoring for defined criteria for SPP/WPP development

Assessing potential conflict for SPP and WPP is done by applying the weighting factors allocated for each of the criteria (adding the products of criteria and their respective weighting factors). The resulting scores for assessed areas are then divided into three categories by application of a linear scale and assigned to three levels (low conflict; medium conflict; high conflict) and presented on conflict maps for SPP (*Figure 14*) and WPP (*Figure 15*).

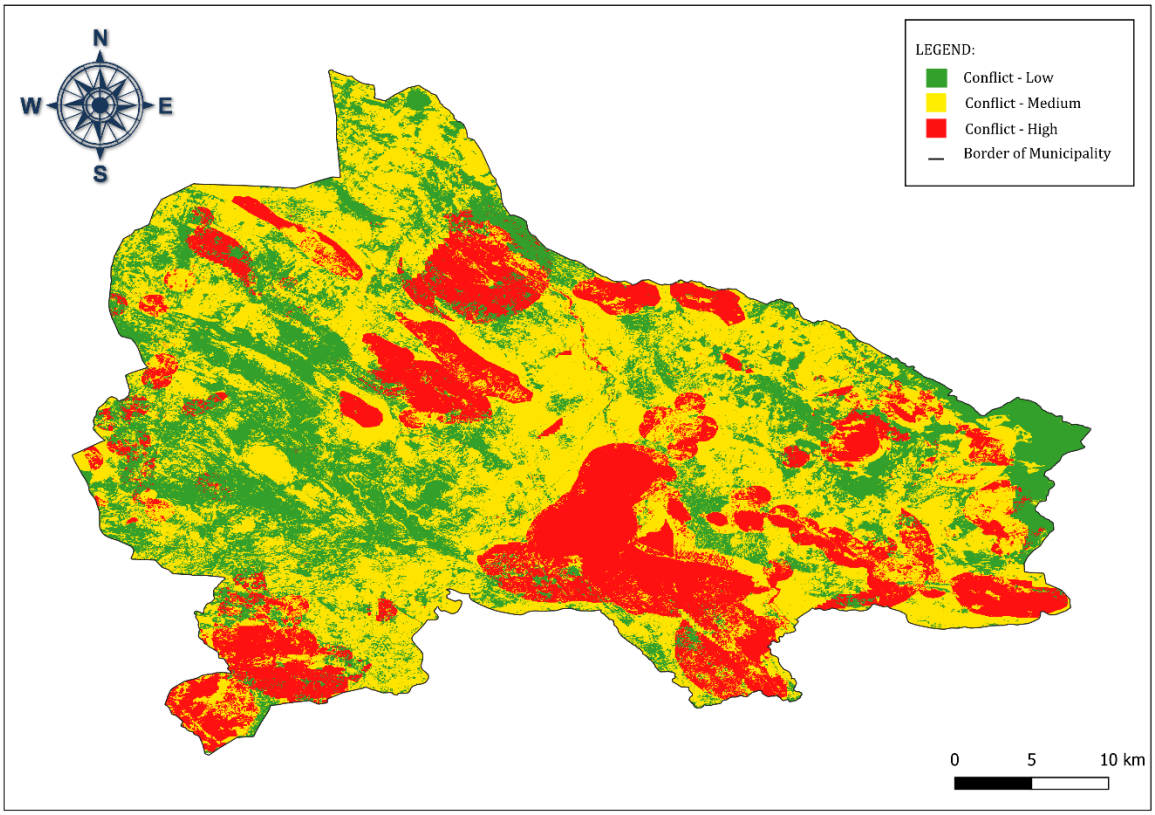


Figure 14: Conflict map for SPP development in the Municipality of Nikšić

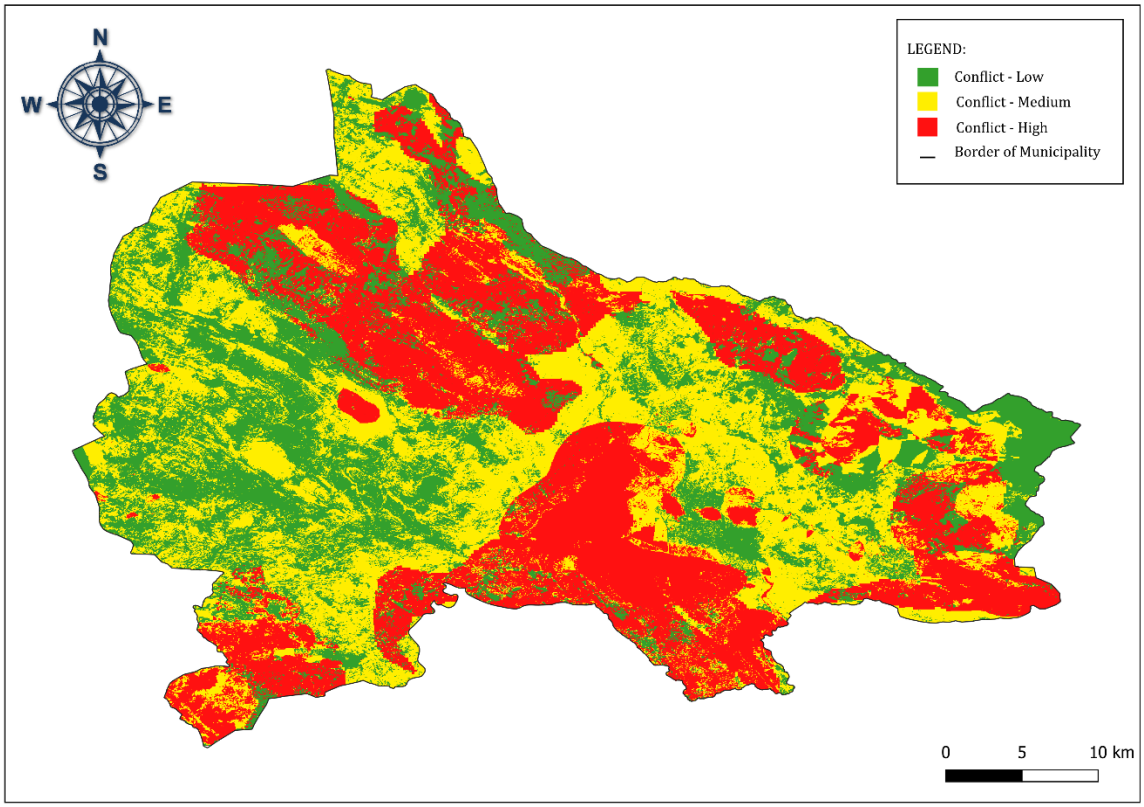


Figure 15: Conflict map for WPP development in the Municipality of Nikšić

4.1 Low-conflict maps for SPP

In the case of SPP, the map showing low-conflict areas suitable for solar development in the Municipality of Nikšić is prepared by overlapping binary datasets of the suitability map for SPP above 1 MW (*Figure 9*) and the conflict map for SPP (*Figure 14*) in a resolution of 28x28 m (*Figure 16*).

The total low-conflict area suitable for the development of SPP above 1 MW is around 81.8 km^2. Assuming that 2 ha of land are required for 1 MW of solar energy capacity, the total potential capacity of the Municipality of Nikšić is 4.1 GW, of which 2.7 GW is located in areas with "high" and "medium" suitability.

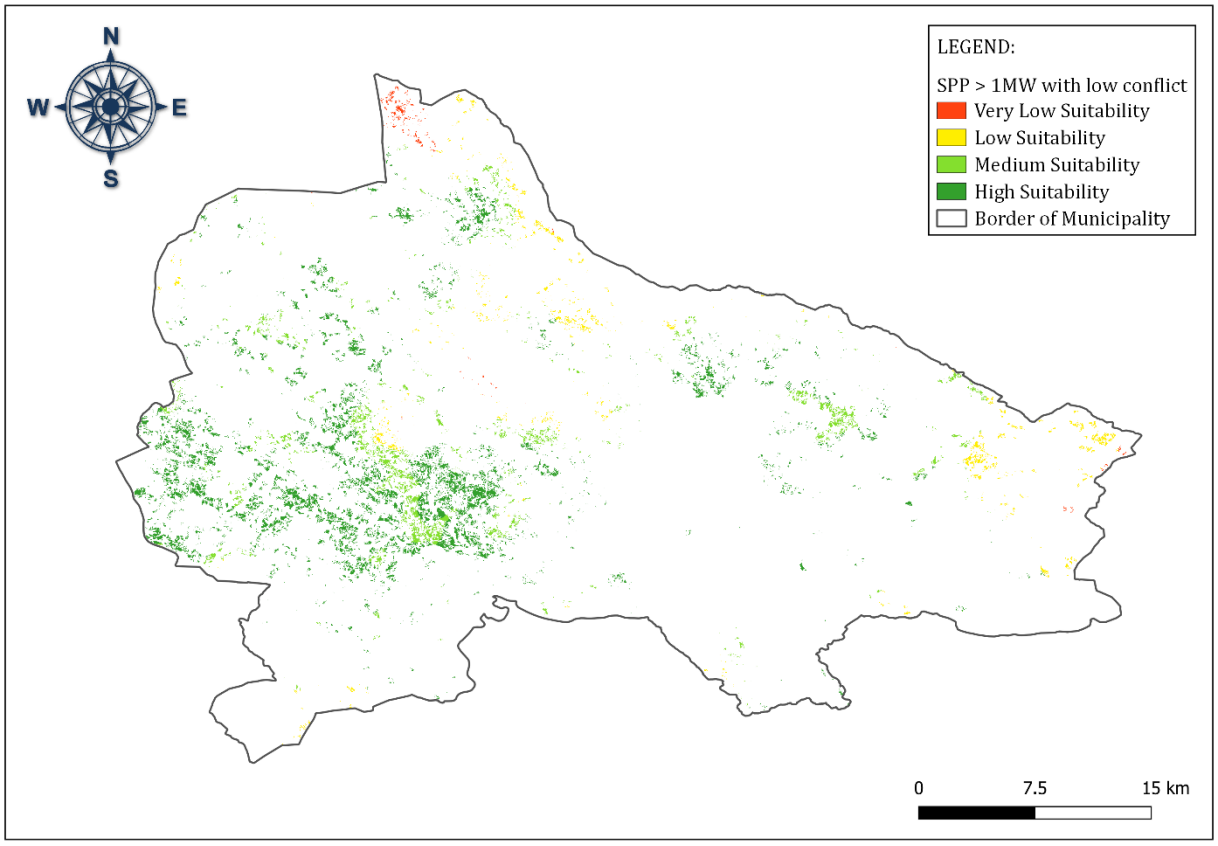


Figure 16: Low-conflict map for development of SPP>1MW in the Municipality of Nikšić

4.2 Low-conflict maps for WPP

In the case of WPP, the map showing low-conflict areas suitable for wind development in the Municipality of Nikšić is prepared by overlapping binary datasets of the suitability map for WPP (*Figure 10*) and the conflict map for WPP (*Figure 15*) in a resolution of 28x28 m (*Figure 17*).

The total low-conflict area suitable for the development of WPP is around 20 km^2. Assuming 10 ha of land is required per 1 MW of wind energy capacity (based on recent WPP built in the region e.g. Montenegro, Croatia, Serbia), the total potential capacity of the Municipality of Nikšić amounts to around 200 MW, out of which 39 MW is located in areas with “high” and “medium” suitability.

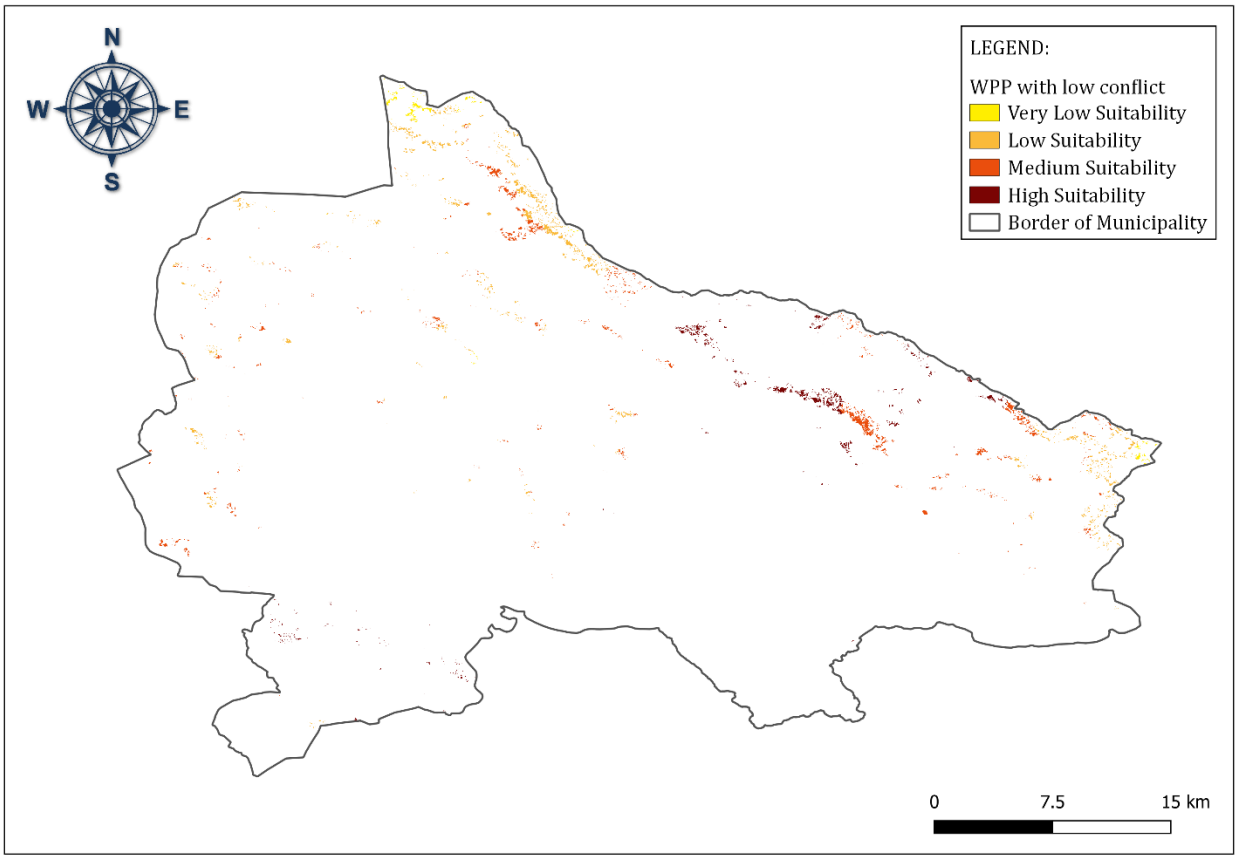


Figure 17: Low-conflict map for WPP development in the Municipality of Nikšić

ANNEX 1: RELEVANT DATA SOURCES

Category	Data description	Data type	Relevant institution/source
General GIS data related to the Municipality of Nikšić	Data on the territory of the Municipality of Nikšić, terrain configuration and other geographical features relevant for the definition of criteria and boundary conditions	Digital elevation model (DEM) Orthophoto map Territorial boundaries of the municipality	DEM data with a resolution of 28x28 from https://data.nextgis.com Borders for the Municipality of Nikšić and orthophoto map from the Spatial plan of the Municipality of Nikšić
Data on power lines	Routes of the transmission and distribution power lines needed in order to introduce criteria for the construction of generation facilities	Data on transmission power lines and power facilities (substations, poles) (voltage level 110, 220 and 400 kV) Data on distribution power lines and power facilities (substations, poles) (voltage level 10 and 35 kV)	Data provided by Transmission system operator (CGES) Data provided by Distribution system operator (CEDIS)
Protected natural areas	Protected areas within the following categories: strict reserves, special reserves, national parks, Ramsar areas, nature monuments, monuments of park architecture, park forests, significant landscapes, Ramsar sites, UNESCO sites	Boundaries of protected natural areas	Data provided by the Environmental Protection Agency
Habitats	Endangered and rare habitats, habitats important for bats, habitats important for birds, habitat suitability for large carnivores. Data collected during the mapping of Natura 2000 habitats and species	Boundaries of the habitats on the basis of the available registers	Data provided by the Environmental Protection Agency Data provided by Center for the Protection and Research of Birds

Cultural heritage	Areas designated as cultural heritage areas and archaeological sites	Settlement zones identified on the basis of the Spatial Plan	Spatial plan of the Municipality of Nikšić
Natural resources	River networks, borders of basins and sub-basins, water springs and water sanitation zones	Data on river networks, water springs and water sanitation zones	Data provided by the Water Administration Global data from https://data.nextgis.com
Infrastructure corridors	Airports, highways and roads, railways, gas pipelines, antennas and the respective legally defined corridors	Infrastructure corridors identified for all types of facilities on the basis of the Spatial Plan	Spatial plan of the Municipality of Nikšić Data on minor roads were supplemented with global data from https://data.nextgis.com
Specially designated areas	Military zones, touristic and recreational zones (hotels, touristic settlements, camps, open air sport facilities)	Specially designated areas identified on the basis of the Spatial Plan	Spatial plan of the Municipality of Nikšić
Settlements	Settlements and their immediate surroundings	Settlement zones identified on the basis of the Spatial Plan	Spatial plan of the Municipality of Nikšić
Woods and woodland	Zones of high and medium woods and woodland	Boundaries of woods and woodland areas	Global data from https://viewer.esa-worldcover.org/ Data provided by the Forest Administration
Arable land and other agriculture land	Areas used for cultivation of crops, both temporary and permanent Other agriculture areas mainly meadows and grassland	Boundaries of the arable land and other agriculture	Data provided by Ministry of Agriculture, Forestry and Water Management Spatial plan of the Municipality of Nikšić

ANNEX 2: Analysis of constraints for RES suitability mapping in the Municipality of Nikšić

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 + buffer	0	m	Law on nature protection ("O.G of Montenegro", No. 54/2016 and 18/2019)	Construction of facilities is forbidden in the protected areas in accordance with Article 31 of the Law.
Cultural, historic and spiritual sites	feature + buffer	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.
Recreational areas	feature + buffer	0	m	Spatial plan	In accordance with the spatial plan the purpose of the zone is recreation.
Touristic zones	feature + buffer	0	m	Spatial plan	In accordance with the spatial plan, the purpose of the zone is the development of tourism.

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Military zones	feature + buffer	0	m	Law on Defense („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. 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				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.
Urban	feature + buffer	500	m		
Rural	feature + buffer	500	m		
Roads				Law on Roads („O.G of Montenegro“ No. 82/2020)	In accordance with Article 92 of the Law, width of the protection zone in which mines and quarries, construction of lime and brick quarries, extraction of
Major	feature + buffer	40	m		

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Minor	feature + buffer	20	m		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: next to highways, expressways and main roads 60 meters, next to regional roads 40 meters, and next to municipal roads 20 meters, counting from the outer edge of the road strip.
Airport (airfield)	feature + buffer	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.
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 220-400 (110) kV – protection zone 30 (25) m on both sides in relation to the vertical projections of the end conductors;
Transmission	feature + buffer	30	m		

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Distribution	feature + buffer	15	m		Distribution line 35kV (10kV) - protection zone 15 (5) m on both sides in relation to the vertical projections of the end conductors.
Power plants (wind)	feature + buffer	0	m	Spatial plan	Location of WPP Krnovo (northern part of the Municipality of Nikšić near the border with the Municipality of Savnik).
Radio/cell towers (wind only)	feature + buffer	0	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	Rulebook defines sizes of protection zones depending on the type, power and frequency of the radio centers 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, serves for the maintenance
Lakes	feature + buffer	15	m		

Constraints	Excludes	Size of the buffer	Unit	Legal basis	Explanation/Note
Rivers	feature + buffer	15	m		of protective structures and troughs for large water and other activities in water management.
Landcover					
Woods and woodland	No	0	m	Law on Forests ("(„O.G of Montenegro“ No. 74/2010, 40/2011 and 47/2015)	In accordance with Article 38 of the Law, the use of woods and the woodland can be changed into construction or other land by clearing only in accordance with the spatial planning document and the forest development plan in accordance with the law.
Croplands (PV only)	No	0	m	Law on Agricultural Land ("O.G of Montenegro", No. 15/1992, 59/1992, 27/1994 73/2010 and 32/2011)	Article 20 of the Law defines the possibility to temporary use agricultural land for non-agricultural purposes. Article 21 of the Law recognises permanent change of use of agricultural land, which permanently prevents the use of that land for agricultural production.
Economic constraints					
Wind speed	values below	5	m/s		
Global Horizonal Irradiance (GHI)	values below	3	kWh/m2 per day		