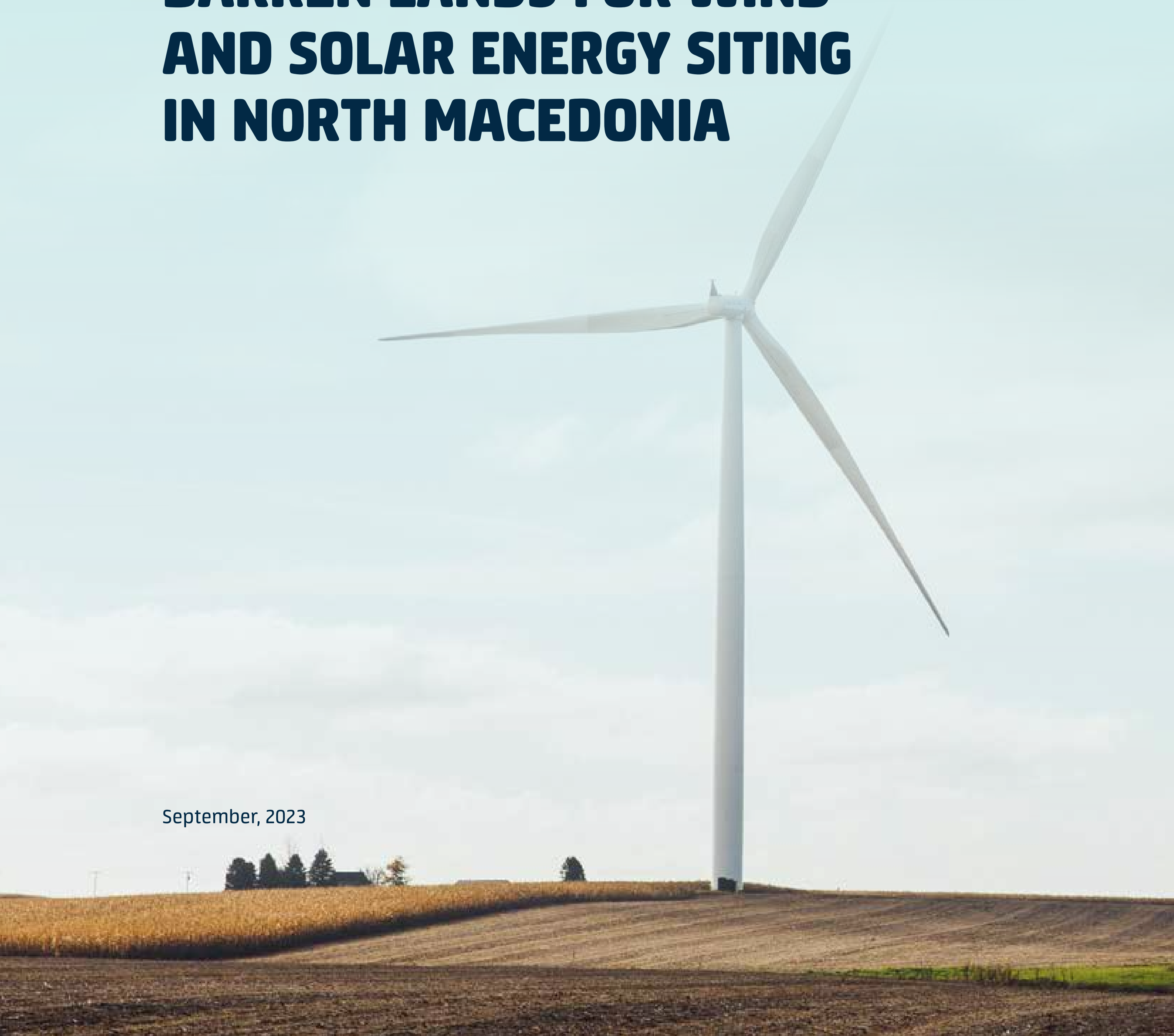
ACCELERATING A RENEWABLE FUTURE: USING BROWNFIELDS AND BARREN LANDS FOR WIND AND SOLAR ENERGY SITING IN NORTH MACEDONIA



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ACCELERATING A RENEWABLE FUTURE: USING BROWNFIELDS AND BARREN LANDS FOR WIND AND SOLAR ENERGY SITING IN NORTH MACEDONIA

Prepared by:

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CONTENT:

List of figures

List of tables

1

INTRODUCTION

Due to a series of crises at the global level (the war in Ukraine, global supply chain interruptions, a flailing world economy, rising inflation, etc.), energy transition, and particularly the development of local carbon-neutral energy production plants, has sped up. The increased pace with which renewable energy source (RES) capacities are being deployed nowadays will be of paramount importance in meeting the national goals relevant to this topic. Furthermore, it will allow for a greater share of total energy production to come from domestic resources, thus increasing the security of supply and creating greater independence in accessing needed energy. However, a structured and mindful approach to this process is very important; otherwise, the associated risks may outweigh the potential benefits.

The construction of RES capacities in North Macedonia has advanced quickly over the past two years. In 2022, the total installed capacity of RES was calculated at 944.5 megawatts (MW), an increase of 16 per cent compared to 2021 and 17 per cent compared to 2020. This trend is expected to continue however, according to the analyses done for MEPSO[1], installing of more than additional 500 MW of wind and solar power plants will have impact on balancing requirements. At the same time, both the transmission system operator (TSO) and the distribution system operator (DSO) have received requests for installation of new capacities, exceeding 12 gigawatts (GW).[2,3] The target for installed RES capacity set in the national Strategy for Energy Development of the Republic of North Macedonia up to 2040[4] is 750 MW for wind power and 1,400 MW for solar photovoltaic power. If it is compared to the submitted requests it is considerably less. The evaluation of RES development must take into account its environmental implications.. One substantial strategy for alleviating the environmental repercussions of RES lies in the selection of construction sites. Selecting suitable locations for RES development can avoid disruptions to local wildlife and preserve arable land for its primary intended purpose, agricultural cultivation. Additionally, by adopting a mindful approach to determining suitable land areas for RES buildout, costs may be cut, and the overall economic feasibility of the projects might be improved.

1 INTERIM REPORT - Sizing of System Rezerves in the Macedonian power systems for scenarios with large scale RES https://www.mepso.com.mk/docs/pubmk/MEPSO_INTERIM_2.1_12.04.2023_Clean.pdf

2 MEPSO, Development plan of the transmission system for the period 2023-2032, October 2022, Skopje Republic of North Macedonia

3 EVN, Development plan of the distribution system for the period 2023-2027, November 2022, Skopje Republic of North Macedonia

4 https://economy.gov.mk/Upload/Documents/Adopted%20Energy%20Development%20Strategy_EN.pdf

2

LITERATURE REVIEW

The assessment and spatial identification of greenfields' RES potential has become an increasingly popular undertaking in recent years, receiving long-awaited and well-deserved attention. The accurate visualisation of greenfields is a complex activity combining cross-sectoral support and expertise in order to obtain functional maps indicating appropriate areas for RES development. However, there have been numerous studies in the last decade that indicate ways to conduct such analyses. One such study is U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis,[5] which elaborates the results of a national spatial analysis for RES technical potential, available land area, installed capacity and electricity generation for six different technologies in solar, wind, hydro, bio- and geothermal systems. Additionally, the study identifies each technology's system-specific power density, capacity factor and land-use constraints. The system performance estimates are based on a multiregional, multi-time period, GIS, and linear programming model.

Today's favoured processes for pinpointing and mapping suitable locations for photovoltaics and wind include a variety of methods and forms of analysis, as well as multiple criteria, indicators, factors, etc. In order to make the entire process smoother and gather the data in a symbiotic way, Malczewski and Rinner (2015)[6] and Oakleaf et al. (2019)[7] use spatial multi-criteria decision analysis (MCDA) as a method to determine RES siting at a global level. Their approach consists of four steps: 1. constraint mapping; 2. criteria mapping and scaling; 3. criteria weighting; 4. combination of weighted criteria. The papers depicts the constraint thresholds, namely average annual global horizontal irradiation and slope and landcover for photovoltaics, and similarly, average annual wind speed, slope, elevation, landcover and wind turbine locations for the identification of potential wind power areas.

Although MCDA is a broadly accepted and used method, some estimations can be made with predictive models, namely the random forest algorithm, as explained by Evans et al. (2014),[8] in which data inputs can mimic the criteria under MCDA. Although this model is machine-learning-based and suitable for accelerated landscape-scale analysis, it requires a significant labelled dataset. Furthermore, in their paper for Zadar County in Croatia, Vorkapić et al. (2021)[9] simplify the development of maps to a three-

5 https://www.researchgate.net/publication/241909619_US_Renewable_Energy_Technical_Potentials_A_GIS-Based_Analysis/link/0c960538c9e48e9684000000/download

6 https://link.springer.com/book/10.1007/978-3-540-74757-4

7 https://www.nature.com/articles/s41597-019-0084-8

8 https://www.researchgate.net/publication/260447918_Shale_Gas_Wind_and_Water_Assessing_the_Potential_Cumulative_Impacts_of_Energy_Development_on_Ecosystem_Services_within_the_Marcellus_Play

9 https://www.researchgate.net/publication/350942353_Integrated_Renewable_Energy_Planning_in_Southeast_Europe_-_Pilot_project_Integrated_Wind_and_Solar_Planning_in_Zadar_County

step approach. First, based on legal constraints and vulnerabilities, disadvantageous areas for RES are excluded, then an evaluation of the beneficial areas is performed using a set of indicators (nature and biodiversity, natural resources important for economic activities, and social and cultural features) and their sensitivity level (low, medium or high) is determined through an MCDA. For each indicator, a weighted factor is introduced and allocated, and the sum of the multiplications yields the final area sensitivity, a process known as the analytic hierarchy process (AHP).

MCDA is taken a step further in Sultan Al-Yahyai et al. (2012)[10] in the case of wind farm siting in Oman. The paper uses AHP with an ordered weighted averaging (OWA) aggregation function to derive a wind farmland suitability index and classification in a geographic information system (GIS) using various selection criteria, such as economic (distance to road, terrain slope), social (urban area), environmental (historical locations, wildlife and natural reserves) and technical indicators (wind power density, energy demand matching, percentage of sustainable wind, turbulence intensity, sand dunes).

The identification and rendering of solar site selections is vital for the fair and objective development of photovoltaics in terms of equal distribution and compliance with national spatial plans. Abdullah Demir et al. (2023)[11] introduce a novel optimality-based site growing (OBSG) approach which also uses AHP, including the land of cost, GIS, and weights of criteria according to the installed capacity of the photovoltaic plant. The proposed method is demonstrated through the case study of Türkiye, and the results show that the method effectively determines the most suitable locations for large-scale photovoltaic plants. Another case study using a similar MCDA methodology was conducted for the southwest region of Russia in a doctoral thesis by Melnikova (2018).[12] The thesis introduces the geospatial data selection, multi-layer approach, scale determination, energy situation and energy infrastructure assessment, impact of environmental effects, buffer zones, and other limitations, as well as the economic and market potential of wind, solar and biomass. In the field of solar- and wind-oriented greenfields, similar approaches are considered in Asare-Addo (2022),[13] Saraswat et al. (2021),[14] and Kowalczyk and Czyża (2022).[15]

Within this project, the established MCDA plus AHP methodology is applied to North Macedonia. This process involves adjusting the criteria and factors to accurately represent the current situation at a national level. Each region possesses unique characteristics, making it essential for experts to adapt and engage extensively with stakeholders. This adaptability and engagement are crucial prerequisites for successful renewable energy development, with a specific emphasis on the widespread distribution of solar and wind sites.

10 https://www.sciencedirect.com/science/article/abs/pii/S0960148112000158

11 https://www.sciencedirect.com/science/article/abs/pii/S0038092X23003638

12 https://inis.iaea.org/collection/NCLCollectionStore/_Public/49/055/49055559.pdf

13 https://www.sciencedirect.com/science/article/abs/pii/S1755008422000254#preview-section-references

14 https://www.sciencedirect.com/science/article/abs/pii/S096014812100063X

15 https://www.mdpi.com/1996-1073/15/18/6693

3

GENERAL OVERVIEW

3.1. Phase 1

In the first phase of the project, the aim was to develop a set of criteria which could be used to grade and therefore quantitatively evaluate the suitability of barren land areas (locations) for solar photovoltaic power plants (PVPP) and wind power plants (WPP). The approach to developing this set of criteria consisted of two phases. Within the first phase, two tasks were performed.

Task 1 – Relevant data were gathered by means of research and a questionnaire which was distributed to relevant stakeholders. Once the necessary data were obtained, they were processed accordingly and used in the second task. Figure 1 depicts the organisational chart for task 1.

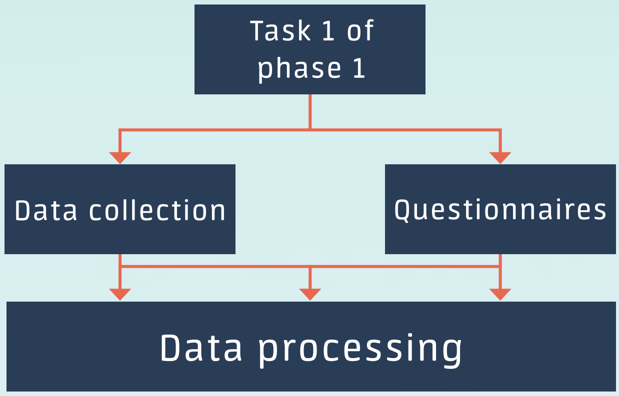


Figure 1: organisational chart for task 1

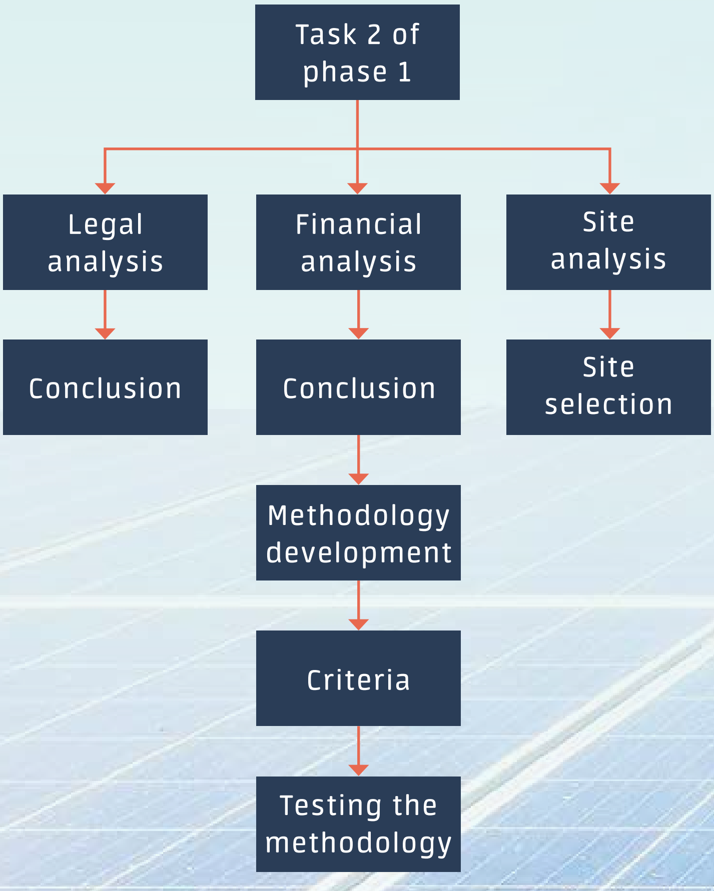


Figure 2: Organisational chart for task 2

Task 2 – A set of analyses was prepared to provide an overview of the relevant legal structure in the Republic of North Macedonia as well as the economic parameters which impact greenfield and brownfield investments in RES. Additionally, an approach was developed for analysing and selecting adequate sites which would later be compared against the set of criteria. In this stage of the project, only existing and closed mines were considered for the site analysis and site selection. Figure 2 depicts the organisational chart for task 2.

3.2. Phase 2

The main aim in **phase 2** of the project was to apply the adopted criteria at a national level and examine the eligibility of pre-selected locations for RES buildout (i.e. spatial identification of potential RES sites). In order for the multi-criteria assessment method to be applied, it was necessary to examine all the land on the territory of North Macedonia and to identify a set of locations from which a map of all viable locations where RES could be built could later be produced.

In order to do this, a multi-criteria decision analysis (MCDA) methodology utilising the analytic hierarchy process (AHP) was adopted. The eligibility of the locations throughout the territory of the Republic of North Macedonia for further analysis was assessed via a pre-assessment process. Within the pre-assessment, each location was compared against a set of pre-assessment criteria which were defined based on and in line with the legal and economic analyses and conclusions from the first phase of the project. Details on the pre-assessment process can be found in the following chapter. Consequently, the eligible locations were then compared against a set of evaluation criteria. The assessment criteria were also defined in line with the conclusions and based on the first phase of the project. In principle, these criteria can be grouped into four categories – environmental (slope, Important Bird Area (IBA) / Important Plant Area (IPA), proximity to water surfaces, and land types), meteorological (average annual solar irradiation and wind speed), economic (power grid connection, roads and installed capacity) and social (available workforce in the vicinity and proximity to urban/rural settlements). A questionnaire was developed, and multiple meetings were held with experts from academia, representatives from the private sector / industry, government officials working in this sphere, etc. in order to determine the importance of each of the assessment criteria. The weights of the considered criteria were determined using AHP. The set of assessment criteria with their corresponding weights was entered into the GIS software and analysis of the eligible sites was conducted.

Simultaneously, data were gathered for the development of GIS maps which mapped the eligible locations considered in the analysis. The development of the GIS maps was based on a national slope raster layer with resolution of 5x5 metres (m) and a map of the ecosystems of North Macedonia, from which four main types of ecosystems were selected as most suitable for greenfield investments (Table 11). In addition, data regarding barren land on the territory of North Macedonia was acquired from the national cadastre. This data was ultimately used as the means to verify the validity of the approach that was applied. The validity of the approach was confirmed when the GIS maps of some of the regions which were defined using the first approach were compared with the regions obtained using the second approach. An 83.15 per cent match (overlap) was calculated between the maps obtained through the first approach and the second approach in which locations were mapped in GIS based on data about barren land supplied from the cadastre. Figure 3 displays the organisational chart for phase 2 of the project.

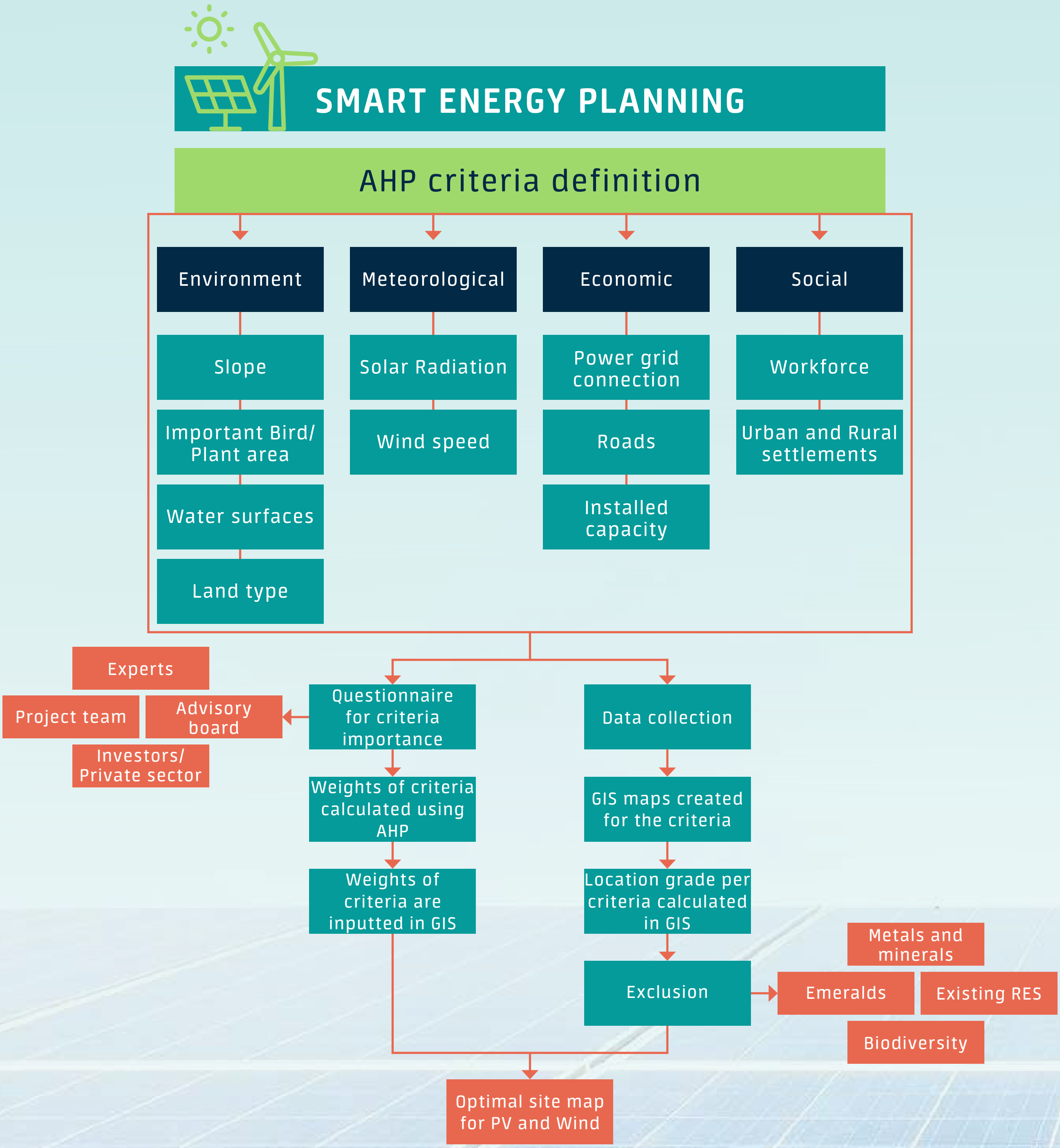


Figure 3: Organisational chart for phase 2 of the project

4

METHODOLOGY FOR PRIORITISATION OF LAND AREAS AND INPUT DATA

This section describes the methodology applied for the prioritisation of locations for photovoltaic and wind power plant construction. The first part discusses the pre-assessment and assessment criteria, along with the input data employed for each criterion. Subsequently, the methodology of multi-criteria decision analysis utilising the analytic hierarchy process (AHP) is explained.

As a first step, the set of locations is developed by dividing the country into polygons with different average slopes (as explained in section 4.1.2.1). The set of locations considered for PVPP construction is different from the set of locations for WPP construction, since locations in which the average wind speed is below 4.5 ms^{-1} were excluded from the WPP location analysis.

4.1. Criteria and input data

4.1.1. Pre-assessment

During the prioritisation of the projects, the first step is the pre-assessment phase. This pre-assessment phase includes location eligibility.

At the beginning, each location is checked for whether it fulfils the eligibility criteria. Each of the eligibility criteria must be met by each location. If at least one of the eligibility criteria is not met, then the location is not eligible and is not considered for further processing.

For location eligibility, the following criteria were selected:

- Whether the location is within protected areas (because of their high risk of vulnerability and their ecological value, protected areas are considered entirely unsuitable for building power plants)
- Whether the wind speed is below 4.5 ms-1 for WPPs (all locations which have recorded annual average wind speeds below 4.5 ms^{-1} were excluded from WPP location analysis)
- Whether the location for PVPPs has a surface area smaller than 0.5 hectares (ha) (all locations which have surface areas smaller than 0.5 ha were excluded from the analysis where the suitability for PVPP buildout on those locations was evaluated)

- Whether the locations considered for WPPs have surface areas smaller than 10 ha (all locations whose surface area is smaller than 10 ha were excluded from the analysis where the suitability for WPP build-out on those locations was evaluated)
- Whether the average slope of the location is higher than 30 per cent (locations with a slope higher than 30 per cent were excluded from the analysis)
- Whether the distance to the 110 kilovolt (kV) power (transmission) grid is farther than 25 kilometres (km) and the distance to 400 kV farther than 15 km (such locations were excluded)
- Whether the distance of WPP locations are closer than 1 km to settlements (such locations were excluded)
- Whether there is a possibility for land acquisition and existing facilities
- Whether building permits can be obtained
- Soil stability and engineering potential
- Reclamation status and containment of environmental risk

4.1.2. Assessment criteria

Based on the analysis conducted in **Phase 1** of the project and the subsequent research, the following set of criteria were adopted for the assessment of a location's suitability:

- Slope;
- Power grid connection;
- Distance to road;
- Wildlife protection;
- Workforce that can be hired for the new investment;
- Proximity to settlements;
- Distance to rivers or lakes;
- Meteorological parameters:
  - Solar irradiation;
  - Wind speed;
- Type of land;
- Installed capacity.

4.1.2.1. Slope

The **slope** of the land is an important criterion that should be considered when selecting the most suitable locations for PVPP and WPP construction. This is because construction on highly sloped grounds can increase the investment and operational costs, as a very steep slope of the area (location) means more difficult access to the locations. In addition, steeply sloped areas can impact the performance of PVPPs. The national slope raster layer, with a resolution of 5x5 m, was paired with the maps of the ecosystems of North Macedonia[16] which were considered in this study (mineral extraction sites (industrial ecosystems), sparsely vegetated areas (rocky and stony fields), transitional woodland-shrub (bushes), and pastures (grasslands)). For each of the ecosystem types, the mean slope was calculated and initially, four different **intervals (categories)** for the slope were considered (Table 1). Based on this, the GIS map displayed in Figure 4 was generated.

Table 1: initial division of slope categories

Category	Slope
Category 1	x<5%
Category 2	5%<x<10%
Category 3	10%<x<20%
Category 4	20%<x<30%

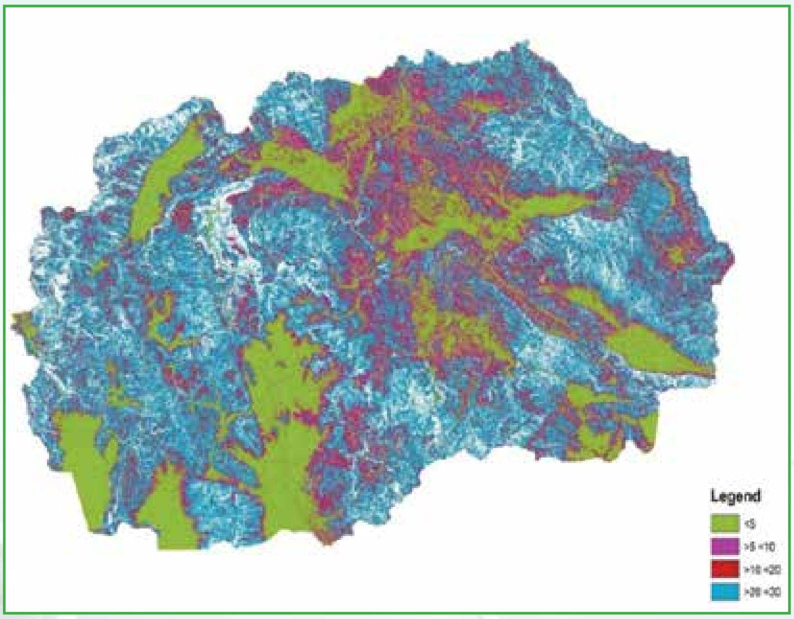


Figure 4: GIS map – the Republic of North Macedonia, with four categories of slope

Source: (Expert team analysis)

16 Courtesy of the Macedonian Ecological Society

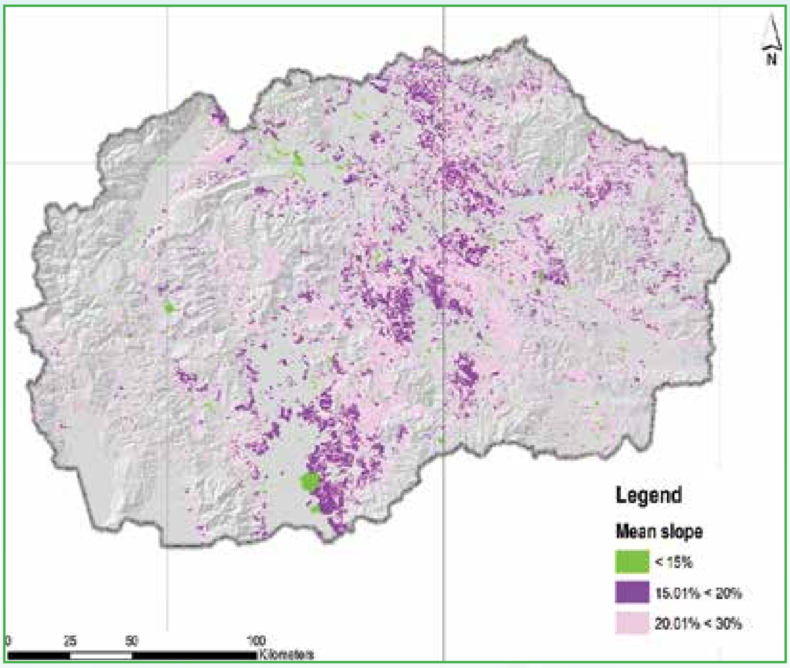
In this setting, a very large number of polygons were obtained. Because of the large number of polygons, the running time of the QGIS model experienced lengthy protractions and the number of polygons needed to be decreased in order for the analysis to be executed in reasonable amount of time. Due to this lagged execution, the land's slope was categorised between three interval values instead (Table 2). Figure 5 displays the GIS map with the polygons' slope categorised as shown in Table 2. **This is the basis for the creation of the set of locations** considered for the analysis made in this report. Any land area (polygon) with a slope steeper than 30 per cent was excluded and not considered in the further analysis.

Table 2: Location's slope – grades

Slope	Grade
x<15%	5
15%<x<20%	3
x>20%	1

Figure 5: GIS map – the Republic of North Macedonia with three categories of Slope

Source: (Expert team analysis)



4.1.2.2. Power grid connection

Power grid connection / proximity to the transmission/distribution network is one of the key criteria when selecting a location for the construction of a power plant. This is because the produced electricity should be fed into the system and delivered to final consumers via the transmission and/or distribution network (power grid). The cost of connection to the power grid can be divided into two parts: first, the cost of construction of the line from the power plant's location to the connection point, which is expressed in currency/km (and depends on the distance); and second, the cost of the work that should be done at the connection point (ex. transformers, sub-stations, etc.), which is the cost per MW of installed capacity and depends on whether the connection is made to an existing line or to the substation.

In this case, the best option for estimating the cost of connecting to the power grid for each location is to obtain the calculations from either the TSO and/or the DSO (MEPSO and EVN, respectively, for North Macedonia), since they are the ones that determine this cost. If these calculations are not available for each location, then an approximate cost can be determined based on the first part of the cost, i.e. the distance from the power plant to the connection point. Based on this, the location with the lowest cost of power grid connection is awarded five points, and the one with the highest cost is awarded one point. Table 3 and Table 4 display the interval range of distances and their corresponding grades for 110 kV and 400 kV power grids.

Table 3: Distance to power grid connection for 110 k

Power grid connection (110 kV)	Grade
x<4 km	5
4 km<x<8 km	4
8 km<x<12 km	3
12 km<x<16 km	2
16 km<x<25 km	1

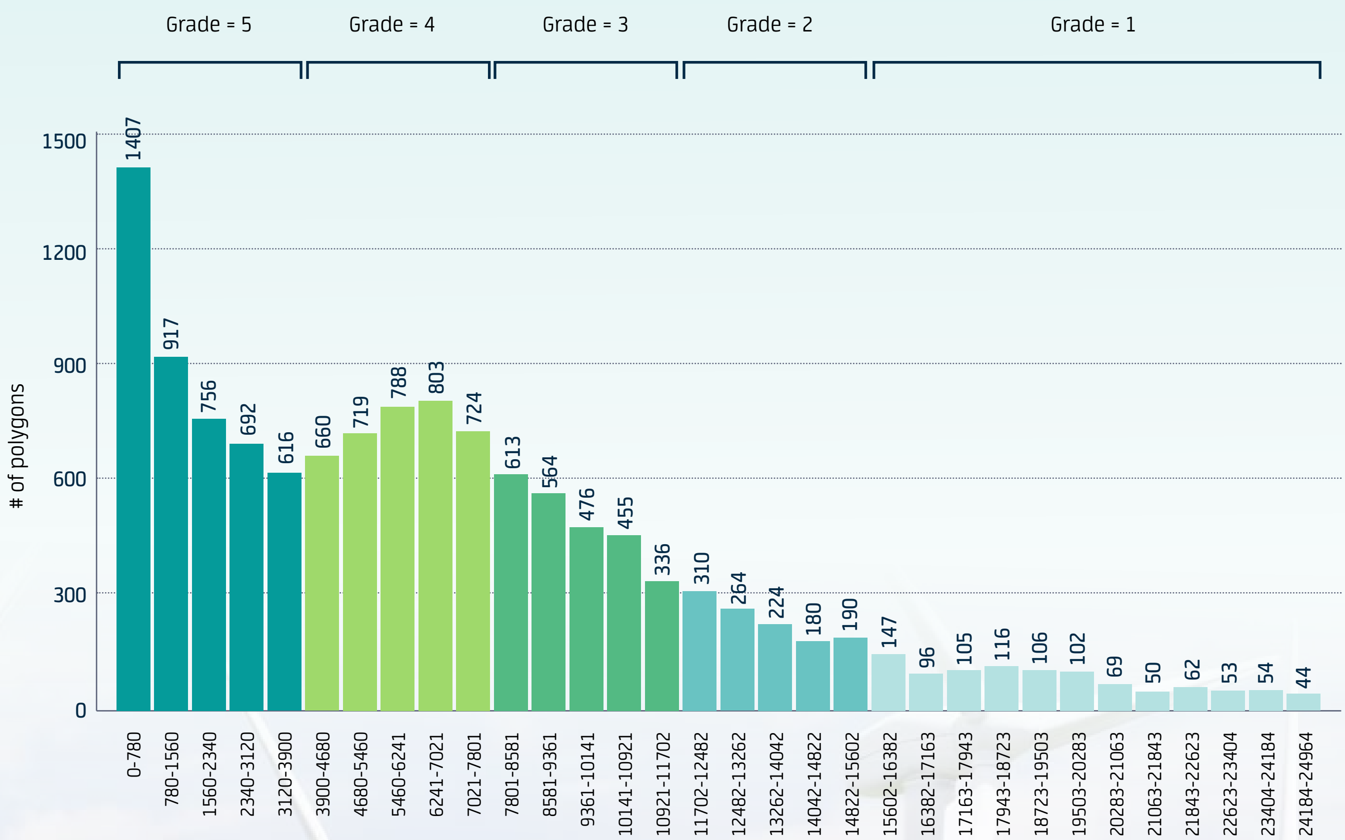
Table 4: Distance to power grid connection for 400 kV

Power grid connection (110 kV)	Grade
x<2.5 km	5
2.5 km<x<5 km	4
5 km<x<7.5 km	3
7.5 km<x<10 km	2
10 km<x<15 km	1

The national TSO has advised that for the 110 kV transmission system network, the maximum distance that can be drawn with a single line from an existing substation is 25 km. For the 400 kV transmission system network, this maximum distance is 15 km. This information was crucial for the determination of the interval values to which corresponding grades were assigned for this criterion. All potential land areas outside of the aforementioned ranges (for the 110 and 400 kV transmission networks) were not considered.

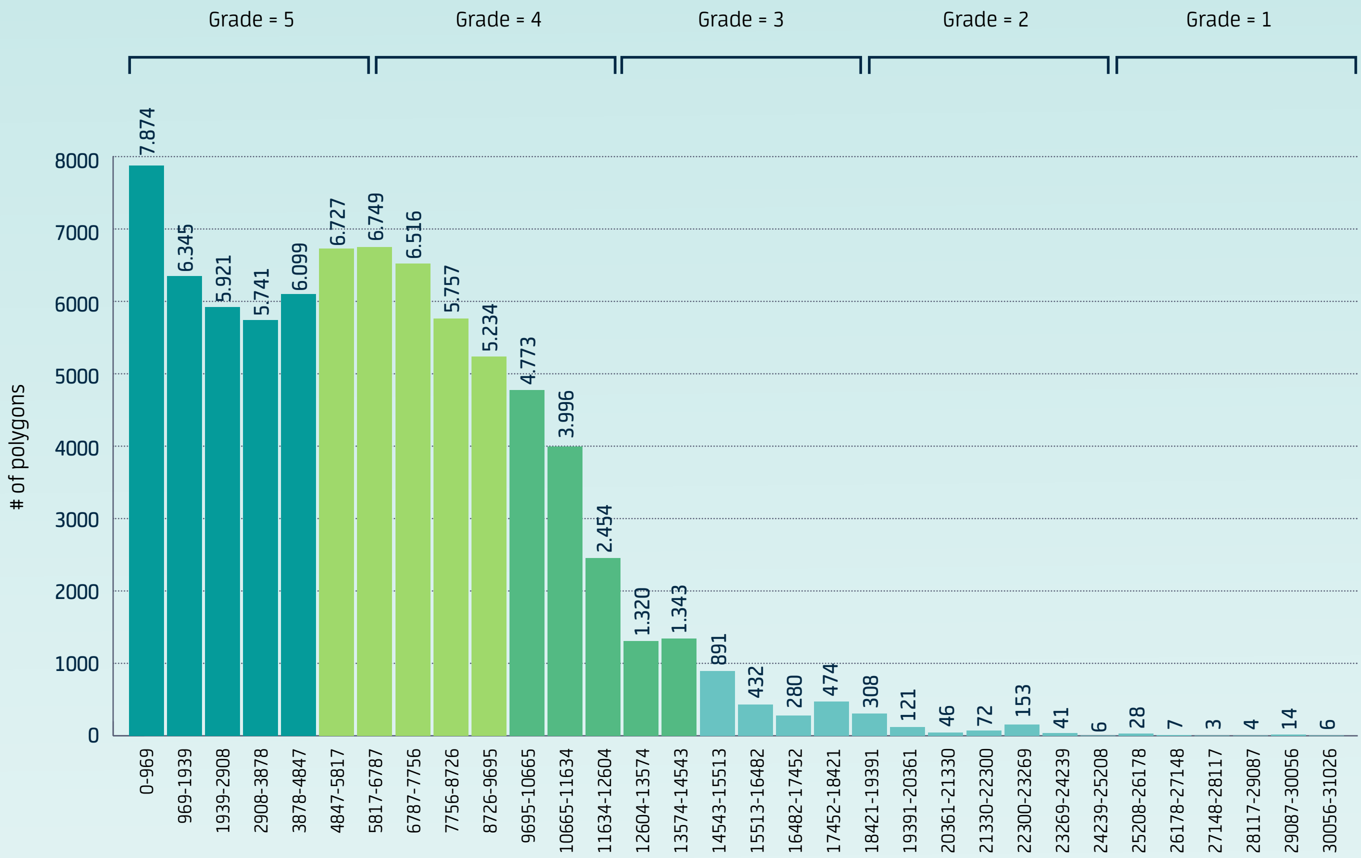
The analysis of the suitability of the locations (polygons) was conducted independently for both wind and photovoltaic power plants. As previously mentioned, this is due to the fact that the locations with average wind speeds lower than 4.5 ms^{-1} were excluded from the analysis of sites for WPP. From the distribution of distances from the locations to the 110 kV transmission network, it can be concluded that approximately 65 per cent of the polygons for PVPP are located within 8 km or less of the 110 kV transmission system network (Figure 6). For WPPs, approximately 80 per cent of the considered polygons are within a radius of 10 km from the 110 kV transmission network (Figure 7).

Figure 6: DISTRIBUTION OF DISTANCES TO THE 110 KV TRANSMISSION SYSTEM NETWORK FOR PVPP



Source: (Expert team analysis)

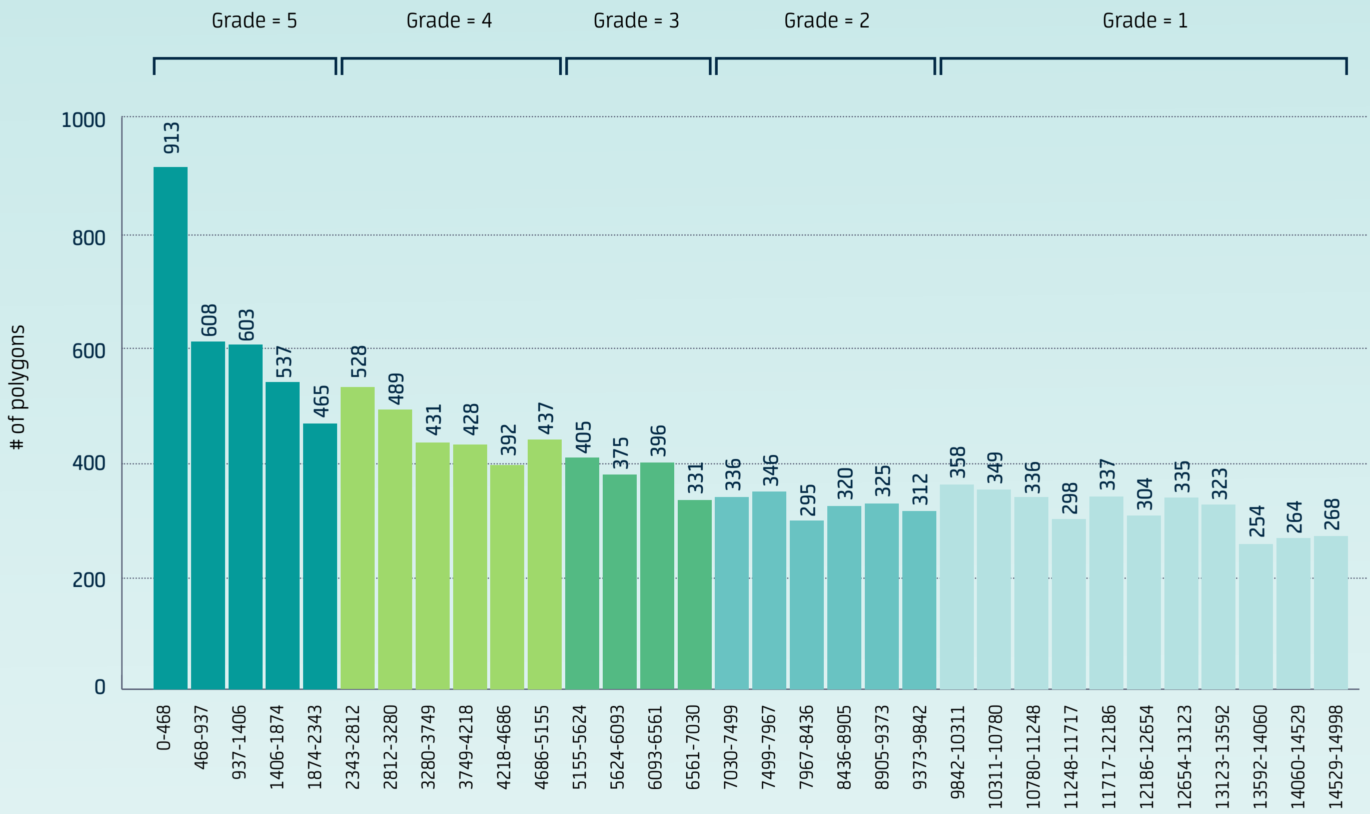
Figure 7: DISTRIBUTION OF DISTANCES TO THE 110 KV TRANSMISSION SYSTEM NETWORK FOR WPP



Source: (Expert team analysis)

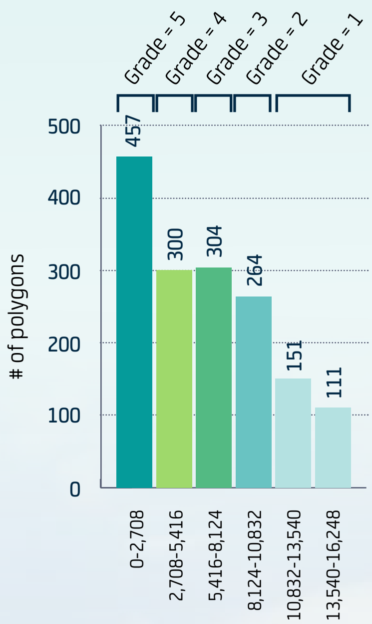
A similar situation can be observed for the distribution of distances from the land area polygons to the 400 kV transmission network (Figure 8). Greater uniformity is characteristic of this distribution, with 45 per cent of all polygons located 5 km or less from the 400 kV transmission system network.

Figure 8: DISTRIBUTION OF DISTANCES TO THE 400 KV TRANSMISSION SYSTEM NETWORK FOR PVPP



Source: (Expert team analysis)

Figure 9: DISTRIBUTION OF DISTANCES TO THE 400 KV TRANSMISSION SYSTEM NETWORK FOR WPP



Source: (Expert team analysis)

4.1.2.3 Proximity to transport infrastructure

The location chosen for the construction of a wind or solar power plant should be close enough to the existing **transport infrastructure**, which will be needed to transport equipment and personnel during the construction and at later stages in the plant's lifetime. Therefore, proximity to transport infrastructure is considered as one of the criteria. The locations that have better access to roads, with a distance from a road of less than 350 m, are considered most suitable and are given five points. A distance of more than 1.4 km is considered most unsuitable (since the construction of a road would be needed) and it is graded with one point (Table 5).

Table 5: Proximity to road infrastructure – grades

Distance to road	Grade
x<350 m	5
350 m<x<700 m	4
700 m<x<1,050 m	3
1,050 m<x< 1,400 m	2
x>1,400 m	1

To conduct this analysis, a GIS map containing the existing road infrastructure in North Macedonia was used (Figure 10). The distribution of distances of each analysed polygon relative to the existing road infrastructure for PVPP is displayed in Figure 11 and that for WPPs in Figure 12. For both types of RES technologies, it can be concluded that the majority of the considered land areas have adequate road access. In the case of PVPPs, approximately 73 per cent of all polygons are located a maximum of 1 km from the nearest registered road (Figure 11) and approximately 67 per cent of the considered polygons are within a radius of 1 km from an existing road (Figure 12).

Figure 10: GIS map – road infrastructure of the Republic of North Macedonia

Source: (Expert team analysis and Cadastre of the Republic of North Macedonia)

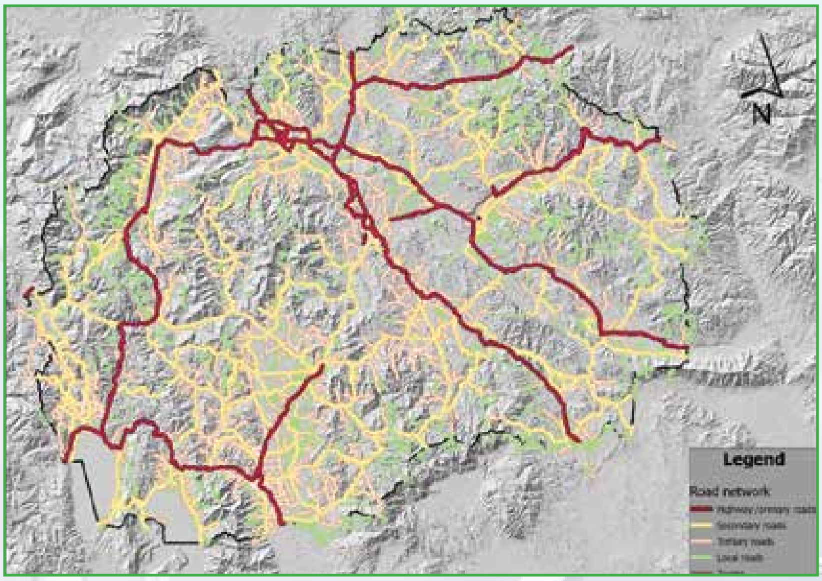
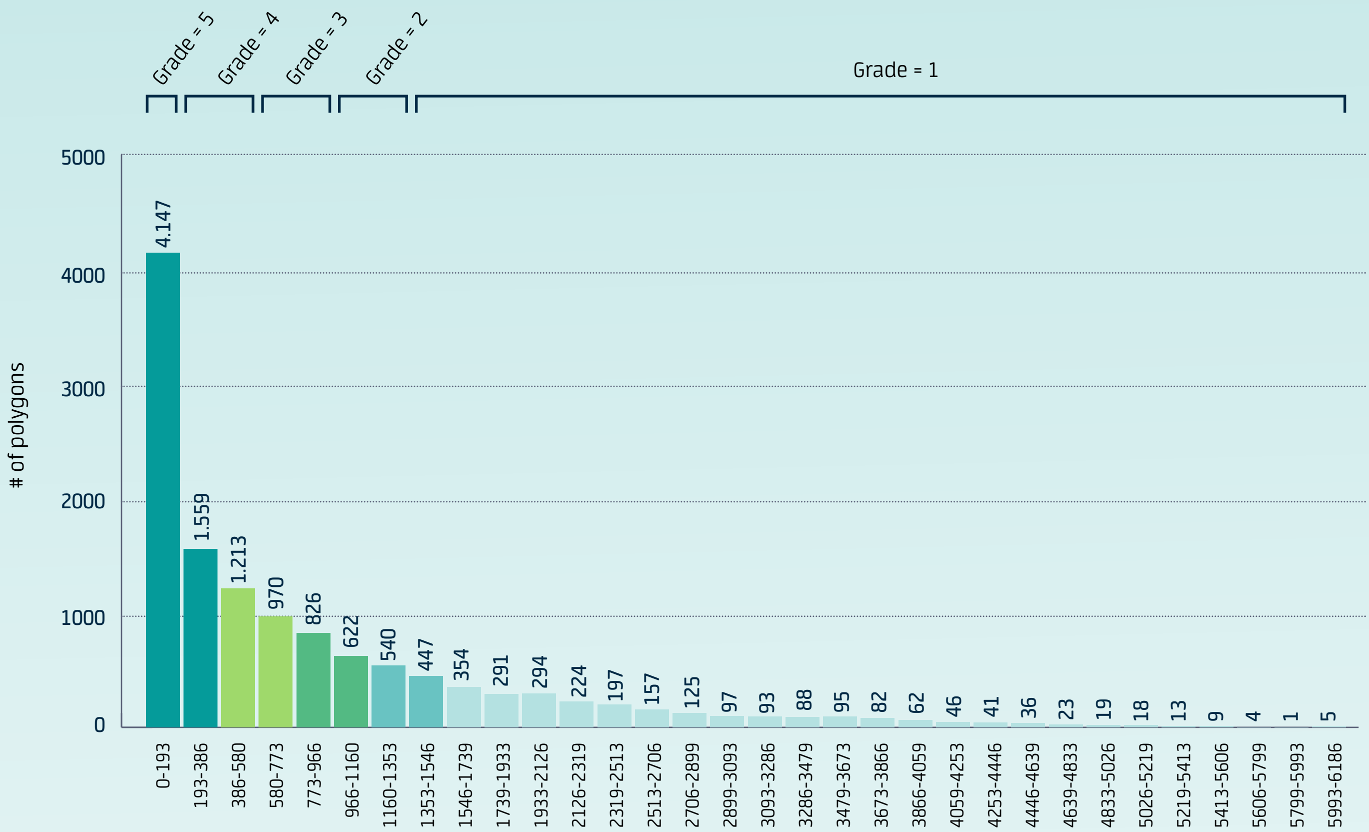
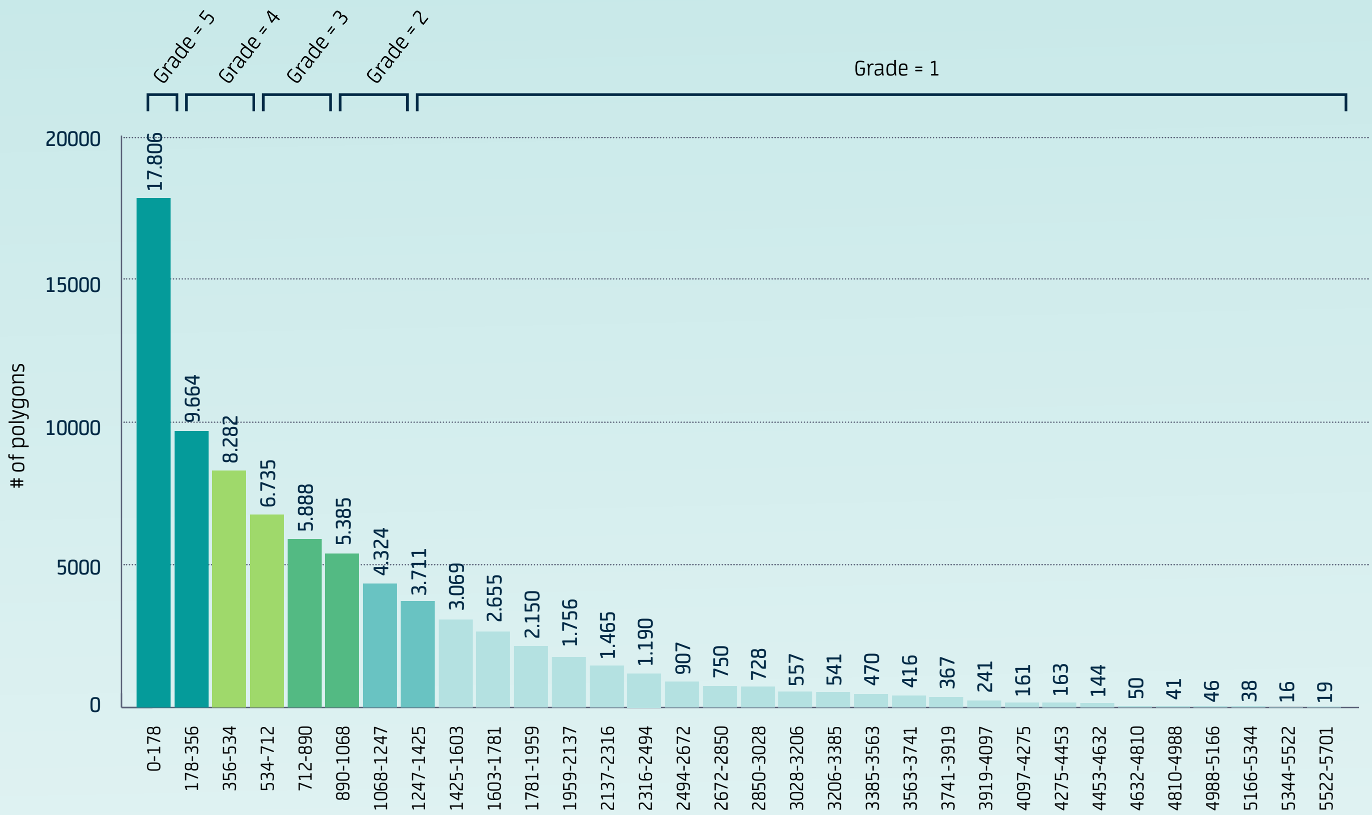


Figure 11: DISTRIBUTION OF DISTANCES OF THE POLYGONS TO THE ROAD NETWORK SYSTEM FOR PVPPS



Source: (Expert team analysis)

Figure 12: DISTRIBUTION OF DISTANCES OF THE POLYGONS TO THE ROAD NETWORK SYSTEM FOR WPPS



Source: (Expert team analysis)

4.1.2.4 Important Bird/Plant Areas

Based on an area's overlap with **Important Bird Areas (IBA)** and **Important Plant Areas (IPA)**, as well as with other important areas related to wildlife protection, each location was classified as high, medium, or low risk. Based on this, corresponding grades were determined; locations outside of IBAs/IPAs were given five points and locations within IBAs/IPAs one point.

The Important Bird Areas' and the Important Plant Areas' GIS maps are displayed in Figure 13. As in the previous cases, for each of the considered RES technologies (PVPPs and WPPs), the relative distance to the protected areas was examined independently. The distribution of the polygons relative to the IBA and IPA for PVPPs is given in Figure 14 and Figure 15, respectively. From Figure 14, it can be observed that on the entire territory of the Republic of North Macedonia, the considered polygons' distance to IBAs is relatively close, with approximately 82 per cent of all polygons located within 10 km of the nearest IBA and approximately 17 per cent of all the considered polygons within 1 km of the nearest IBA. The situation is quite different when IPAs are considered, and because areas such as national parks and other protected areas were initially 'disqualified', the majority of the analysed polygons for PVPP construction are within a 10 km radius of IPAs. In this case, approximately 89 per cent of all polygons are located within 10 km of the nearest IPA and less than 10 per cent of all the considered polygons were determined to be within 1 km from the nearest IPA (Figure 15).

Figure 13: GIS maps – IBA areas (left) and IPA areas (right)

Source (Expert team analysis and Macedonian Ecological Society)

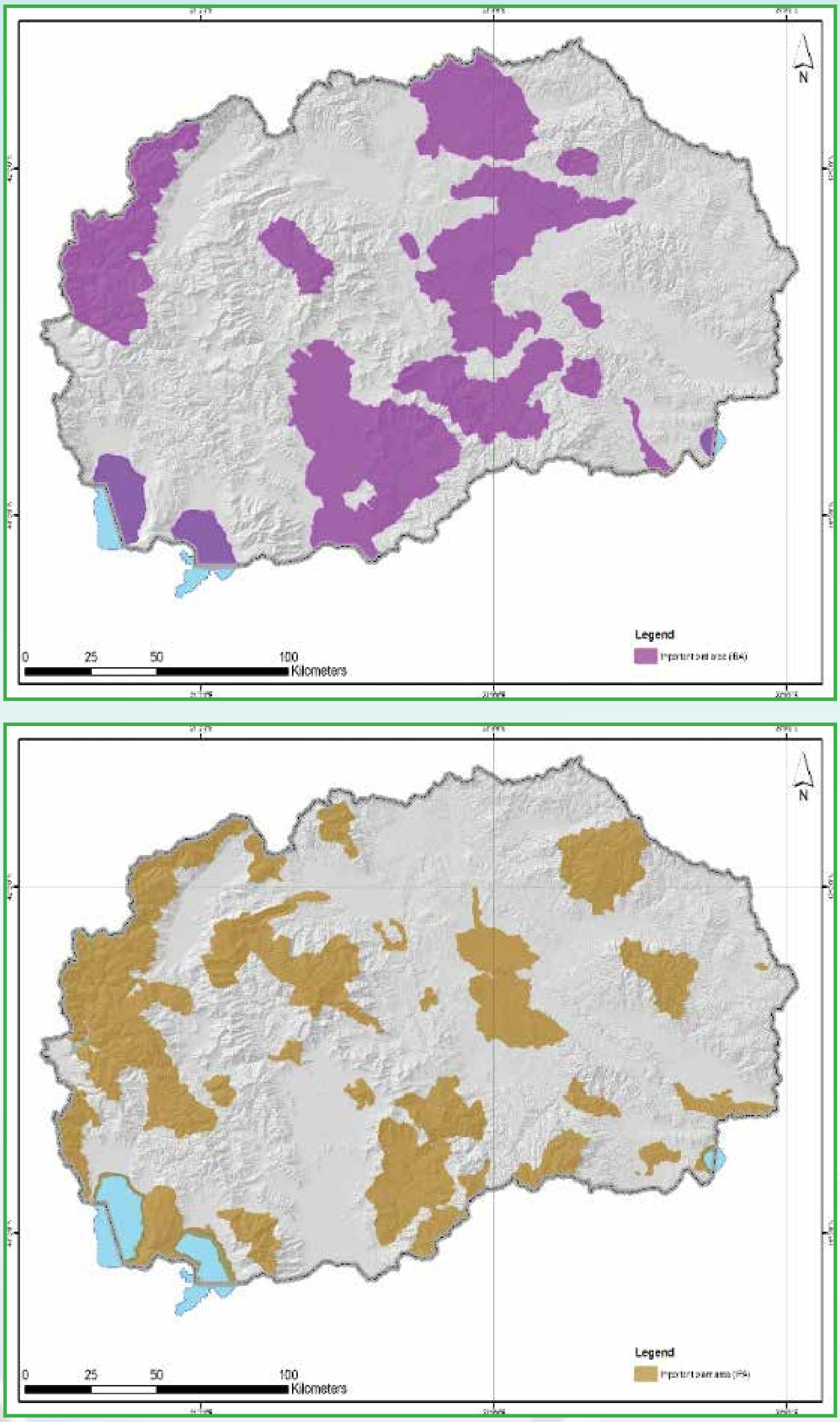
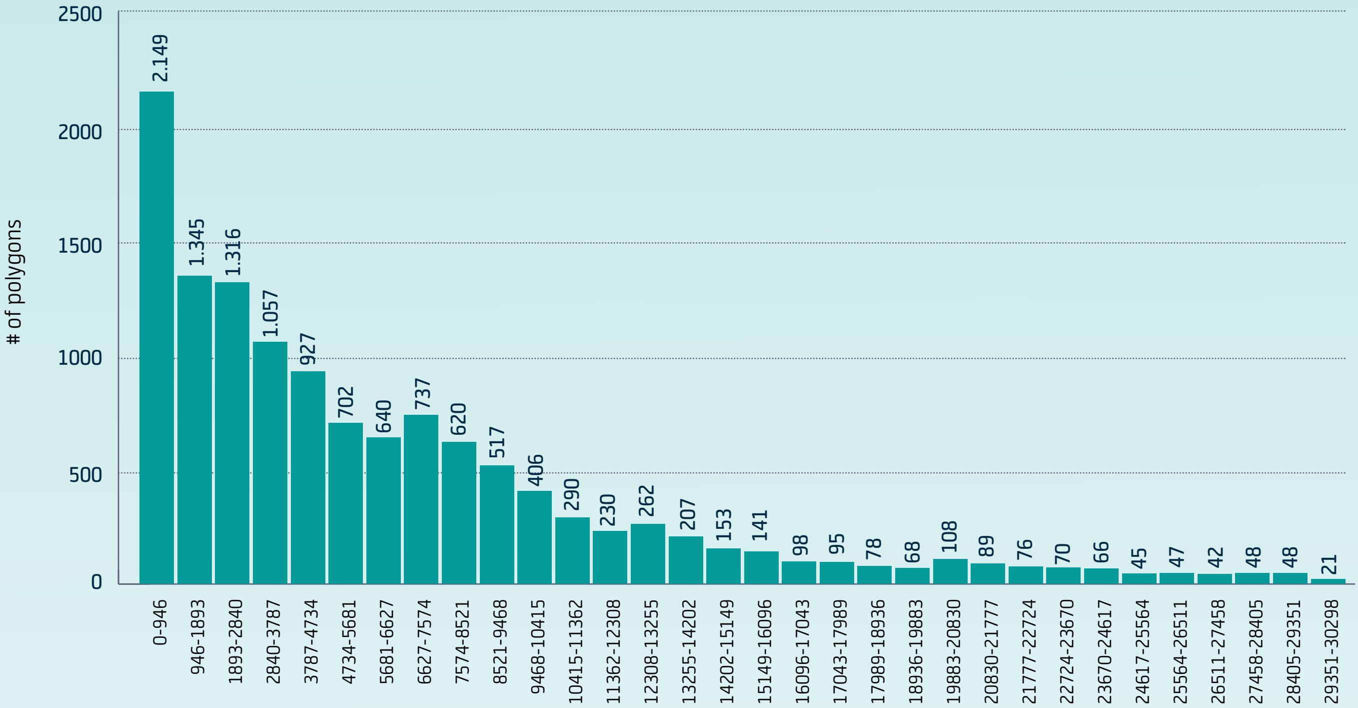
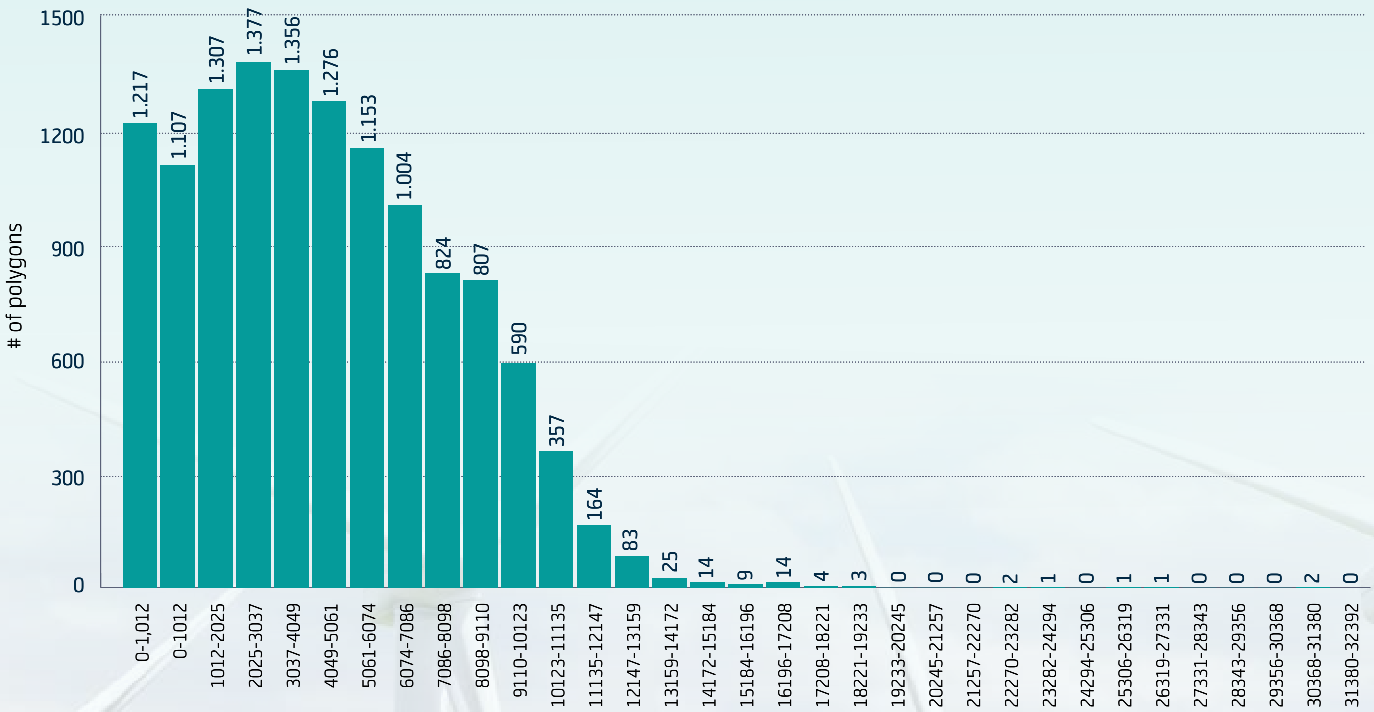


Figure 14: DISTRIBUTION OF DISTANCES TO IMPORTANT BIRD AREAS (IBAS) FOR PVPPS



Source: (Expert team analysis)

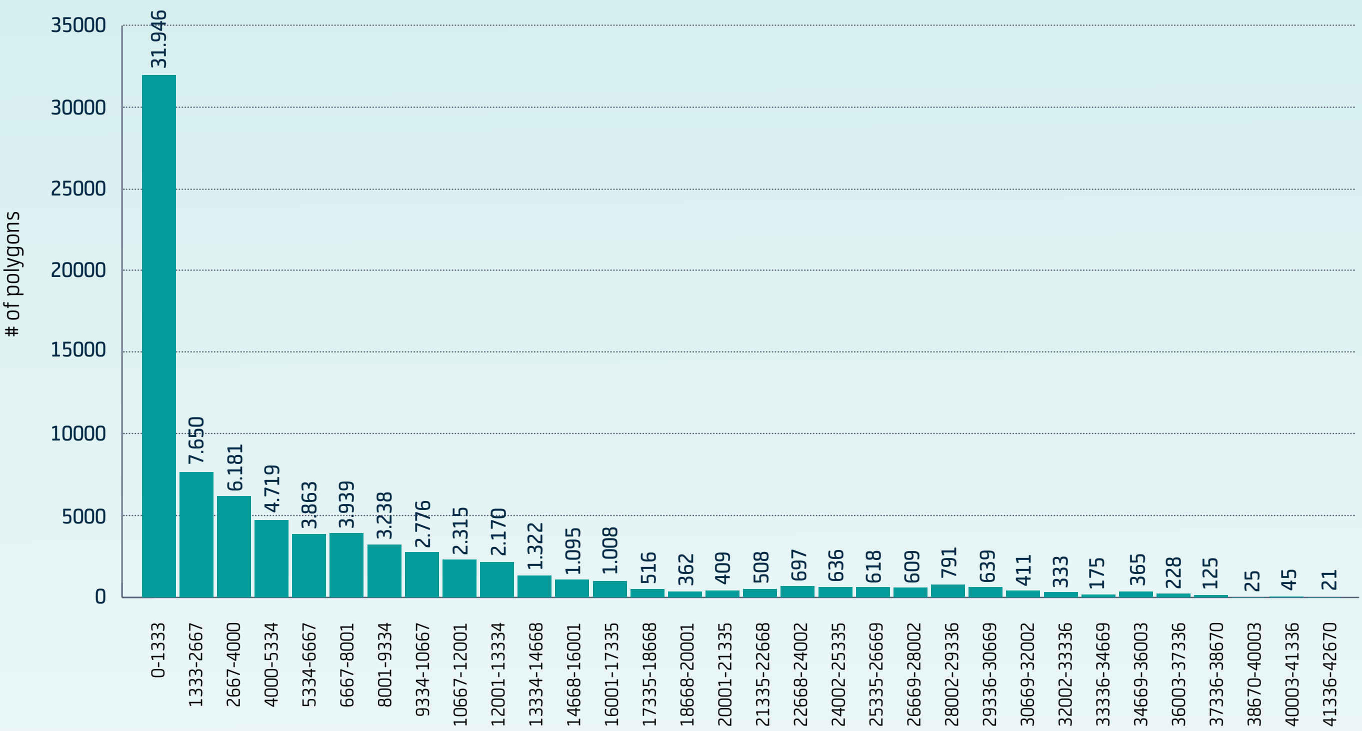
Figure 15: DISTRIBUTION OF DISTANCES TO IMPORTANT PLANT AREAS (IPAS) FOR PVPPS



Source: (Expert team analysis)

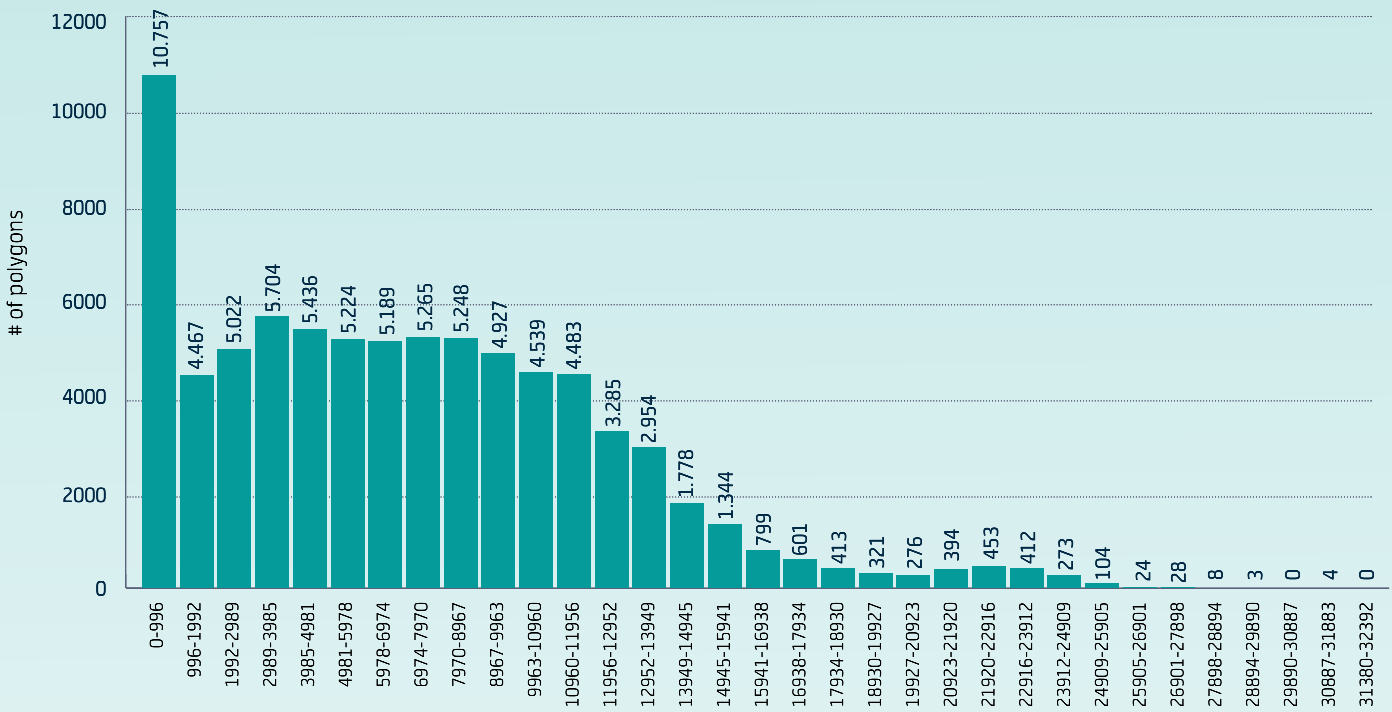
The distribution of distances of the polygons considered for WPP buildout is provided in Figure 16 for IBA and Figure 17 for IPA. As was the case with the polygons that were considered for PVPP buildout, a similar situation can also be observed if the distributions in Figure 16 and Figure 17 are seen. Namely, approximately 80 per cent of the considered polygons are within a radius of 10 km or less from an IBA, but half of those (approximately 40 per cent) of the considered polygons are within a radius of 1.3 km from an IBA. On the other hand, approximately 77 per cent of the considered polygons are within a radius of 10 km from an IPA, but only approximately 14 per cent of the considered polygons are within a radius of 1 kmfrom an IPA.

Figure 16: DISTRIBUTION OF DISTANCES TO IMPORTANT BIRD AREAS (IBAS) FOR WPPS



Source: (Expert team analysis)

Figure 17: DISTRIBUTION OF DISTANCES TO THE IMPORTANT PLANT AREAS (IPAS) FOR WPPS



Source: (Expert team analysis)

4.1.2.5 Social component

Another important aspect that should be considered is the **social aspect**. In this regard, the **available workforce (unemployed individuals)** that can be hired to work on a new investment at a given location is estimated. In this analysis, the available workforce per capita (i.e. the number of unemployed individuals per capita) was considered and the data was based on the number of unemployed people in the nearest municipality, which was obtained from the State Statistical Office and the State Employment Agency.[17] The grades and the corresponding interval values given to each considered polygon are provided in Table 6. A GIS map based on records from the State Employment Agency's regional employment offices is provided in Figure 18.

17 https://av.gov.mk/content/Statisticki podatoci/Април 2023/P1_gradselo042023.pdf

Table 6: Available workforce criteria and corresponding grades

Available workforce (number of unemployed individuals per capita)	Grade
0.13<	5
0.09 – 0.13	4
0.07 – 0.09	3
0.05 – 0.07	2
0.03 – 0.05	1

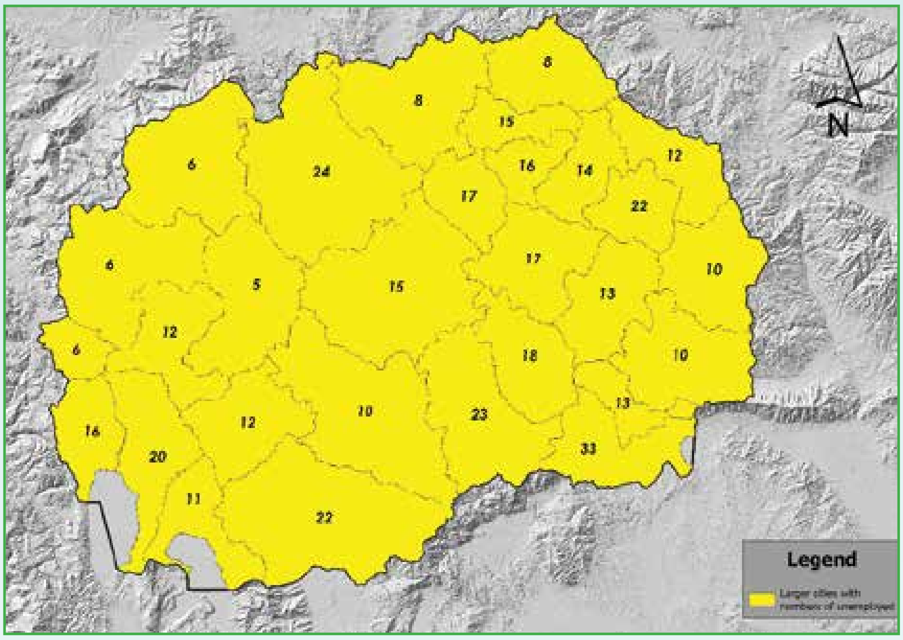


Figure 18: Unemployed workforce statistics

Source: (Expert team analysis and State Employment Agency)

4.1.2.6 Proximity to urban and rural settlements

A location's **proximity to urban and rural areas** is another factor that was considered when determining its suitability as a site for RES development. If the distance between the location of the RES power plant and the residential areas is too big, then the costs for supplying the residents with electricity from this plant increase proportionately to the distance. Additionally, the transport of workers to and from the work site / power plant can also impact the overall cost of the project. In the analyses conducted, which evaluated the suitability of the considered land areas for WPP buildout, locations that were less than 1 km from urban settlements were not considered due to WPPs' contribution to noise pollution. In this analysis, proximity to urban and rural settlements is treated as two separate criteria that are not co-related to each other. Depending on the type of area (urban or rural), different grades are given to the locations based on their proximity to the corresponding area. The corresponding grades for an urban settlement are presented in Table 7 and the corresponding grades for rural settlements are presented in Table 8. The distribution of the considered polygons for each of the respective RES technologies considered in this analysis is provided below.

Table 7:
Proximity to urban settlements

Urban settlements	Grade
x < 2 km*	5
2 km ≤ x < 8 km	4
8 km ≤ x < 14 km	3
14 km ≤ x < 20 km	2
x ≥ 20 km	1

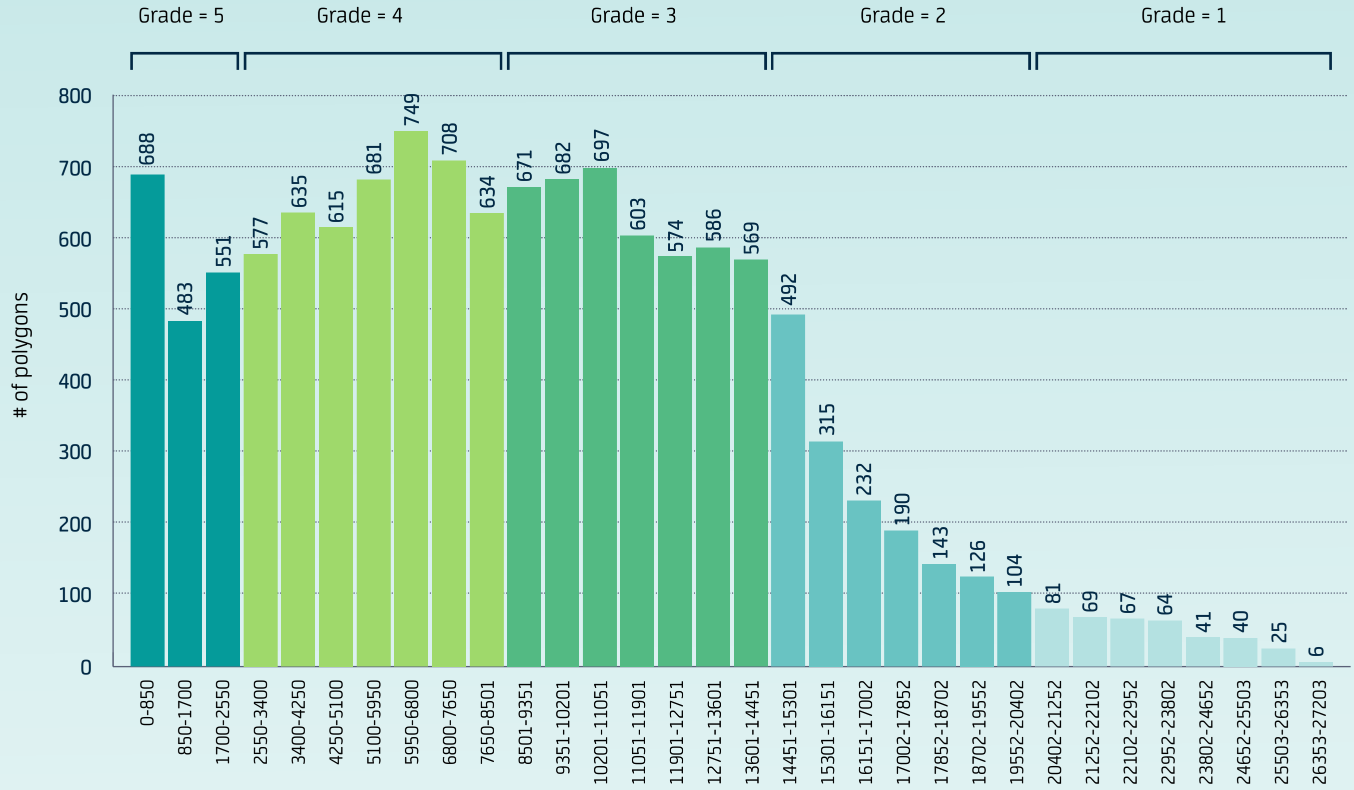
*Locations for wind that are closer than 1 km to settlements are excluded in order to account for noise pollution.

Table 8:
Proximity to rural settlements

Rural settlements	Grade
x < 500 m	5
500 m ≤ x <2.7 km	4
2.7 km ≤ x < 4.8 km	3
4.8 km ≤ x < 7 km	2
x ≥ 7 km	1

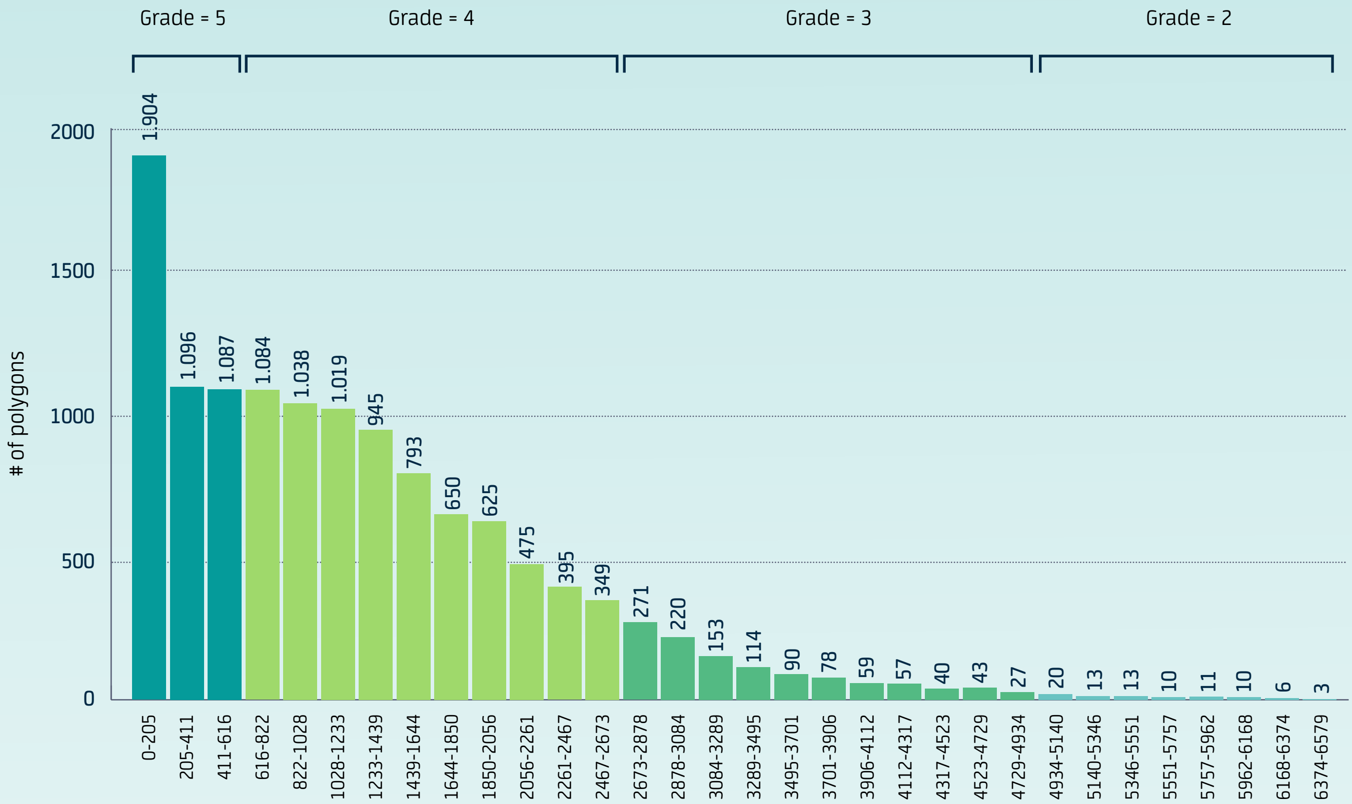
Figure 19 displays the distribution of distances of the considered polygons for PVPP buildout relative to urban areas. Approximately 90 per cent of the considered polygons are concentrated within a radius of 16 km from the country's urban areas. Figure 20 displays the distribution of distances of the polygons relative to the rural settlements. Approximately 80 per cent of all polygons are located within 2 km of rural areas.

Figure 19: DISTRIBUTION OF DISTANCES TO URBAN AREAS FOR PVPPS



Source: (Expert team analysis)

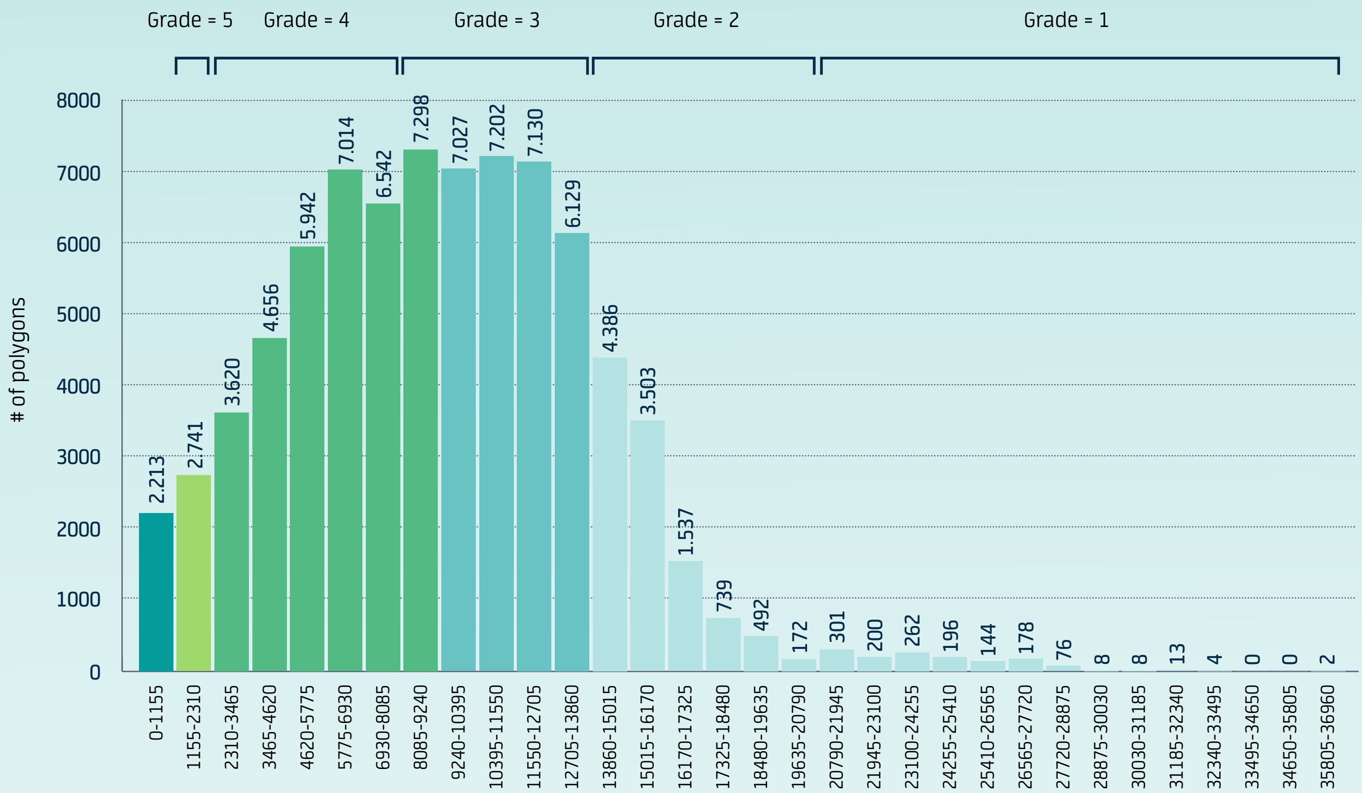
Figure 20: DISTRIBUTION OF DISTANCES TO RURAL AREAS FOR PVPPS



Source: (Expert team analysis)

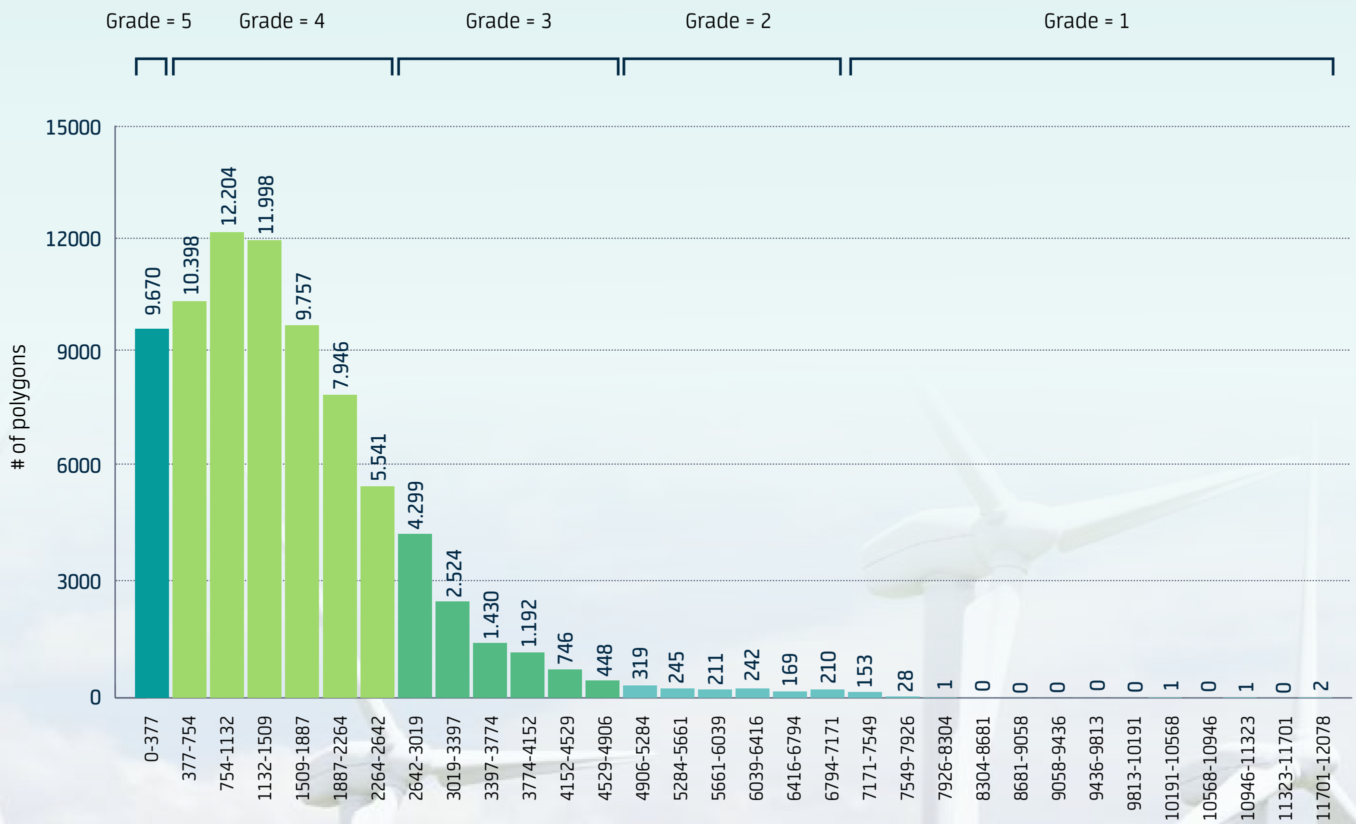
Figure 21 and Figure 22 display the same distributions for the polygons considered in the WPP analysis. Approximately 94 per cent of the considered polygons are located 16 km or less from urban areas, with 41 per cent of all polygons within an 8 km radius. As for the rural areas, approximately 87 per cent of the considered polygons are within a radius of 2.7 km from rural areas.

Figure 21: DISTRIBUTION OF DISTANCES TO URBAN AREAS FOR WPPS



Source: (Expert team analysis)

Figure 22: DISTRIBUTION OF DISTANCES TO RURAL AREAS FOR WPPS



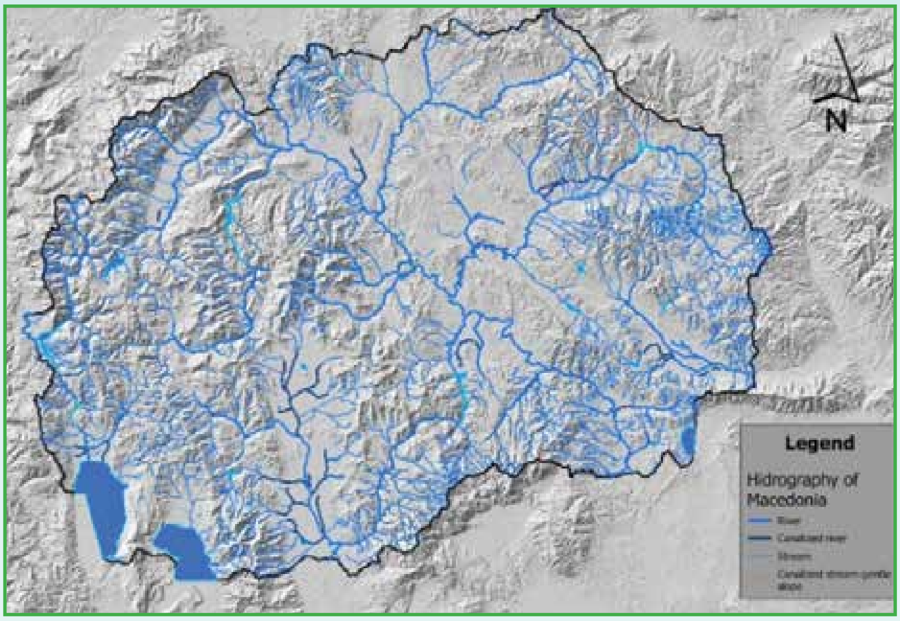
Source: (Expert team analysis)

4.1.2.7 Proximity to water surfaces

According to the Law on waters, a power plant has no legal obligation to develop a hydrology study if it is at least 50 m away from a river or lake. This factor is also used for evaluating the locations which will ensure environmental safety while at the same time ensuring economically favourable power generation. If the distance is closer than 50 m, then a hydrology study should be developed. Locations that are less than 50 m from a lake or river are graded with 1 point, and locations more than 50 m from a lake or river are graded with 5 points. Figure 23 displays a hydrographic GIS map of the river system in the Republic of North Macedonia.

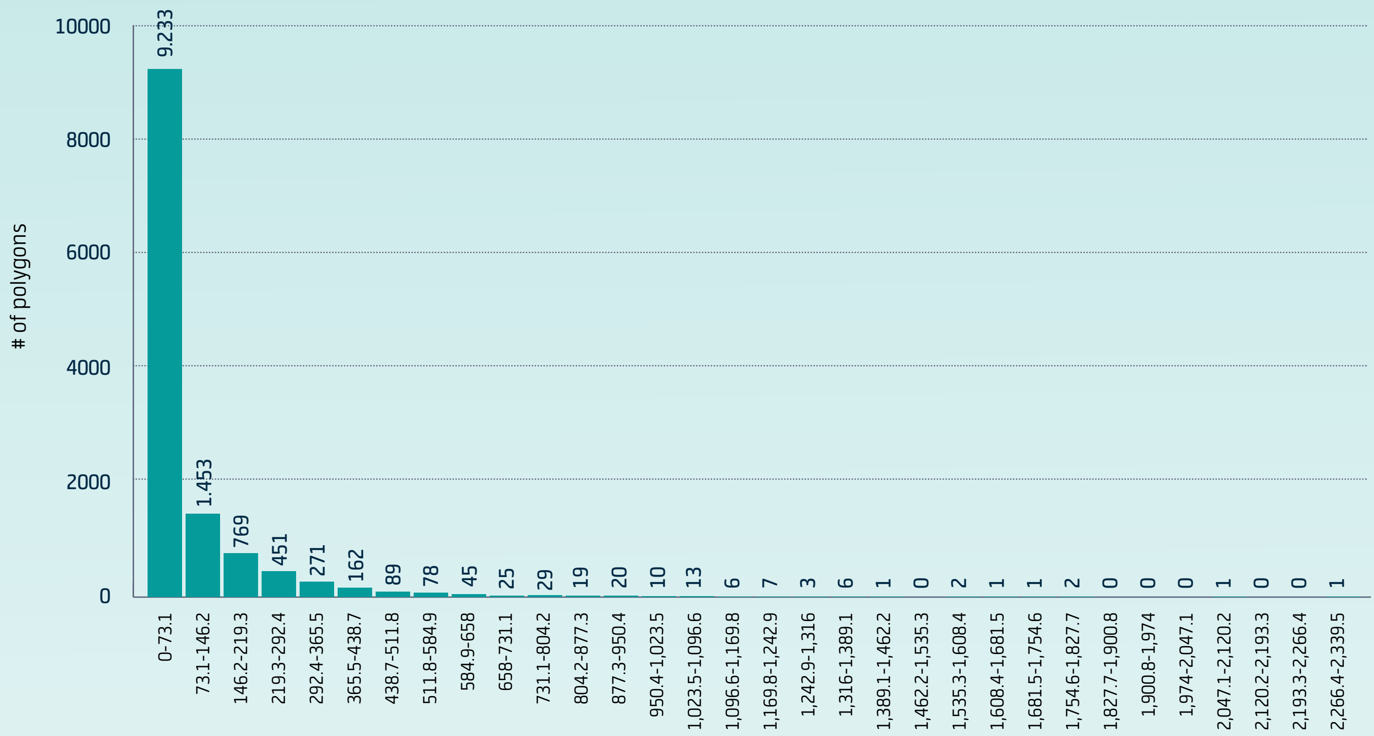
Figure 23: GIS map – river system in the Republic of North Macedonia

Source: (Expert team analysis and National Cadastre)



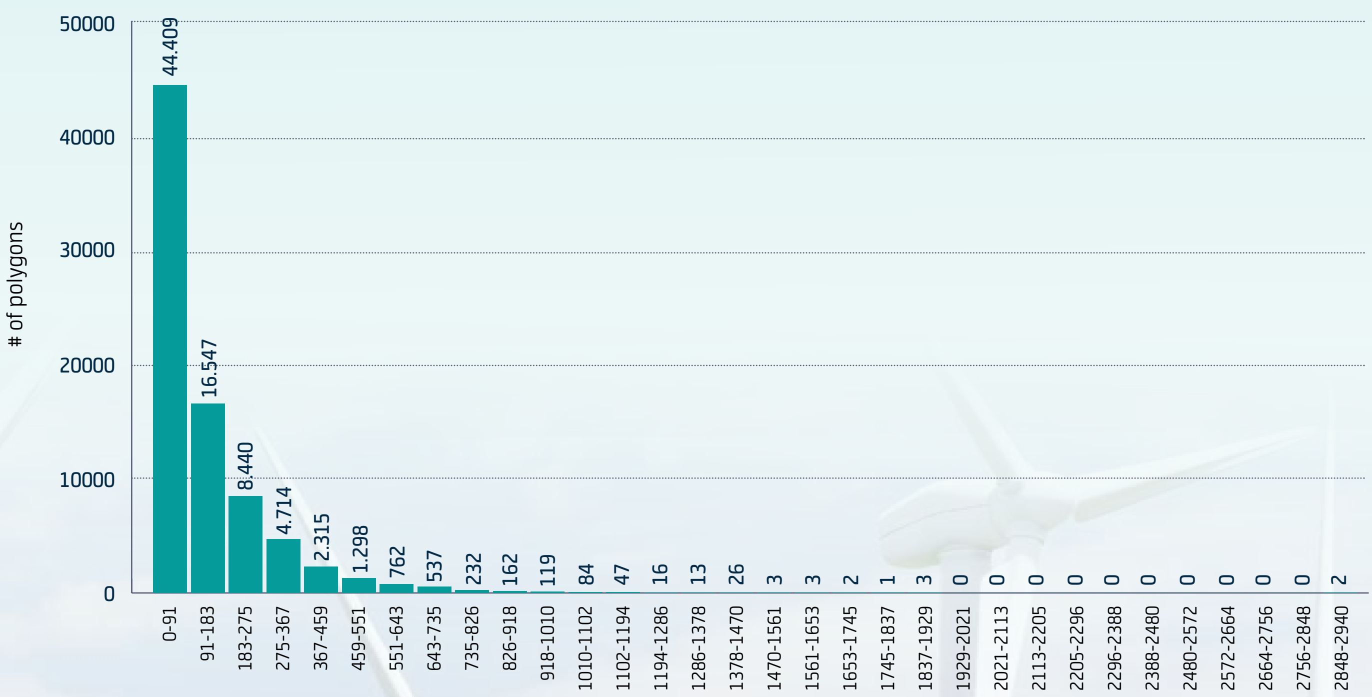
The distribution of distances of the polygons considered in the analysis for PVPP and WPP buildout relative to the water bodies on the territory of North Macedonia is displayed in Figure 24 for PVPP and Figure 25 for WPP. From both figures, it can be observed that the majority of the polygons are in close proximity to water bodies. In the case of the polygons considered for PVPP buildout, it is estimated that approximately 72 per cent of all polygons are located within 73 m of the river system in the Republic of North Macedonia (Figure 24). Additionally, approximately 76 per cent of the considered polygons for WPP are 200 m or less from the river system in the country (Figure 25).

Figure 24: DISTRIBUTION OF DISTANCES TO WATER AREAS FOR PVPPS



Source: (Expert team analysis)

Figure 25: DISTRIBUTION OF DISTANCES TO WATER AREAS FOR WPPS



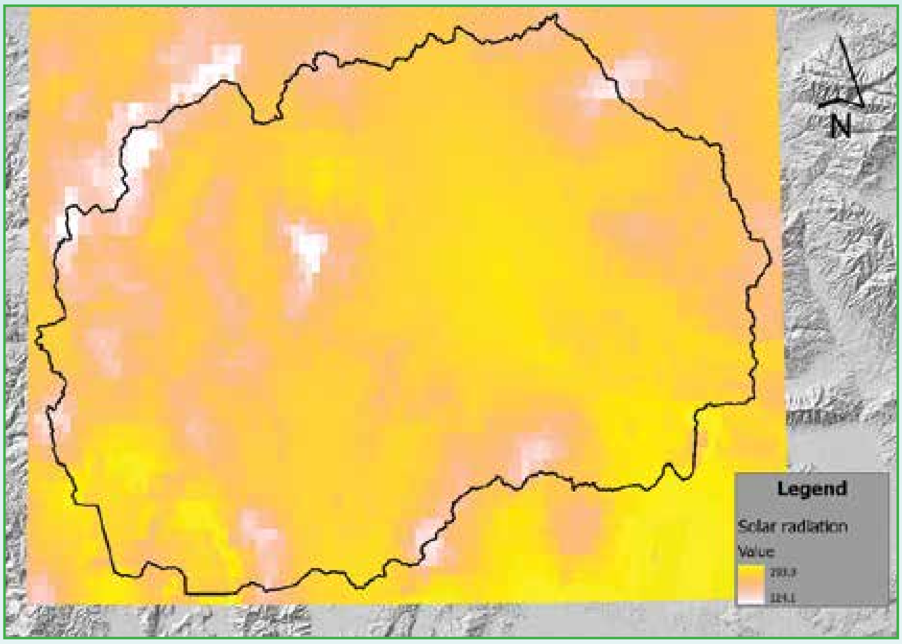
Source: (Expert team analysis)

4.1.2.8 Meteorological parameters

For the selection of the best location for the construction of solar power plants, **solar irradiation** is, of course, one of the key parameters. The number of sunny hours is directly related to the amount of energy received from the sun; therefore, for each location, the average annual solar irradiation in watt per square metre (W/m^2) is calculated. Data for solar irradiation was obtained from the EU's Climate Monitoring Satellite Application Facility[18] (CM SAF). The resolution of the obtained data is 200 x 200 m. The corresponding GIS map is displayed in Figure 26.

Figure 26: Average annual solar irradiation in North Macedonia

Source: (Expert team analysis and EUMETSAT - CM SAF)



As was done for the other criteria, the meteorological parameters' favourability was graded from 1 to 5. The location that has the highest average value for solar irradiation was thus awarded 5 points and the location with the lowest average value for solar irradiation was awarded 1 point. A linear interpolation between the minimum and maximum solar irradiation was used to assign grades for the other locations' solar irradiation. The interval values corresponding to each of the grades are given in Table 9.

18 https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis/pvgis-data-download/cm-saf-solar-radiation_en

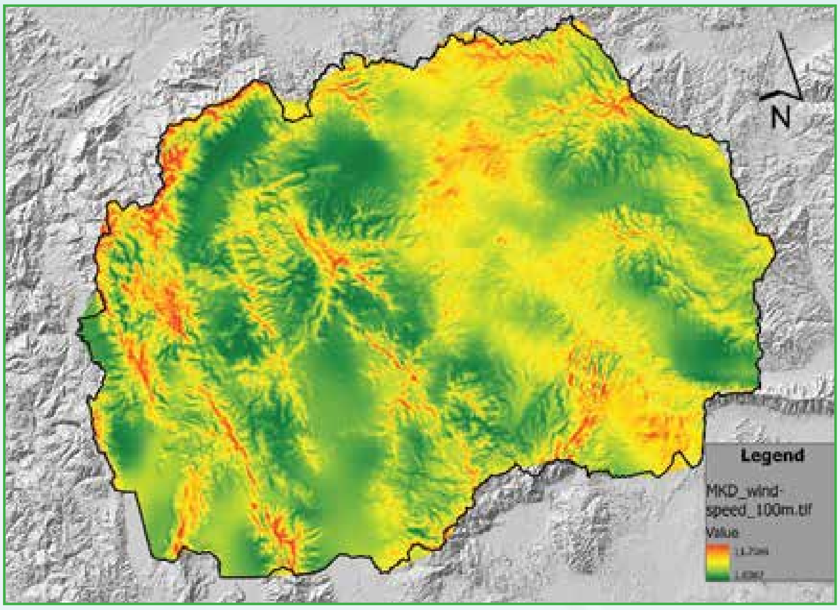
Table 9: Average annual solar irradiation in North Macedonia and corresponding grades

Solar Irradiation (/m^2)	Grade
< 138	1
138 – 152	2
152 – 166	3
166 – 180	4
180 - 194	5

Accordingly, average annual **wind speed** is used to select the most suitable location for the construction of WPPs. This is because the electricity produced at the WPP is proportional to the wind speed at that location. Therefore, for each location the average annual wind speed should be evaluated. Data for the wind profile (i.e. the average annual wind speed distribution across the country) was obtained from the Global Wind Atlas.[19] The resolution of the data is 200 x 300 m, and the wind speed is measured at a height of 100 m above the ground. The distribution of the average wind speeds for North Macedonia is mapped in Figure 27.

Figure 27: GIS map – wind profile for North Macedonia

Source: (Expert team analysis and Global Wind Atlas 3.0)



Based on this, the location with the highest average wind speed is awarded 5 points and the location with the lowest average wind speed is awarded 1 point. **Additionally, all locations which have recorded**

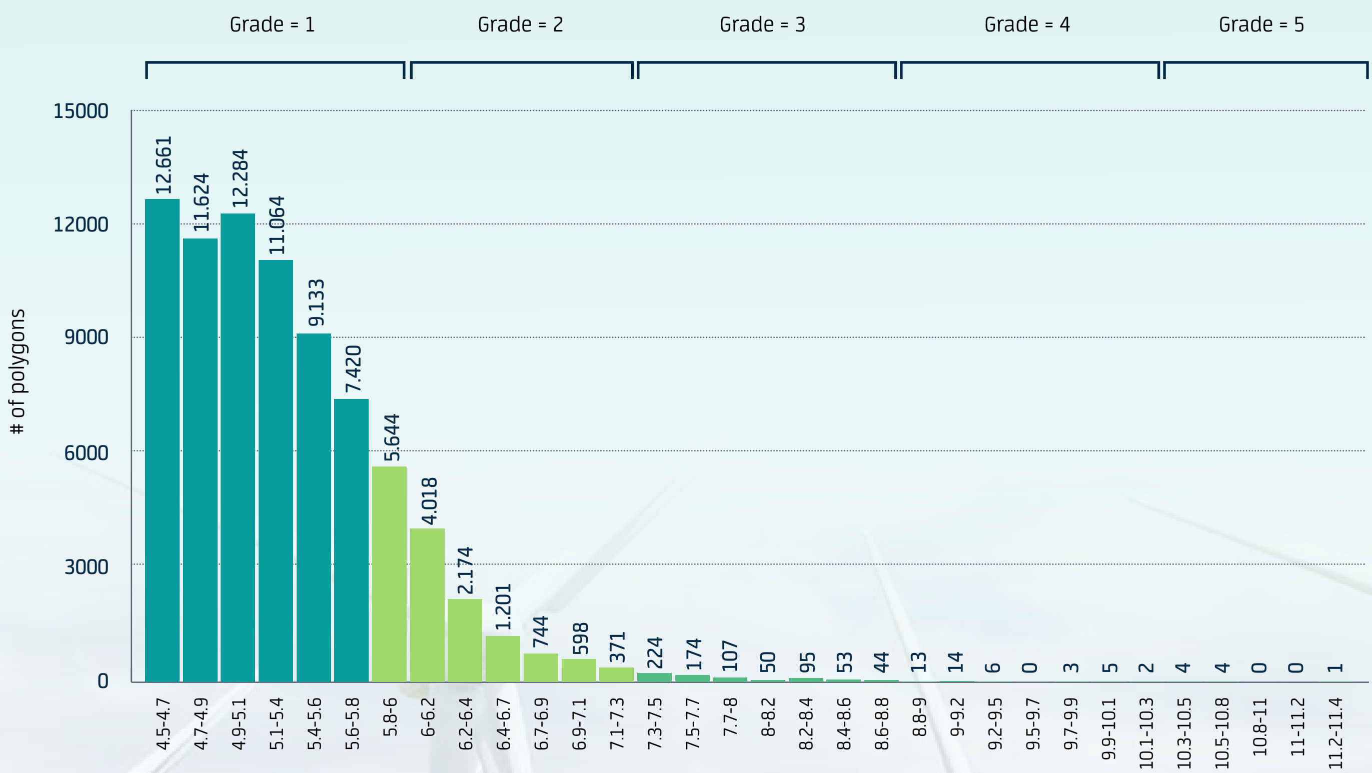
19 Data obtained from Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilising data provided by Vortex and funded by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

average annual wind speeds below 4.5 ms^{-1} are awarded 0 points, i.e. they are excluded from further analysis. In order to score the other locations in the considered range, linear interpolation between the points awarded for the minimum and the maximum wind speed is used. The equivalent grades and their corresponding wind speed intervals are given in Table 10. In addition, the distribution of the considered polygons for WPP buildout and the corresponding wind speeds at the considered areas are displayed in Figure 28. In approximately 87 per cent of the considered polygons, the average wind speed is less than or equal to 6 ms^{-1}.

Table 10: Average annual wind speed intervals and corresponding grades

Wind speed (m/s)	Grade
$4.5 \leq x < 5.94$	1
$5.94 \leq x < 7.38$	2
$7.38 \leq x < 8.82$	3
$8.82 \leq x < 10.26$	4
$10.26 \leq x \leq 11.70$	5

Figure 28: DISTRIBUTION OF POLYGONS PLOTTED AGAINST THE WIND SPEEDS AT THE LOCATIONS



Source: (Expert team analysis)

4.1.2.9 Type of land

The **type of land** is also very important, because it takes into account the environmental aspects related to RES buildout. For example, a location with very good meteorological conditions for electricity generation should be given less priority if it is on agricultural land. Therefore, land categorisation as defined by the national cadastre is used, and for each land type a corresponding grade is given, as presented in Table 11. Arable land, forests, biodiversity areas and protected land (national parks) were completely excluded from the analysis. Figure 29 displays a GIS map of all the ecosystems (arable lands, forests, etc.) that were not included in the analysis. Figure 30 displays a GIS map where the IPAs and IBAs have been plotted alongside the Emerald and other protected areas on the territory of North Macedonia.

Table 11: Type of land area and corresponding grades

Type of area	Grades
Sparsely vegetated areas	5
Mineral extraction sites and industrial areas	4
Transitional woodland-shrub	3
Pastures	2

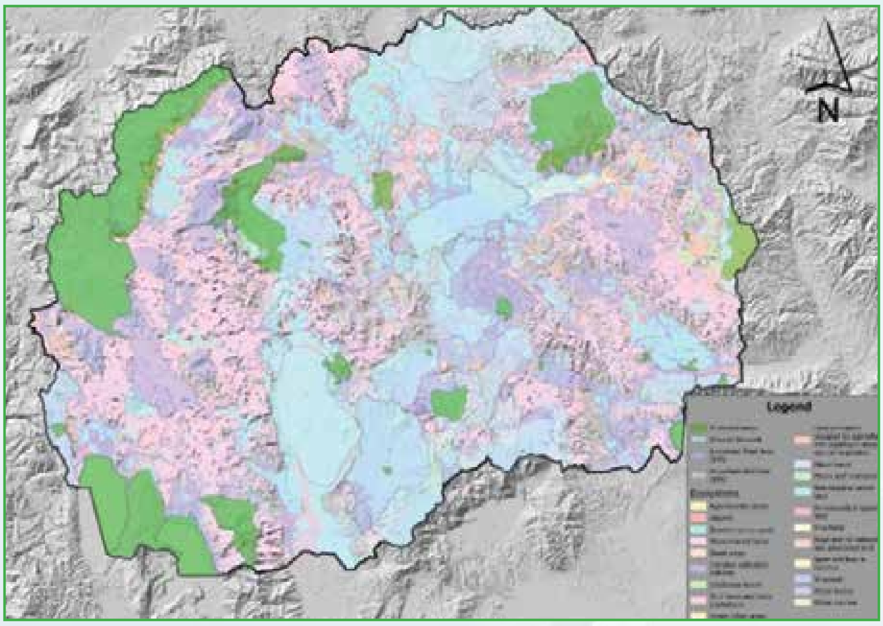


Figure 29: GIS map – all protected and biodiversity areas in the Republic of North Macedonia

Source: (Expert team analysis and Macedonian Ecological Society)

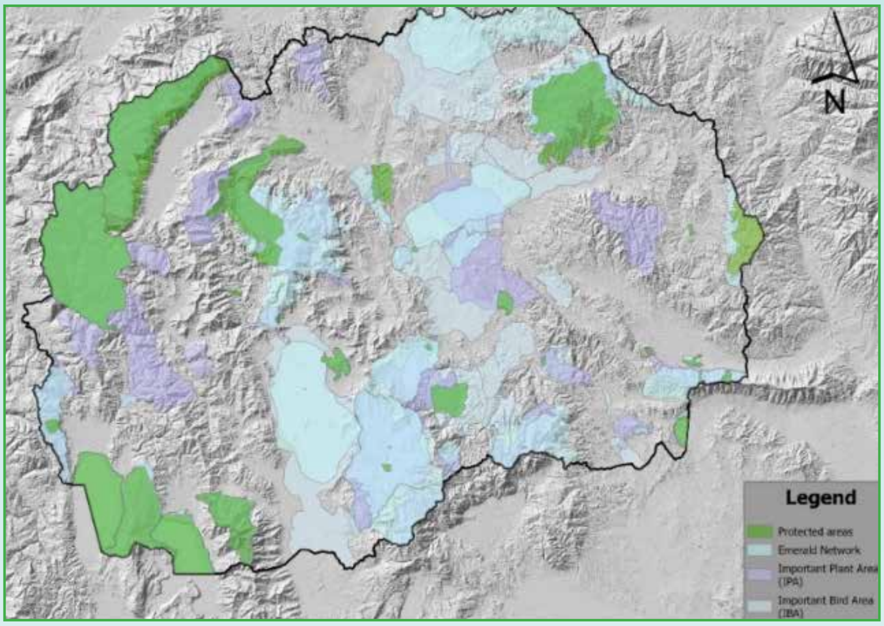


Figure 30: GIS map – IPA, IBA, emerald and protected areas in the Republic of North Macedonia

Source: (Expert team analysis and Macedonian Ecological Society)

4.1.2.10 Installed capacity

The **potential for the installed capacity** on the given location is also a valuable parameter. The installed capacity is mostly affected by the location of the area. The locations on which power plants with larger installed capacity can be built are more cost effective, so they are more favourable. The fixed costs incurred during installation, such as those associated with the feasibility of road construction, access to the network, etc., will be more cost-effective if more electricity is generated at the given location (i.e. the installed capacity of the power plant is higher). Therefore, the location on which a power plant with the highest installed capacity can be built is graded with 5 points, and the one with the lowest potential for capacity is graded with 1 point. For PVPPs, it is assumed that 1 MW of capacity can be installed on 1.3 ha of land. For WPPs, it is assumed that 1 MW can be installed on 10 ha of land; this assumption is based on currently existing and operating WPPs, as well as WPP development requests the national TSO has received. The benchmarks and their associated grades for PVPPs are shown in Table 12 and those for WPPs are shown in Table 13. In the case of the PVPPs, areas with a surface area of less than 0.5 ha are not considered in the analysis.

Table 12: Potential for installed capacity – criterion data and grades for PVPPs

Surface area (ha)	Equivalent capacity (MW)	Grade
0.5 ≤ x < 26.16	0.4 ≤ x < 20	1
26.16 ≤ x < 52.12	20 ≤ x < 40	2
52.12 ≤ x < 78.08	40 ≤ x < 60	3
78. 08 ≤ x < 104.04	60 ≤ x < 80	4
104.04 ≤ x	80 ≤ x	5

Table 13: Potential for installed capacity – criterion data and grades for WPPs

Surface area (ha)	Equivalent capacity (MW)	Grade
20 > x	2 < x	1
20 ≤ x < 50	2 ≤ x < 5	2
50 ≤ x < 80	5 ≤ x < 8	3
80 ≤ x < 110	8 ≤ x < 11	4
110 ≤ x	11 ≤ x	5

4.1.3 Additional Data input

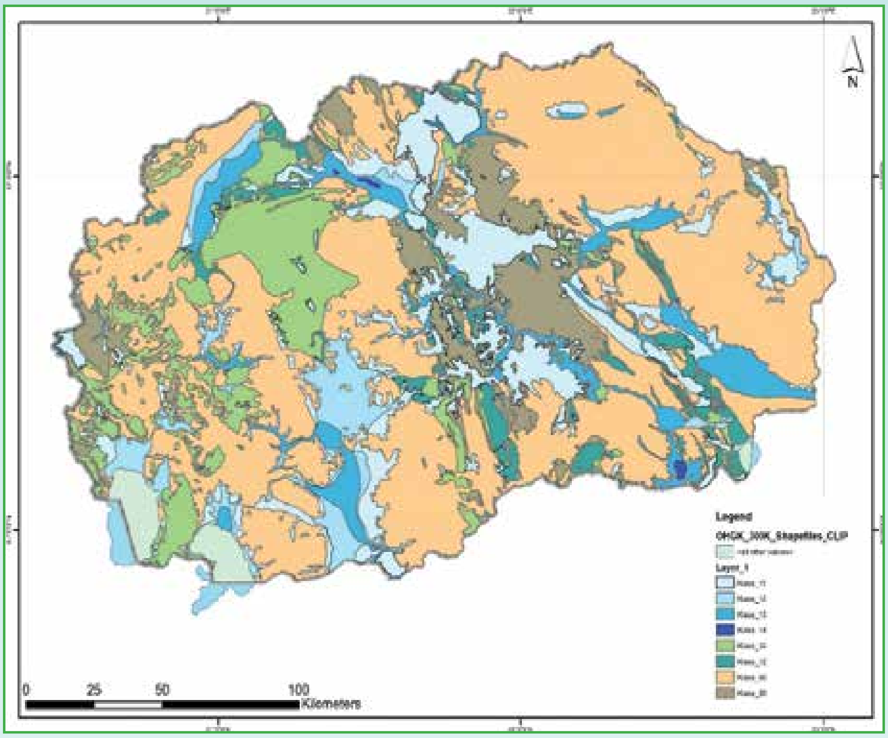
In addition to the data referenced in the previous chapter, additional parameters were considered in the analysis and selection of suitable sites. Some of the additional input parameters and categories considered were the locations of karst regions and the locations of currently operating RES power plants, as well as the locations of existing industrial capacities, Emerald network protected sites, mineral sites, etc. In parallel with the development of this report, a strategy for mineral resources is being prepared and the locations of karst regions were taken from the analysis conducted for the strategy. Based on this, karst regions were not taken into consideration in this study, since the impact and influence of karst on renewable energy production was not clear according to the parameters of the analysis. Once the final analysis for the strategy for mineral resources is finished, the results can be incorporated in the methodology as additional criteria.

Figure 31 displays a GIS map of the karst regions in North Macedonia. Their importance is of great significance, as a large share of the country's drinking water comes from karst regions.

Figure 31:
GIS map – karst regions in North Macedonia

Note: The classes (klasa) on the figure represent the type of karst region are not related with the analysis done as part of the project

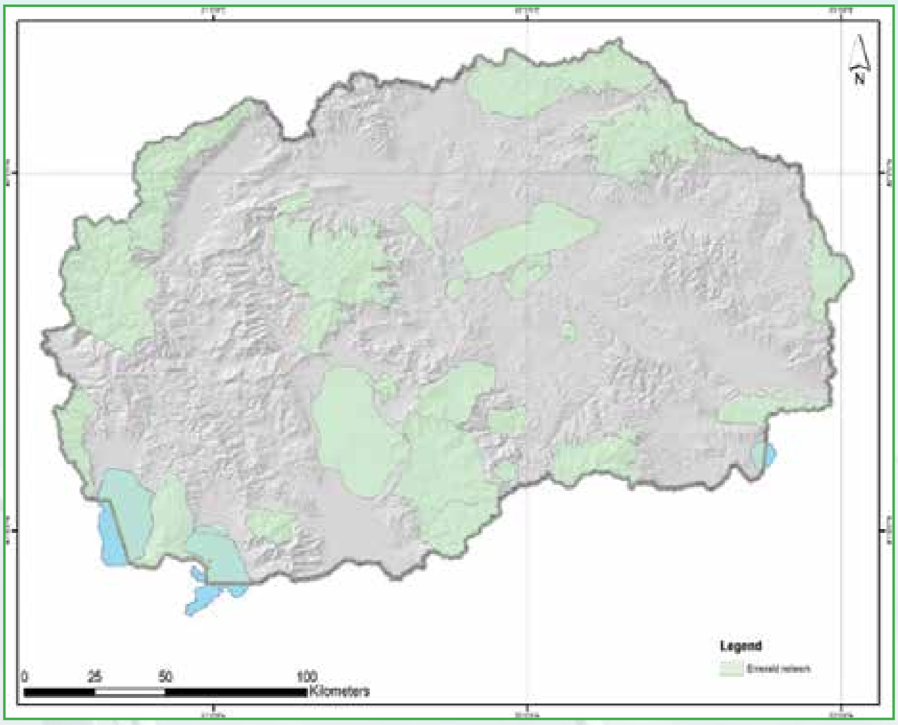
Source: (Draft Analysis of the Strategy for geological research and sustainable utilisation and exploitation of mineral resources of the Republic of North Macedonia 2025-2045)



The locations of Emerald sites were also mapped and considered in this study. Locations classified as Emerald sites were omitted in accordance with the adopted methodology. Figure 32 displays the GIS map of the Emerald sites in North Macedonia.

Figure 32:
GIS map – Emerald protected areas in North Macedonia

Source: (Expert team analysis + Draft Analysis of the Strategy for geological research and sustainable utilisation and exploitation of mineral resources of the Republic of North Macedonia 2025-2045)



Additionally, the locations of existing industrial sites and the locations where metal and non-metallic mineral ores can be found and/or are excavated were also mapped and layers in the form of a GIS map for each of these categories were developed. Figure 33 and Figure 34 depict the locations of the existing industrial capacities and the locations of metal and non-metal mineral ores, respectively.

Figure 33: Locations of industrial capacities

Source: (Expert team analysis + Draft Analysis of the Strategy for geological research and sustainable utilisation and exploitation of mineral resources of the Republic of North Macedonia 2025-2045)

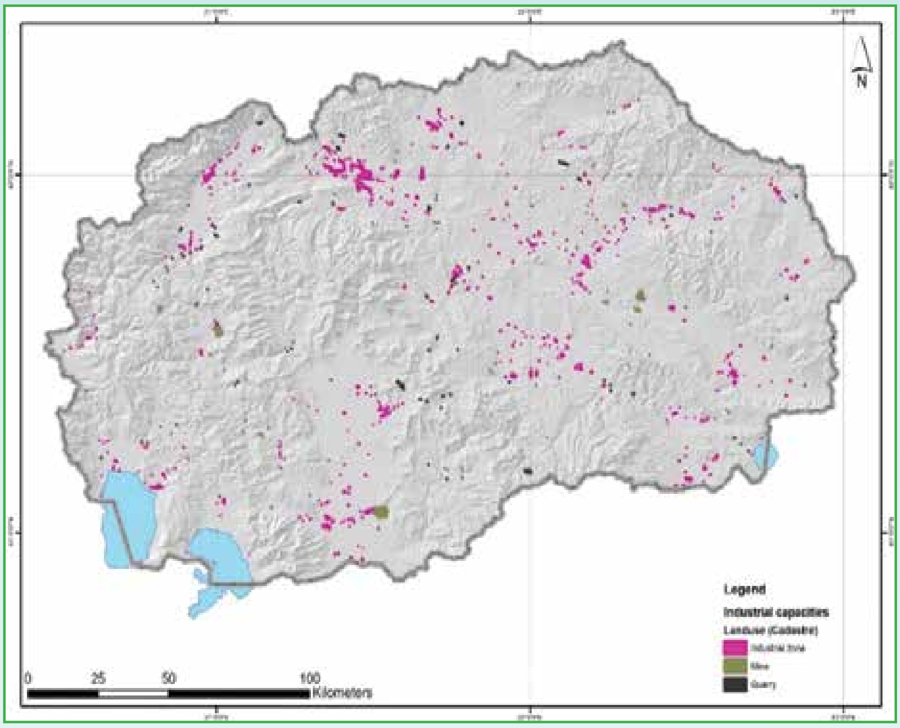
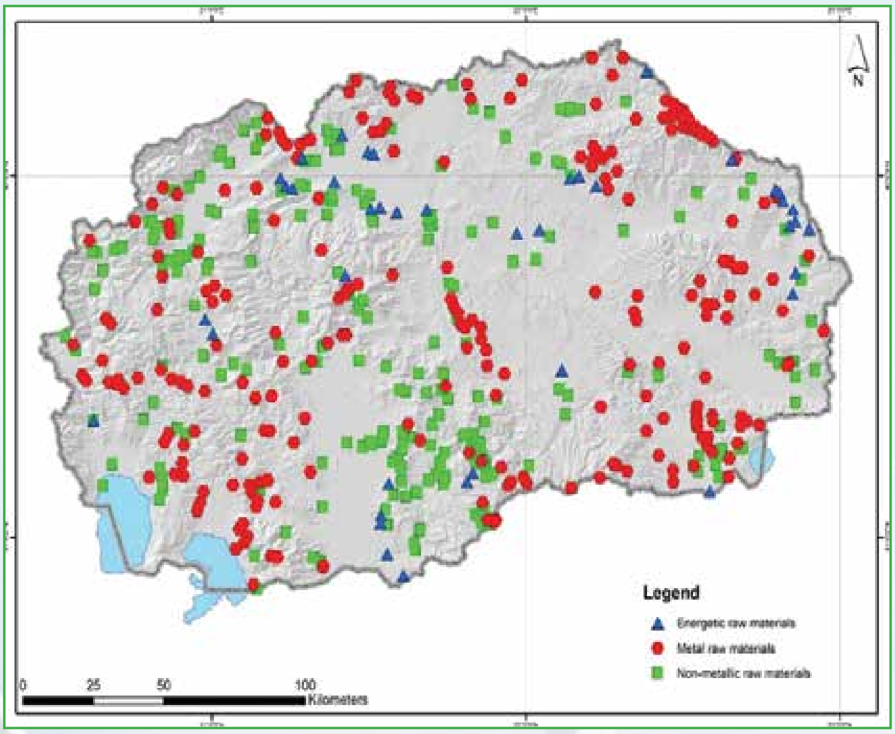


Figure 34: Locations of metal and mineral ores in North Macedonia

Source: (Draft Analysis of the Strategy for geological research and sustainable utilisation and exploitation of mineral resources of the Republic of North Macedonia 2025-2045)



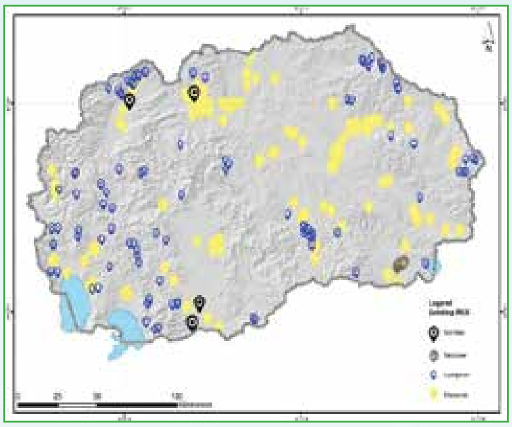
As of March 2023, there are a total of 270 PVPPs (including both roof installations and ground mounted PVPPs), one WPP, 105 small hydropower plants (SHPPs), three power plants running on biogas and one power plant using biomass as the primary fuel in the Republic of North Macedonia (National register, 2023). Data for the locations of the RES plants was obtained from the Energy Agency of North Macedonia's online register.[20] A GIS map of all currently installed and operational RES was created. Concerning PVPPs, only the ground mounted PVPPs were mapped, as populated areas were not taken into account (Figure 35, left). The obtained layer was then compared against the IBA and IPA areas, key biodiversity areas, protected areas and Emerald sites. This demonstrated that some of the presently operational RES plants were built on protected grounds with disregard for the protected status of their corresponding area.

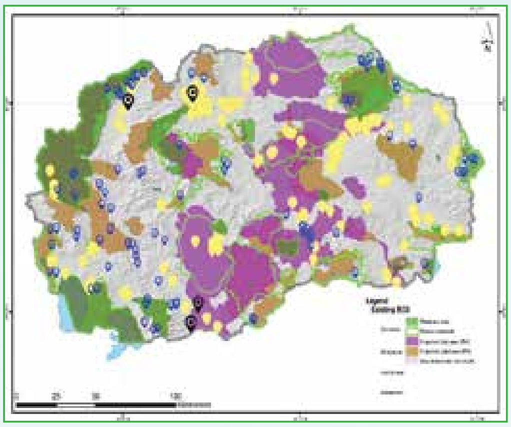
Other parameters which were considered in the pre-selection of polygons (areas) were the locations of existing RES power plants, as well as proposed locations for new RES power plants for which the TSO has received permit requests. Both the locations of the currently installed RES power plants and the locations of those for which the TSO has received requests were compared against the previously mentioned GIS maps (layers). This was done to determine the respective (potential) positions of these RES power plants in relation to the aforementioned areas (layers) of interest. The corresponding GIS maps are shown in Figure 35, where the locations of the existing RES power plants are displayed on their own (left), and the same locations compared against the previously mentioned GIS map layers (right). The locations of the RES power plants for which requests have been submitted to the TSO on their own are displayed on the left side of Figure 36, and their overlap with the other layers is displayed on the right side of Figure 36.

Figure 35: GIS map – existing RES locations in North Macedonia

Source: (Expert team analysis + Energy Agency of the Republic of North Macedonia)

Note: The figure on the left represents the layer with the RES locations. The figure on the right represents the RES locations compared against protected areas.





20 https://www.ea.gov.mk/dokumenti/registri/

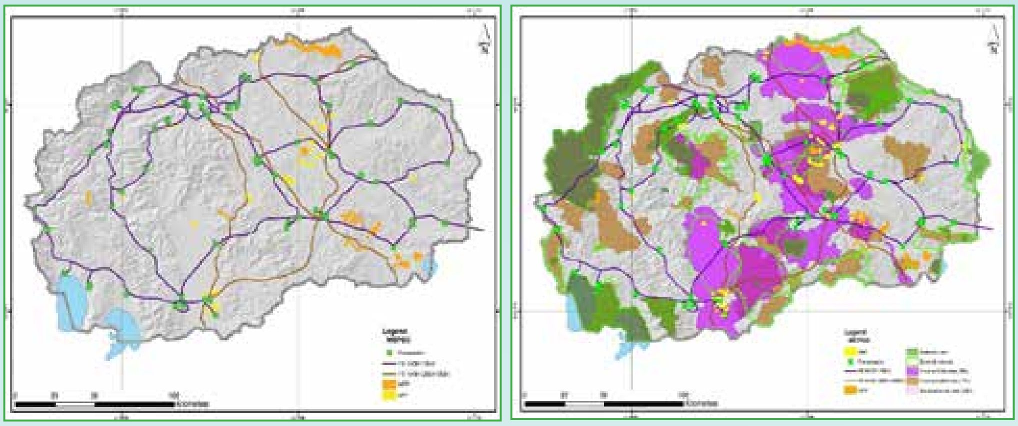


Figure 36:
GIS map – locations of RES power plants requested from the TSO

Source: (Expert team analysis + National TSO (MEPSO))

Note: The layer on the left represents the proposed locations of the potential RES. The layer on the right represents the overlap between protected areas and the proposed locations for the potential RES sites.

A GIS map was created with all the protected and considered areas' layers overlapped on one map. Thereby, the locations of existing and operational RES were compared against all the areas of interest. The resulting image is displayed in Figure 37.

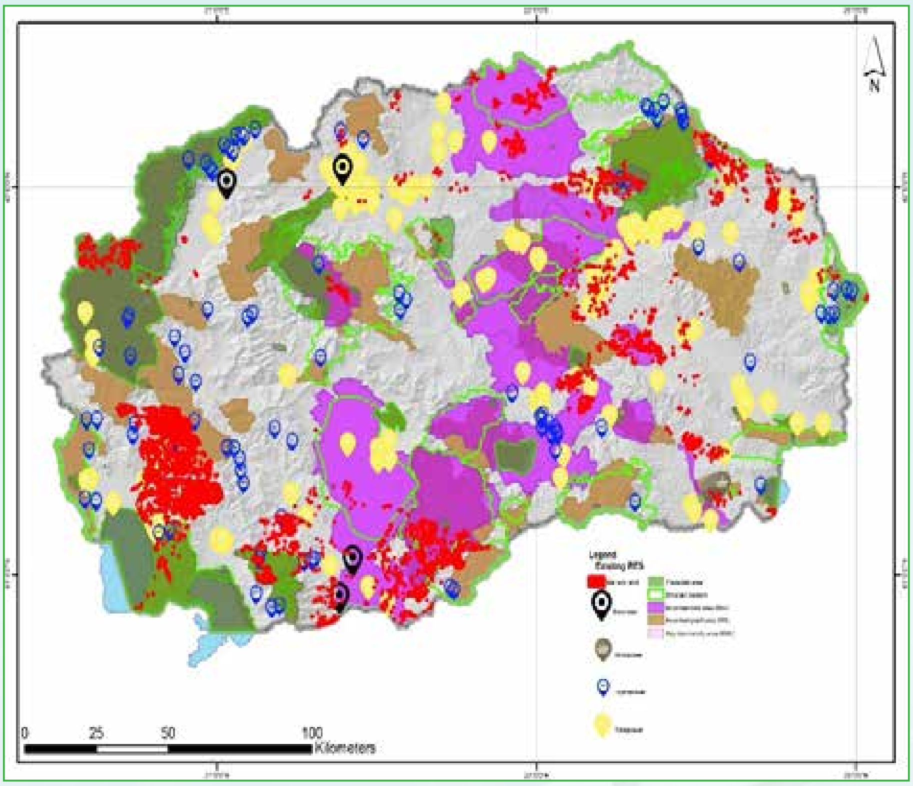


Figure 37:
GIS map – overlap of existing and considered RES development areas and protected areas

Source: (Expert team analysis)

4.2. Analytic hierarchy process (AHP) methodology

The weights for each criterion are determined by using the analytic hierarchy process (AHP) method. AHP is a multi-criteria decision-making method that is used to derive ratio scales from paired comparisons. These ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.

In order to compute the weights for the different criteria, at the beginning a pairwise comparison matrix A is created. The matrix A is a $m \times m$ real matrix, where m is the number of evaluation criteria considered. Each entry a_{jk} of the matrix A represents the importance of the j^{th} criterion relative to the k^{th} criterion. If $a_{jk} > 1$, then the j^{th} criterion is more important than the k^{th} criterion. To evaluate the importance of the two criteria a numerical scale from 1 to 9 is used. If the j^{th} criterion is equally or more important than the k^{th} criterion, the following scoring may be used:

- $a_{jk} = 1$ – j and k are equally important;
- $a_{jk} = 3$ – j is slightly more important than k;
- $a_{jk} = 5$ – j is more important than k;
- $a_{jk} = 7$ – j is strongly more important than k;
- $a_{jk} = 9$ – j is absolutely more important than k.

If the k^{th} criterion is equally or more important than the j^{th} criterion, the corresponding reciprocal values are used.

After the comparison matrix, a priority vector is calculated. In this project, an approximation of the Eigen vector (and Eigen value) of a reciprocal matrix is used. First, the normalised pairwise comparison matrix A_{norm} is calculated according to the following equation:

$$\underline{a_{jk}} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \qquad (1)$$

$$w_j = \frac{\sum_{l=1}^{m} \underline{a_{jl}}}{m} \qquad (2)$$

Finally, the criteria weight vector w, or the normalised principal Eigen vector, can be obtained by averaging across the rows using equation 2.

The vector w_j, which is also called the priority vector, shows the relative weights among the criteria that we compare.

4.2.1 Consistency check

When many pairwise comparisons are performed, some inconsistencies may arise. To check the consistency of each expert's answer, a Principal Eigen value is used. Principal Eigen values are obtained from the summation of products between each element of the Eigen vector and the sum of the columns of the reciprocal matrix:

$$\lambda_{MAX} = \sum_{j,k=1}^{m} (w_j * \sum_{l=1}^{m} a_{lk} \qquad (3)$$

A Consistency Index (CI) is obtained by using equation 4:

$$CI = \frac{\lambda_{max} - m}{m - 1} \qquad (4)$$

where m is the number of criteria.

A perfectly consistent decision maker should always obtain $CI = 1$, but small values of inconsistency may be tolerated. So, this consistency index is compared with a Random Consistency Index (RI). The values for RI for small problems, where m is less than 10, are given in Table 14.

Table 14: Values for the random consistency index

m	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

According to this, a Consistency Ratio is calculated as follows:

$$CR = \frac{CI}{RI} \qquad (5)$$

If the value of the Consistency Ratio is less than or equal to 10 per cent ($CR \leq 0.1$), the inconsistency is acceptable.

4.2.2 Calculations for the weight of each criterion

Experts and professionals from different energy sector institutions and companies in Macedonia each carried out their own pairwise comparison. A consistency check of the results provided by each participant was applied and a single weight for each criterion was calculated by weighting the assessments of each participant . For the purpose of establishing a credible basis for the pairwise comparison, a survey was created and answered by 93 individuals representing different entities (public, private, educational and research) in North Macedonia. Private entities that work in the energy sector (companies) provided 80 per cent of the responses and public institutions (academia and government institutions) 20 per cent. The calculated weights for each of the criteria are shown in Table 15.

Table 15:
Weight of criteria

Criteria	Weight
Proximity to transmission/distribution networks	21%
Proximity to road infrastructure	10%
Slope (average)	10%
Important Bird Area (IBA) / Important Plant Area (IPA)	9%
Eligible workforce	6%
Proximity to settlements (km)	5%
Distance to rivers or lakes	4%
Wind speed (m/s) / solar irradiation (kWh/m^2)	14%
Type of land	7%
Installed capacity (km^2)	13%

5

GIS MAPS

5.1 Data analysis

Raw data, supplied by the national cadastre, included all the barren land parcels (a total of 60,000 individual parcels) as well as their reference numbers in the OSSP cadastre online tool. However, because there were inconsistencies between the provided data and what the parcels were in reality (existing roads, parcels with houses built on them and/or parcels in densely populated areas were included, for example), the raw data provided by the cadastre was filtered and compared against a set of criteria that were used when determining whether a parcel needed to be considered further in the analysis. The OSSP cadastre online tool was used for examination and comparison of the parcels. Because the OSSP tool supports only one parcel at a time, this was done by hand for each parcel individually.

The criteria used to exclude parcels in the cadastre list from further investigation contained the following benchmarks:

- If a parcel was smaller than 200 m^2;
- If a parcel was too long and not wide enough (such as a public road);
- If a parcel was registered in a densely populated area;
- If a parcel had any buildings on it;
- If a parcel was in fact not barren land.

Figure 38 displays a type of parcel that is a road in a populated environment. Because of that, this parcel and others which fulfilled the aforementioned criteria were eliminated when the cadastral data was examined.

Figure 38:
Land parcel in a populated area

Source: (Expert team analysis + OSSP system of the National Cadastre of the Republic of North Macedonia)

After detailed refinement, around 17,000 sites (parcels) were marked as suitable. The next step of the process was to create a map of the parcels in QGIS. The easiest way to do this was to gather data from local surveying companies which possess this kind of data and were willing to share it, as this was the only way to avoid buying the data at a very expensive price from the national cadastre. However, this was a challenge on its own, as data was available for only 13 of the 31 cadastral regions and was stored in an AutoCAD format that needed further conversion and adaptation in order to be transferred into the adequate ESRI shapefile. Because of this, only 13 out of 31 cadastral regions were mapped using the data that was supplied by the cadastre (Figure 39).

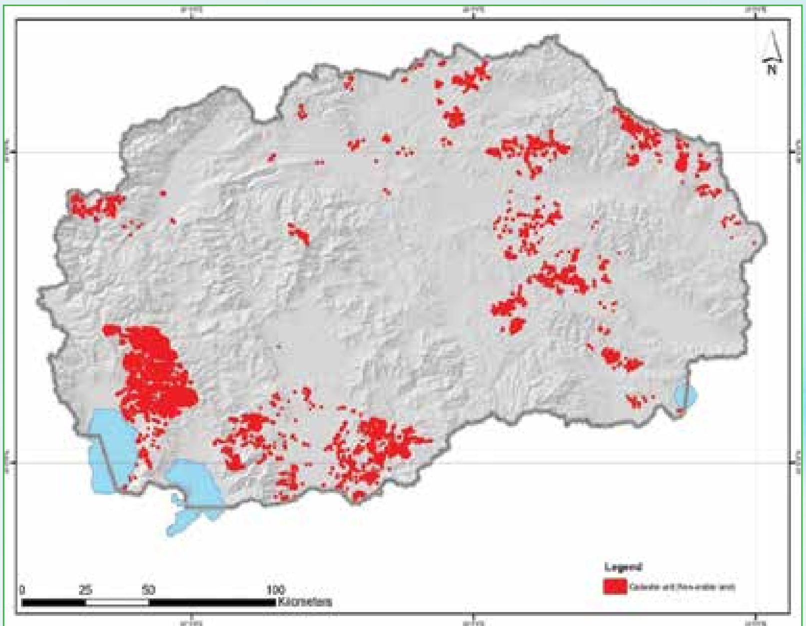


Figure 39:
GIS map – using the cadastre supplied data set

Source: (Expert team analysis + National Cadastre of the Republic of North Macedonia)

5.2 Developing the GIS maps

Instead, a more elegant and time efficient approach was used to create a map of all the barren land in North Macedonia. Namely, the researchers used the national slope raster layer with a resolution of 5x5 m and a map of the ecosystems of North Macedonia. From this, four main types of ecosystems were selected as most suitable for greenfield investments: mineral extraction sites (industrial ecosystems), sparsely vegetated areas (rocky and stony fields), transitional woodland-shrub (bushes), and pastures (grasslands). The validity of the approach was confirmed by comparing the GIS maps of some of the regions defined using the first approach with the same regions obtained using the second approach. An 83.15 per cent match (overlap) was calculated between the total cadastre area (expressed in ha) identified in both the first and second approaches. The results of the overlay are displayed in Figure 40 and Figure 41.

Figure 40: Overlap between national cadastre data and ecosystems (ES) and slope data

Source: (Expert team analysis)

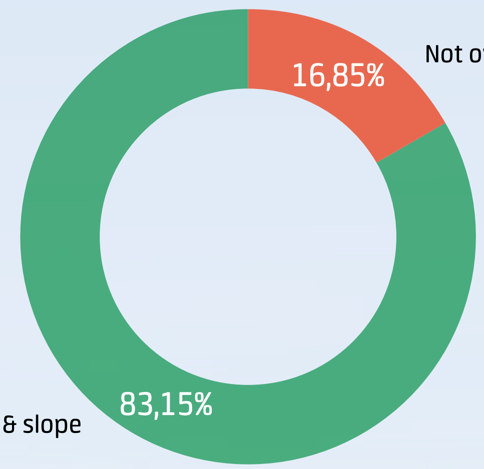
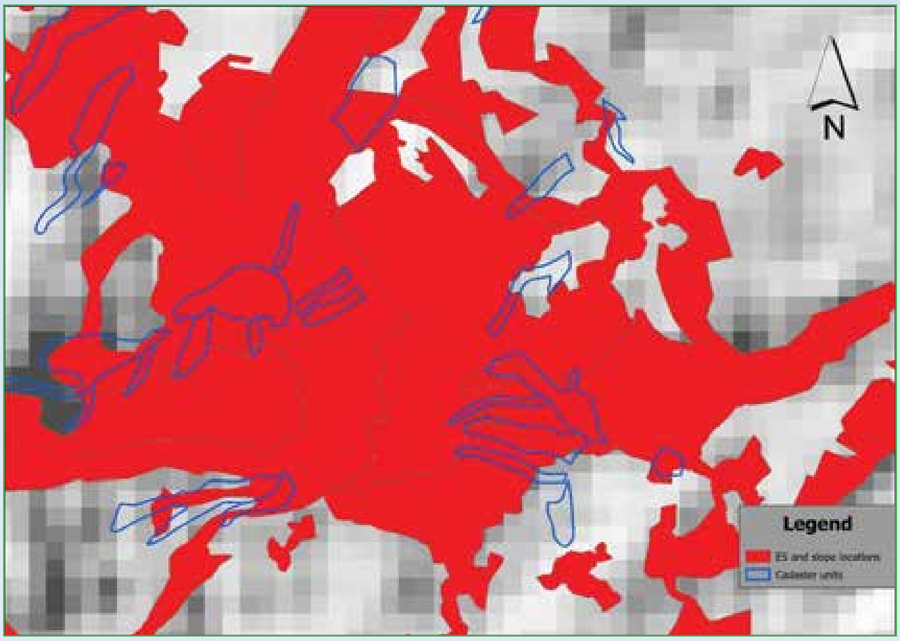


Figure 41: Confirmation of the validity of the second approach

Source: (expert team analysis)



6

RESULTS AND DISCUSSION

6.1 Evaluation of land area for photovoltaic power plants

The total considered surface area whose suitability was evaluated for PVPP installations is equal to 459,689 ha. Primarily, this surface area was obtained by completely excluding land which is part of protected areas and Emerald sites. After applying the methodology explained in the previous chapter, the results show that the total surface area of the best locations (those whose grade was greater than or equal to 4.2 points) was approximately 64,420 ha (Figure 42). Bearing in mind the assumption that 1.3 ha of land are needed to install 1 MW of PVPP, an estimated 50 GW of PVPP can be installed in locations that obtained a grade of 4.2 points or higher. In Figure 42, the areas in dark red are the locations with highest scores (greater than or equal to 4.2 points).

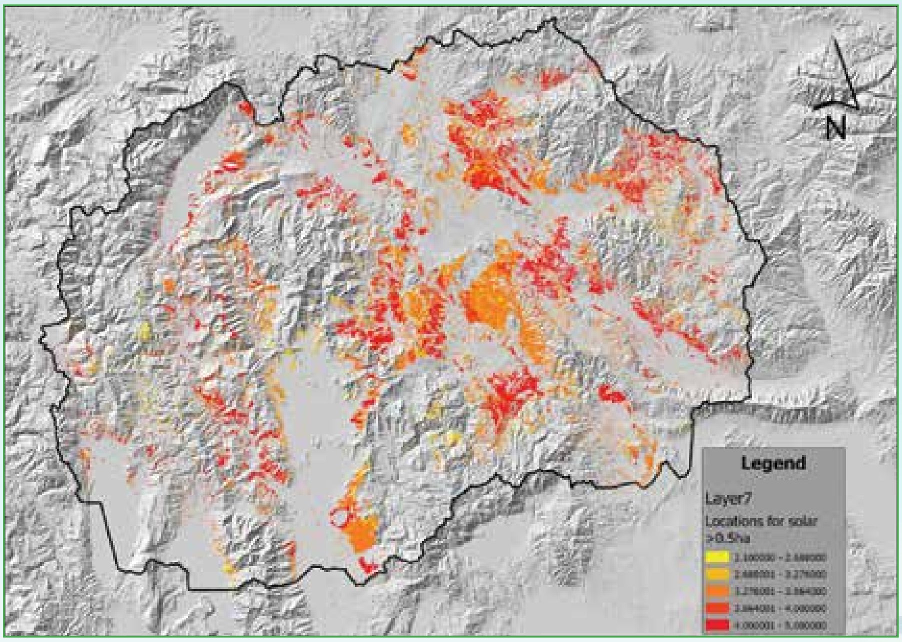


Figure 42: Evaluated area for PVPP installation, excluding national parks, Emerald sites and areas smaller than 0.5 ha

Source: (Expert team analysis)

Additional analyses were conducted excluding the locations within IBAs and IPAs. The considered area was decreased to an estimated 276,545 ha by excluding only Important Plant Areas (IPAs). The total surface area of the locations which achieved 4.2 points or more under these conditions was equal to 29,625 ha, or approximately 30 GW of PVPP that could be installed (see Figure 43 – the areas in dark red are those which scored 4.2 or more points).

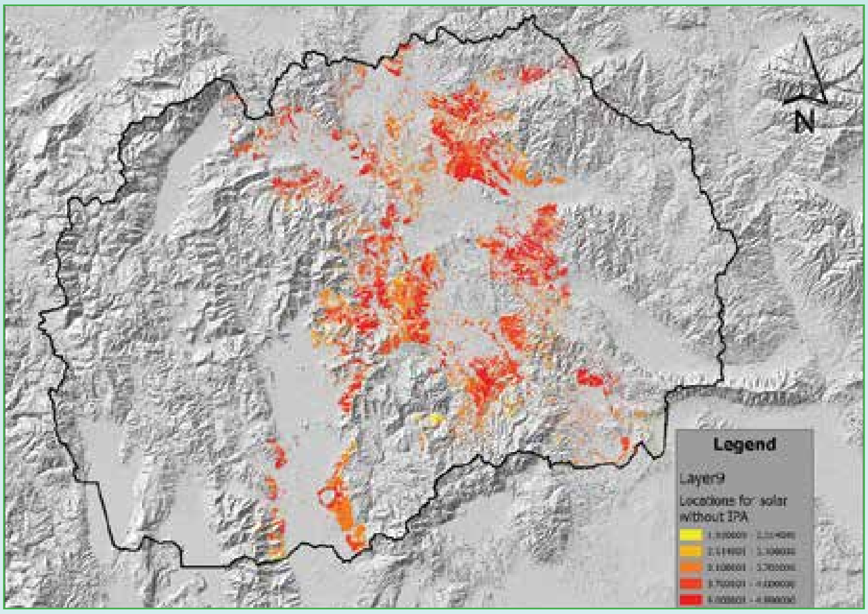


Figure 43:
Evaluated locations excluding national parks, Emerald sites, biodiversity areas and IPAs

Source: (Expert team analysis)

When only Important Bird Areas (IBAs) were excluded, the resulting surface area of the locations considered for evaluation shrunk to 233,334 ha. Based on the multi-criteria assessment, the total surface area of the locations with a grade greater than or equal to 4.2 points was estimated to be 25,942 ha, or approximately 20 GW of PVPP capacity that could be installed under these assumptions (Figure 44).

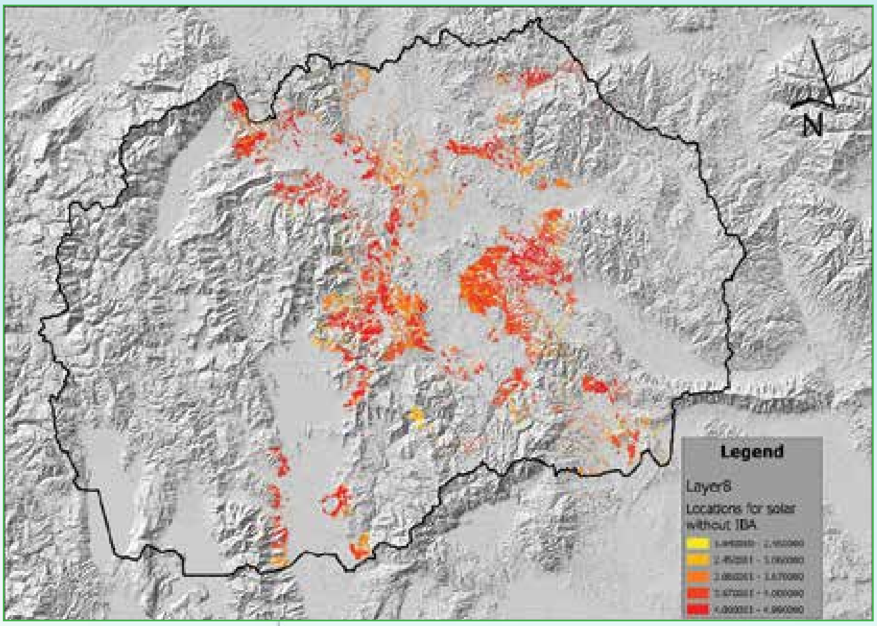


Figure 44:
Evaluated locations excluding national parks, Emerald sites, protected areas and IBAs

Source: (Expert team analysis)

Last, the sites located within IBAs or IPAs were both excluded from the analysis. This left the total area for further evaluation at 174,456 ha. The surface area of the best rated locations – those which received grades greater than or equal to 4.2 points – was equal to 14,347 ha, indicating that approximately 11 GW of PVPP could be installed under these assumptions (Figure 45). The areas marked in dark red are those which scored 4.2 or more points.

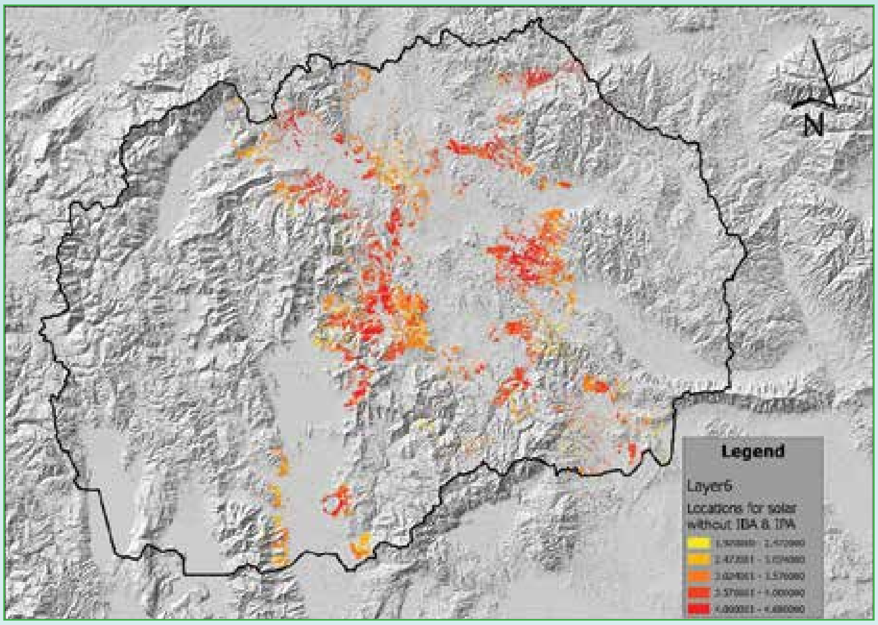


Figure 45: Evaluated locations, excluding national parks, Emerald sites, protected areas, IPAs and IBAs

Source: (Expert team analysis)

Table 16 provides a summary comparison of the total area of the eligible locations that were considered for PVPP buildout and the best graded locations from this analysis.

Table 16: Summary of results for PVPP

Source: (Expert team analysis)

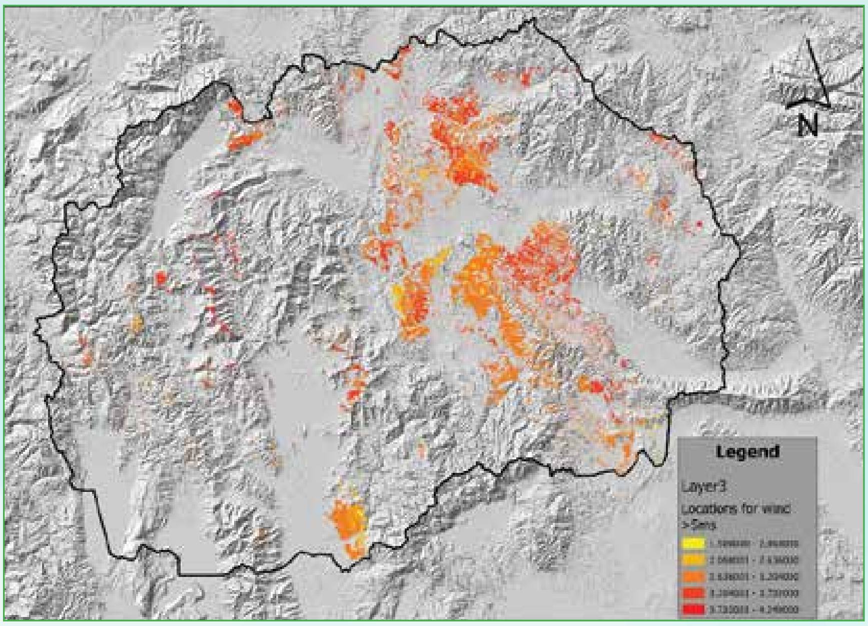
Scenario	Eligible locations that were considered (ha)	Best graded locations (ha)	Assumed potential for PVPP instalment (GW)
Excluded national parks, Emerald protected areas and areas smaller than 0.5 ha	459,689	64,420	~ 50
Excluded national parks, Emerald protected areas, areas smaller than 0.5 ha and IPAs	276,545	29,625	~ 30
Excluded national parks, Emerald protected areas, areas smaller than 0.5 ha and IBAs	233,334	25,942	~ 20
Excluded national parks, Emerald protected areas, areas smaller than 0.5 ha, IBAs and IPAs	174,456	14,347	~ 11

6.2 Evaluation of land area for wind power plants

The assessed area available for WPP installations amounted to 209,026 ha. Similar to the process for PVPPs, this area was determined by excluding land designated as protected areas or Emerald sites. Additionally, any parcel whose total surface area was smaller than 10 ha was excluded from the analysis in the first case-scenario, as these land areas are unsuitable for WPP due to their small size, regardless of their characteristics when compared against the other criteria. The geographic distribution of the locations assessed through a multi-criteria evaluation is shown in Figure 46. Among the assessed locations, approximately 4,563 ha constituted the total surface area that received a grade of 3.7 points or higher (marked in dark red in Figure 46). If it is assumed that 1 MW of WPP could be built on land with a surface area of 10 ha, then within this scenario, approximately 457 MW of WPPs could be installed on the locations which received grades greater than or equal to 3.7.

Figure 46: Distribution of considered locations for WPP buildout, excluding national parks, Emerald sites and biodiversity protected areas, locations with surface areas smaller than 10 ha and arable land

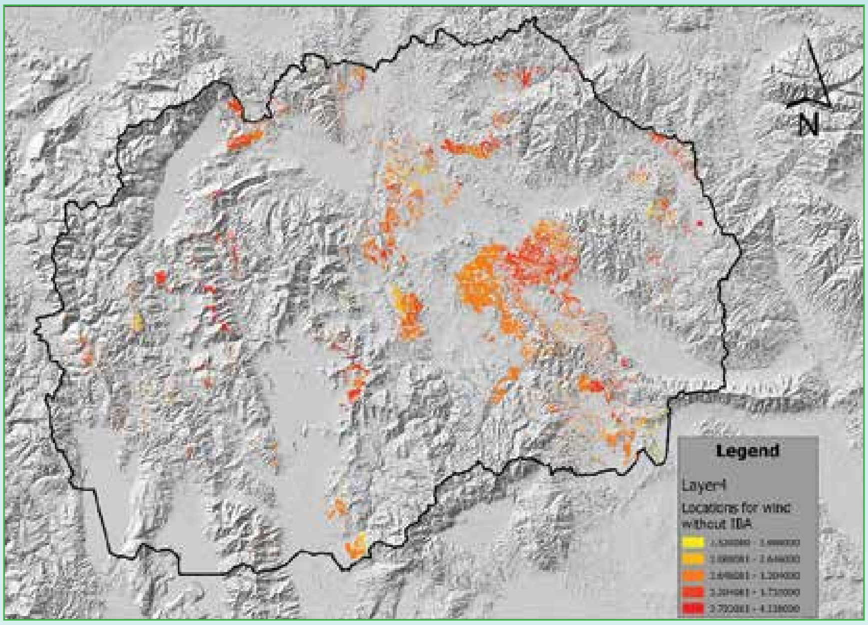
Source: (Expert team analysis)



In the second case scenario of this sensitivity analysis, along with national parks, Emerald sites and the locations whose total surface area is smaller than 10 ha, Important Bird Areas (IBAs) were also removed from consideration. The overall land area assessed in the comprehensive evaluation was 132,620 ha. Consequently, the total land area of the locations that received a rating of 3.7 points or higher was approximately 4,324 ha, the distribution of which is marked in dark red in Figure 47. If the previous assumption regarding the needed surface area to house 1 MW of WPP is applied, then on the locations with grades greater than or equal to 3.7, approximately 433 MW of WPPs could be installed.

Figure 47: GIS map – the considered polygons for WPP buildout, excluding national parks, Emerald sites, protected areas, locations with surface areas smaller than 10 ha and IBAs

Source: (Expert team analysis)



For the third case scenario within this sensitivity analysis, all IPAs, IBAs, national parks and Emerald sites, as well as any parcels which had surface areas smaller than 10 ha, were excluded from the analysis. The total land area taken into account for this scenario was roughly 79,293 ha. The area of the highest-rated locations, those receiving a score of 3.7 or more points, amounted to approximately 3,534 ha, indicating that approximately 354 MW of WPPs can be installed on these locations. Figure 48 illustrates the distribution of the assessed locations, with the dark red areas indicating locations that scored 3.7 or more points.

Figure 48: Distribution of considered locations, excluding national parks, Emerald sites, protected areas, locations with surface areas smaller than 10 ha, IPAs and IBAs

Source: (Expert team analysis)

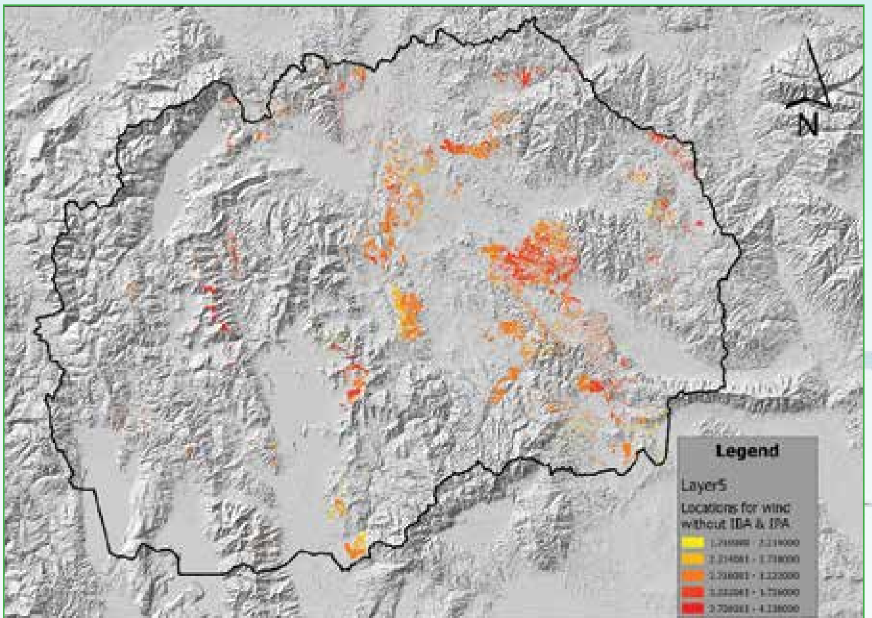


Table 17 provides a summary comparison of the total areas of the eligible locations that were considered for WPP buildout and the best graded locations from this analysis.

Table 17: Summary of results for WPP

Source: (Expert team analysis)

Scenario	Eligible locations that were considered (ha)	Best graded locations (ha)	Assumed potential for WPP instalment (GW)
Excluded national parks, Emerald protected areas and areas smaller than 10 ha	209,026	4,653	~ 0.457
Excluded national parks, Emerald protected areas, areas smaller than 10 ha and IBAs	132,620	4,324	~ 0.433
Excluded national parks, Emerald protected areas, areas smaller than 10 ha, IBAs and IPAs	79,293	3,534	~ 0.354

Based on the sensitivity analysis conducted for both PVPPs and WPPs, it is evident that a sufficient amount of renewable energy capacity can be installed without causing harm to local wildlife or significant damage to the surrounding environment, even when bold constraints are considered, according to initial assumptions made in the analysis of the land areas' suitability under the adopted methodology. At a national level, there are abundant locations with sufficient surface area that have received a score of 4.2 for PVPP buildout and 3.7 for WPP buildout. Moreover, these locations offer optimal conditions, such as proximity to road infrastructure, the availability of workforce, and proximity to transmission/distribution grids, among other factors. The results obtained from the analysis indicate that the process has been productive and positive. With careful and rational planning, it is possible to preserve nature while meeting mankind's energy requirements.

6.3 Analysis of the highest graded locations for PVPP and WPP buildout

The locations which received the best grades, i.e. those which are best suited for PVPP and WPP buildout, were examined in greater detail. In this section, the properties of the best graded locations – in line with the criteria under the adopted methodology, are presented and examined. Additionally, GIS maps with the locations of the highest graded land areas are displayed. It should be taken into account that multiple locations may be awarded the same grade; as such, all the locations which share the same grade are included in this analysis.

Table 18 presents the properties of the locations for PVPP that achieved the five highest grades (which might consist of more than five locations since some of them share the same grade) under the case scenario where national parks, Emerald sites, protected areas, all land areas whose total surface area is less than 0.5 ha, IPAs and IBAs are excluded. Additionally, the corresponding properties of the locations which were given the five best grades under the case scenario where national parks, Emerald sites, protected areas and all land areas whose total surface area is less than 0.5 ha are excluded are provided in Table 19. Several conclusions can be drawn from examination of these tables. The majority of the ecosystems (types of land) where the best graded locations are located are mining and industrial ecosystems. All of the considered land areas have good access to road transport infrastructure and most are well placed relative to either rural or urban settlements. The annual average solar irradiation in all considered locations is quite high, with values ranging from 170 to 186 W/m^2. Additionally, all considered locations are well placed relative to the existing transmission network system and within reasonable proximity of it.

For WPPs, Table 20 displays the properties of the locations that received the ten best grades under the case scenario where national parks, Emerald areas, protected areas, all land-areas whose total surface area is less than 10 ha, IPAs and IBAs are excluded. From the locations' properties, it can be seen that the average annual wind speed varies between 4.7 and 6.74 m/s. Additionally, the highest grades awarded to the locations whose eligibility was evaluated for WPP buildout are between 3.90 and 4.23. If the results from Table 20 are studied in detail, it can be concluded that the geographic and physical conditions in the Republic of North Macedonia are less allowing for WPP buildout – especially when compared against the set of conditions for PVPP buildout.

Table 18: Properties of the locations with the five highest grades for PVPPs (6 locations) under the case scenario where all national parks, Emerald sites, protected areas, land areas whose total surface area is less than 0.5 ha, IPAs and IBAs are excluded

Grade	Type of ecosystem	Surface area (ha)	Distance from road (m)	Distance from IBA (km)	Distance from IPA (km)	Distance from rural settlements (km)	Distance from urban settlements (km)	Distance from the 110 kV transmission system network (km)	Distance from the 400 kV transmission system network (km)	Avg. annual solar irradiation (W/m²)
4.7	Mining and industrial	182.60	0	21.30	4.28	0.34	0.00	0.00	4.33	179.36
4.6	Mining and industrial	2.69	1	19.71	6.83	0.73	0.74	0.50	2.11	182.70
4.6	Mining and industrial	151.23	0	11.03	8.34	0.04	6.64	0.00	4.54	179.90
4.6	Mining and industrial	5.10	69	17.87	7.75	0.00	2.87	0.03	1.26	182.80
4.6	Mining and industrial	1.77	175	15.10	5.54	0.12	2.91	2.34	2.31	185.20
4.6	Mining and industrial	69	0	3.81	2.87	0.05	0.39	0.00	0.38	183.89

Table 19: Properties of the locations with the five highest grades for PVPPs (6 locations) under the case scenario where national parks, emerald sites, protected areas, and all land areas whose total surface area is less than 0.5 ha are excluded, with IPA and IBA included

Grade	Type of ecosystem	Surface area (ha)	Distance from road (m)	Distance from IBA (km)	Distance from IPA (km)	Distance from rural settlements (km)	Distance from urban settlements (km)	Distance from the 110 kV transmission system network (km)	Distance from the 400 kV transmission system network (km)	Avg. annual solar irradiation (W/m²)
5.0	Mining and industrial	347.40	0	14.73	7.42	0.06	3.37	0.94	51.28	175.85
4.8	Mining and industrial	219.59	505	11.56	7.09	0.62	5.44	0.13	30.97	170.51
4.8	Mining and industrial	0.98	100	23.51	7.54	2.05	5.45	0.39	29.16	183.40
4.9	Mining and industrial	156.20	0	21.30	4.28	0.34	0.00	0.00	0.00	179.36
4.9	Mining and industrial	151.15	0	11.03	8.34	0.04	6.64	0.00	0.00	179.90
4.9	Mining and industrial	2	175	15.10	5.54	0.12	2.91	2.34	0.01	185.20

Table 20: Properties of the locations with the ten highest grades for WPPs (thirteen locations) under the case scenario where all national parks, Emerald sites, protected areas, land areas whose total surface area is less than 10 ha, IPAs and IBAs are excluded

Grade	Type of ecosystem	Surface area (ha)	Distance from road (m)	Distance from IBA (km)	Distance from IPA (km)	Distance from rural settlements (km)	Distance from urban settlements (km)	Distance from the 110 kV transmission system network (km)	Distance from the 400 kV transmission system network (km)	Mean wind speed (m/s)
3.90	Sparsely vegetated areas	52.84	1206.51	5.47	3.76	2.12	10.29	10.84	1.74	6.74
3.90	Sparsely vegetated areas	52.84	1206.51	5.47	3.76	2.12	10.29	10.84	1.74	6.74
4.05	Sparsely vegetated areas	14.28	108.51	6.73	4.60	4.01	9.98	9.68	0.33	6.73
4.10	Sparsely vegetated areas	55.86	295.29	5.51	2.87	2.08	9.34	9.45	0.52	6.23
3.90	Mining and industrial	11.17	0.00	0.00	2.08	0.11	7.48	1.97	4.45	6.12
4.03	Mining and industrial	95.71	20.76	4.69	1.58	0.88	2.10	1.98	4.49	6.08
4.07	Mining and industrial	15.83	7.66	3.11	15.76	0.02	1.48	3.79	5.27	4.91
4.23	Mining and industrial	12.26	0.00	3.74	15.18	0.04	1.75	3.54	5.96	4.86
4.09	Sparsely vegetated areas	10.58	263.58	5.18	4.68	1.72	22.22	1.40	33.80	5.16
3.93	Sparsely vegetated areas	57.71	177.26	5.21	4.82	1.94	21.28	1.73	33.75	4.72
3.97	Sparsely vegetated areas	43.10	0.00	17.32	4.65	1.61	14.84	3.15	47.00	6.61
3.97	Sparsely vegetated areas	43.10	0.00	17.32	4.65	1.61	14.84	3.15	47.00	6.61
4.00	Mining and industrial	15.14	0.00	0.00	16.73	1.27	2.99	3.06	7.39	5.38

Under the aforementioned assumptions, where national parks, Emerald sites, protected areas, land areas whose total surface area is less than 0.5 ha, IPAs and IBAs are excluded, the total surface area of all the locations which were awarded the five best grades for PVPP buildout is estimated to be approximately 380 ha. Figure 49 displays a GIS map where only the land areas which scored the highest grades are shown. A tabular representation of the properties of the locations with the highest grades is given in Table 18.

Based on the assumption that 1 MW of solar photovoltaics can be installed on land with a surface area of 1.3 ha, then the total surface area that has received the best five grades under this case-scenario can house approximately 0.3 GW of PVPP.

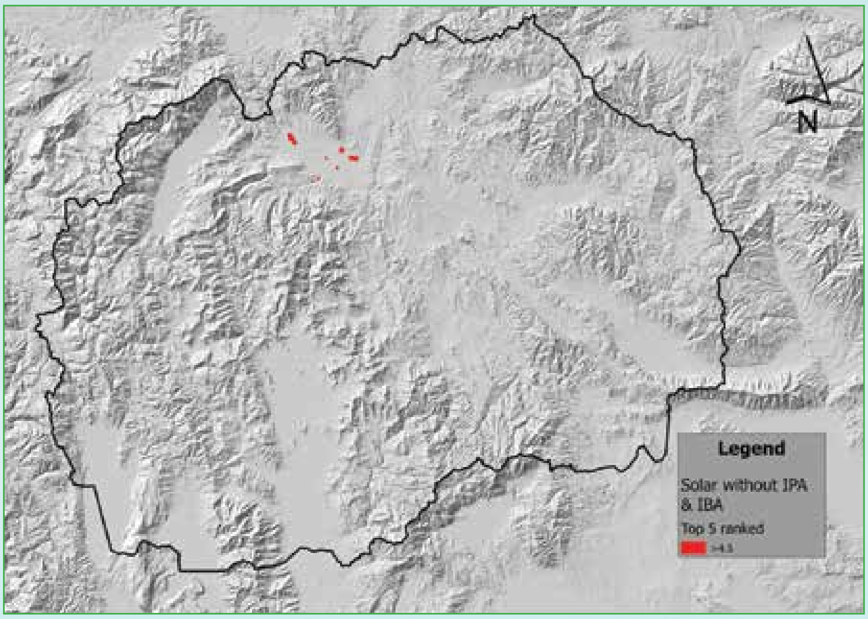


Figure 49: GIS map – the locations with the five best grades for PVPP buildout, under the case scenario where all national parks, Emerald sites, protected areas, land areas whose total surface area is less than 0.5 ha, IPAs and IBAs are excluded

Source: (Expert team analysis)

In the case of WPPs, the circumstances surrounding the locations which received the ten best grades are different than those for the PVPPs. The properties of the locations which were awarded the five best grades under the considered assumptions are displayed in Table 20. Figure 50 displays a GIS map of the locations which received the ten best grades for WPP buildout. The corresponding total surface area they cover is approximately 480 ha; if it is assumed that 1 MW capacity of WPP requires 10 ha, then on the locations which were awarded the ten best grades approximately 48 MW of WPP capacity could potentially be built.

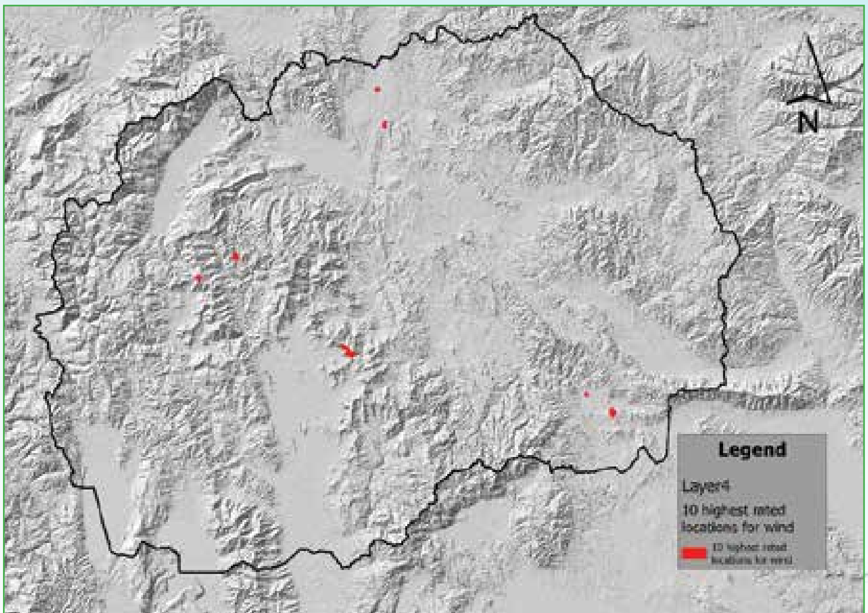


Figure 50: GIS map – the locations with the five best grades for WPP buildout, under the case scenario where all national parks, Emerald sites, protected areas, land areas whose total surface area is less than 10 ha, IPAs and IBAs are excluded

Source: (Expert team analysis)

7

CONCLUSION

Spatial visualisation and identification of sites that are suitable, yet not contradictory to one another is of the utmost importance for the transition to renewable energy. As a continuation of Phase 1, which was centred on assessing the wind and solar potential of brownfield areas in North Macedonia, Phase 2 sought appropriate locations for WPPs and PVPPs on the entire territory of N. Macedonia. The methodology used is based on the multi-criteria assessment method using the analytic hierarchy process, including expert judgement and consistency checks.

The next step towards the spatial identification of suitable areas for RES deployment was gathering geo-referenced data as input into GIS. Raw data of 60,000 barren land parcels was supplied by the national cadastre. Due to inconsistencies with the provided data and its current status, the data was filtered, compared against a set of criteria and scaled down to 17,000 proper areas for further analysis. However, using this approach, only 13 out of 31 cadastral regions were mapped using the data that was supplied by the cadastre. As for the remaining areas, it was concluded that the digitalisation process would be too time and labour consuming.

As the primary approach could not provide nationwide siting, an alternative top-down method was conducted by using the national slope raster layer and a map of the ecosystems of North Macedonia from which four main types of ecosystems were selected as most suitable for greenfield investments. For each ecosystem type, the mean slope was calculated, then simplified within three categories: x<15%; 15%<x<20% and x<30%. In order to verify this approach, a comparison and layer overlaying was performed in a selected area, which confirmed the validity of the method with an overlap greater than 80 per cent.

Furthermore, individual GIS maps were generated for each of the criteria taken into account, which were subsequently utilised during the evaluation of the locations. The maps incorporated various layers, including industrial capacities, Emerald protected areas, Important Bird Areas (IBA), Important Plant Areas (IPA), biodiversity regions, rivers and infrastructure, existing renewable energy sites, areas designated for new capacity requests, the locations of metals and other non-metallic minerals, and karst areas. To create a comprehensive overview, a complex map was developed, integrating all the protected and considered areas, existing and operational renewable energy sites, average horizontal annual solar irradiation, and the national wind profile, all overlapping on one layer.

As a final step, a sensitivity analysis was conducted for each of the RES types. The multi-criteria assessment was applied and each of the considered locations was graded in accordance with the pre-determined grading scheme. After including all data, overlaying the different maps, and excluding the areas not suitable for greenfield investments, the total considered surface area whose suitability was evaluated for PVPP installations is approximately 14,500 ha, or approximately 11 GW of solar photovoltaics that could be installed on this land. The total surface area for WPP is approximately 3,534 ha, or an equivalent of 354 MW of onshore wind power that could be installed on this land. The findings obtained from the analysis indicate that the process was effective and yielded reliable results, serving as a solid foundation for making informed energy plans that align with national targets.

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