European Commission

Clean energy for EU islands: Assessment of the Wind Power potential on Öland, Sweden

Clean energy for EU islands

Assessment of the Wind Power potential on Öland, Sweden

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Executive summary

This report provides an in-depth assessment of wind energy development potential in Öland. It analyses existing wind energy plans, technological advancements, land use constraints, and wind resource availability to identify priority areas for future wind power projects.

First, the technical, cultural and environmental constraints for the deployment of wind farms are assessed, leading to the definition of a list of priority areas. Then, the wind energy potential in those areas is estimated, together with the technical potential in terms of installable capacity.

The constraint mapping identifies three levels of priority areas for the development of wind energy based on different distances from buildings and consideration of the natural conservation constraints:

- Level 1 priority areas, i.e. areas without natural conservation constraints and at a distance of at least 1000 m from buildings.
- Level 2 priority areas, i.e. areas without natural conservation constraints and at a distance of at least 500 m from buildings.
- Level 3 priority areas, which fall under natural conservation constraints.

The high-level wind resource assessment is developed based on the New European Wind Atlas (NEWA). The analysis reveals the availability of good resources on Öland, with higher wind speeds found in the southern part of the island. The technical potential, i.e., the amount of installable wind capacity and the expected yield, is estimated using sample wind turbines with an installed capacity of 4.2 MW, a hub height of 99 m, and a diameter of 138 m. The results indicate a potential of approximately 200 MW in Level 1 priority areas, 1,020 MW in Level 2 priority areas, and 4,275 MW in Level 3 priority areas.

Additionally, the potential for repowering is estimated based on the areas that are actually used. Thanks to technological developments and the larger turbines available on the market nowadays, the older wind turbines (built before 2016) – which have a total capacity of 28.3 MW – can be replaced, achieving a total installed capacity of approximately 188 MW.

1. Introduction

The first activity of the technical assistance delivered by the Clean energy for EU islands (CE4EUI) Secretariat to the island of Öland (Sweden) consists of the review of the wind energy development plan of the island. The secretariat has been tasked with assessing the new potential for wind energy development, taking into account existing technical and environmental constraints, as well as the potential for repowering existing wind farms. This assessment will consider both wind resource availability and the installable capacity in the identified eligible areas.

The work was distributed in two main phases:

1. Assessment of technical and environmental constraints for the deployment of wind farms, resulting in the definition of a list of priority areas.
2. Estimation of the wind energy potential in those areas, and of the technical potential in terms of installable capacity.

This report presents the outcomes of the work. Following this introduction, Section 2 presents the constraint mapping and wind resource assessment. Section 3 presents the assessment of the technical wind potential. Section 4 draws the main conclusions and recommendations.

2. Resources Used

This activity involves analysing the current wind energy development plan for Öland to identify the need for updates, considering new data and technological trends. Additionally, the land use plans for Öland are compiled, and new potential wind development areas are considered. Lastly, the wind power resource on the island is analysed using data from the New European Wind Atlas (NEWA, 2022), and a list of new potential wind development areas is identified.

2.1.1. The Wind Energy Handbook (Vindkraftshandboken), 2009

The Wind Energy Handbook (Vindkraftshandboken) (Boverket, 2009) was published by Boverket, a Swedish government agency responsible for providing expertise and support in the fields of housing, building, and planning, to serve as a comprehensive guide or handbook for wind power development in Sweden. It aims to provide valuable information, guidelines, and best practices for the various stakeholders involved in the wind energy sector. This includes policymakers, energy companies, investors, engineers, environmentalists, and the general public.
It delves into topics such as wind conditions assessment, technical specifications of wind turbines, infrastructure requirements, noise and shadow considerations, landscape analysis, impacts on biodiversity, interactions with local communities and industries, regulatory frameworks, and permit application processes.

2.1.2. The Wind Energy Development Plan (Vindkraftsplan), 2011

This report aims to identify possible areas for wind project development in Öland using constraint mapping (Martinsson, Stjärndahl, Werthwein, Forsberg, & Hammarstedt, 2011). It was compiled in 2011 and has not been updated since. Part of the Öland Island Trajectory involves updating this information with the new technologies available today, as well as the emerging technological and environmental constraints. The list in Table 1 explains the considerations as discussed in the Wind Energy Development Plan (Vindkraftsplan) relevant to this report.

2.1.3. Wind power: An important part of the future energy system (Vindkraft: En viktig del av framtidens energisystem, Swedish Society for Nature Conservation (Naturskyddsföreningen), 2021

This report, published by the Swedish Society for Nature Conservation in 2021, emphasises the crucial role of wind power in Sweden's future energy system. It highlights the need for a significant expansion of renewable electricity production to combat climate change. The report outlines the benefits of wind power, including its competitiveness and minimal climate impact, while also addressing the challenges associated with its expansion, such as environmental considerations and the importance of responsible site selection. The goal is to ensure that wind power development is sustainable and minimises negative impacts on nature and wildlife.
The main restrictions for wind energy development in natural reserves, as outlined in the document, are:

- No Construction in Protected Areas: Wind energy projects are prohibited in protected areas, including Natura 2000 sites, nature reserves, national parks, biotope protection areas, and key biotopes.
- Avoid High Nature Value Areas: Areas with high natural values, including important bird and bat habitats and migration routes, should be excluded from wind energy development.

- Consultation with Indigenous Communities: Any wind energy projects in reindeer grazing and calving areas must be done in consultation with the Sami people.
- Minimize Negative Impacts: Efforts should be made to minimise negative impacts on red-listed species and their habitats, as well as on marine environments.

As this is the most recent document on nature protection related to wind development planning, the constraints and restrictions described here will be taken into account.

2.2. Comparing the constraints of the different sources

All considerations and constraints relevant to this high-level feasibility study on Öland are summarised in Table 1. Other aspects that should be considered, such as noise levels, shadow analysis, and grid connection restrictions, will be discussed at later stages.

Table 1: Summary of the considerations and constraints when planning wind development areas

	English Name	Swedish Name	Vindkraftsplan, 2011	Naturskyddsföreningen, 2021	Additional sources
Technical constraints	Buildings		500 m buffer from all houses, all year round, as well as holiday homes, urban areas, areas with established detailed plans and areas with ongoing planning work	/	
	Roads		125 m buffer from public roads	/	
	High voltage lines		100 m distance when power line is at a total height < 50 m; 200 m distance when powerline is at a height > 50 m	/	
	Military areas		The armed forces should always be informed and have a right to decline permitting.	/	
Natural constraints	National Parcs	Nationalpark		Wind development prohibited	
	Woodland key habitats			Wind development prohibited	
	Natural object	Naturminne		Wind development prohibited	
	Animal and plant protection areas	Djur- och växtskyddsområde		Wind development prohibited	
	Natura 2000		Wind development should be avoided; a special permit is required.	Wind development prohibited	According to the EU Commission, it is not prohibited, but there exist strong guidelines (Wind energy developments and Natura 2000, 2010)
	Nature Reserves	Naturreservat	Wind development should be avoided; a permit is only given if the natural value is compensated.	Wind development prohibited	
	Key biotope areas	Biotopskydds-område	Wind development should be avoided; a permit is only given if the natural value is compensated.	Wind development prohibited	
	Coastal protection	Strandskydds-område	Wind development prohibited 300 m from the coast	Wind development prohibited 100 m from the coast	
	Nature conservation areas	Riksintresse Naturvård	Wind development should be avoided; a special permit is required.	Wind development prohibited	
	Protected wetland	Myrskyddsplan			

	Water protection areas	Vattenskyddsområde			
Cultural constraints	Leisure and recreation areas	Riksintresse Friluftsliv	no explicit prohibition against wind power	no explicit prohibition against wind power	
	Cultural Heritage reserves	Kulturreservat	/	/	
	UNESCO World Heritage		/	/	According to UNESCO, it is not prohibited but needs a case-by-case analysis (UNESCO, 2024)
	Protected cultural sites and heritage buildings		200 - 500 meters from certain selected ancient monuments, 500 meters from larger cairns ('större rösen') and stone string systems, and 200 meters from specific smaller installations were excluded.	/	

2.3. Technological considerations

In Table 2, the technological trends for wind turbines have been summarised. Notably, the average total (tip) height of turbines is strongly increasing to a predicted 260 m by 2030. Also, the capacity per wind turbine is increasing. This means that for the same wind farm capacity, a lower number of turbines is required, and turbines should be further apart from one another.

Table 2: Common parameters of wind turbines in Sweden and their forecast (BayWa r.e., 2021)

	2010	2015	2020	2025	2030
Power [MW/turbine]	2.00	3.00	4.20	6.50	8.00
Capacity Factor	25%	26%	37%	40%	45%
Production [MWh/turbine]	4,380	6,833	13,613	22,776	31,536
Total height [m]	130	150	200	240	260
Tower height [m]	80	100	140	170	200
Swept Area [m²]	5,024	7,850	15,386	22,687	31,400

Moreover, the understanding of wake effects in the context of onshore wind turbines has undergone significant evolution over the past decade. The wake effect refers to the phenomenon where the wind flow is disturbed downstream of a turbine, impacting the performance of other turbines in its wake. This can have a significant impact on the overall wind park's performance and should be carefully considered from the layout design phase.

3. Constraint Mapping

The constraints used for the identification of potential wind development areas and their impact are summarised in Table 3. Some constraints are fully excluded, as no wind turbine can be built there, while others are considered disadvantages in site analysis but are not excluded. Some of the constraint layers underwent processing to create a buffer or for ease of use.

Table 3: List with constraints for Wind Development sites on Öland

	ENGLISH NAME	SWEDISH NAME	IMPACT	LAYER SOURCE
Technical constraints	Buildings with a 500/1000 m buffer		Excluded	(Lantmäteriet, 2023)
	Buffer of 125 m from roads		Excluded	(Lantmäteriet, 2023)
	Buffer of 100 m around high voltage lines (under 50 m)		Excluded	Own assumption
	Buffer of 500 m around airport		Excluded	Lansstyrelsen geodatakatalog
	Military areas		Excluded	Lansstyrelsen geodatakatalog
Nature constraints	National Parcs	Nationalpark	Not excluded, a permit might be difficult to obtain	INSPIRE
	Woodland key habitats		Not excluded, a permit might be difficult to obtain	INSPIRE
	Natural objects with 200 m buffer	Naturminne	Not excluded, a permit might be difficult to obtain	INSPIRE
	Animal and plants protection areas	Djur- och växtskyddsområde	Not excluded, a permit might be difficult to obtain	INSPIRE
	Natura 2000		Not excluded, a permit might be difficult to obtain	(eea.europe, 2022)
	Nature Reserves	Naturreservat	Not excluded, a permit might be difficult to obtain)	INSPIRE
	Key biotope areas	Biotopskyddsområde	Not excluded, a permit might be difficult to obtain	(European Commission, 2024)
	Coastal protection 100 m buffer	Strandskyddsområde	Not excluded, a permit might be difficult to obtain	(County Administrative Board of Kalmar)
	Nature conservation areas	Riksintresse Naturvård	Not excluded, a permit might be difficult to obtain	INSPIRE
	Protected wetland (RAMSAR)	Myrskyddsplan	Not excluded, but permit might be difficult to obtain	INSPIRE
	Water protection areas	Vattenskyddsområde	Not excluded, take special care during the construction phase	Lansstyrelsen
Cultural const	Leisure and recreation areas	Riksintresse Friluftsliv	Not excluded, take special care during the design phase	

	Cultural Heritage reserves	Kulturreservat	Excluded (no such areas on Öland)	INSPIRE
	UNESCO World Heritage		Special permit required	(UNESCO, n.d.)
	Cultural places of National interest	Riksinteresse Kulturvård	Not excluded, take special care during the design phase	Lansstyrelsen

3.1.1. Assumptions

Due to the high-level nature of this constraint mapping, certain assumptions and boundaries to the scope were made to limit the complexity of the task.

- It is assumed that there are no regulations on environmental protection (Naturvard) areas. However, this varies from area to area and will require further investigation in the following tasks.
- The orography is not yet taken into account. This is another technical constraint that should be considered when micro-siting wind farms on a project basis.
- The possible grid connections for each area have not been investigated. This generally represents an economical aspect rather than a technical constraint.
- To account for the impact of shadow flicker and noise, a conservative buffer of 500 m for the level 2 and level 3 priority areas and a buffer of 1000 m for the level 1 priority areas around all residences is taken into account.

3.1.2. Technical Constraints

Technical constraints in wind energy development refer to the factors related to the physical, engineering, and technological aspects of wind energy projects that can limit or affect their feasibility, design, and operation. These constraints include a buffer from residential housing and other buildings, a 125 m buffer from roads (Lantmäteriet, 2023), and a 100 m buffer from overhead high voltage cables (own assumption), and all military constraints (Boverket, 2009). A summary of these constraints can be found in Table 3.

All these areas are strictly excluded when analysing new wind development sites. Only one constraint is subject to discussion, which is the distance a turbine should keep from housing. In the previous wind development plan, this distance was defined as 500 m. This also follows the industrial standard and the guidelines followed in the previous wind development plan (Borgholms kommun och Mörbylånga kommun, 2011). Recently, a more conservative buffer of 1000 m has been used when planning turbines in Sweden. However, a buffer of 1000 m would significantly restrict the available sites on Öland. Therefore, a buffer of 500 meters will be used in this report, and in later stages, a noise and shadow analysis should be done to justify the distance. These noise and shadow flicker measures should at least follow the guidelines of the World Bank Group (World Bank Group, 2015).

The following maps show the technical restrictions on Öland, relevant for this report.

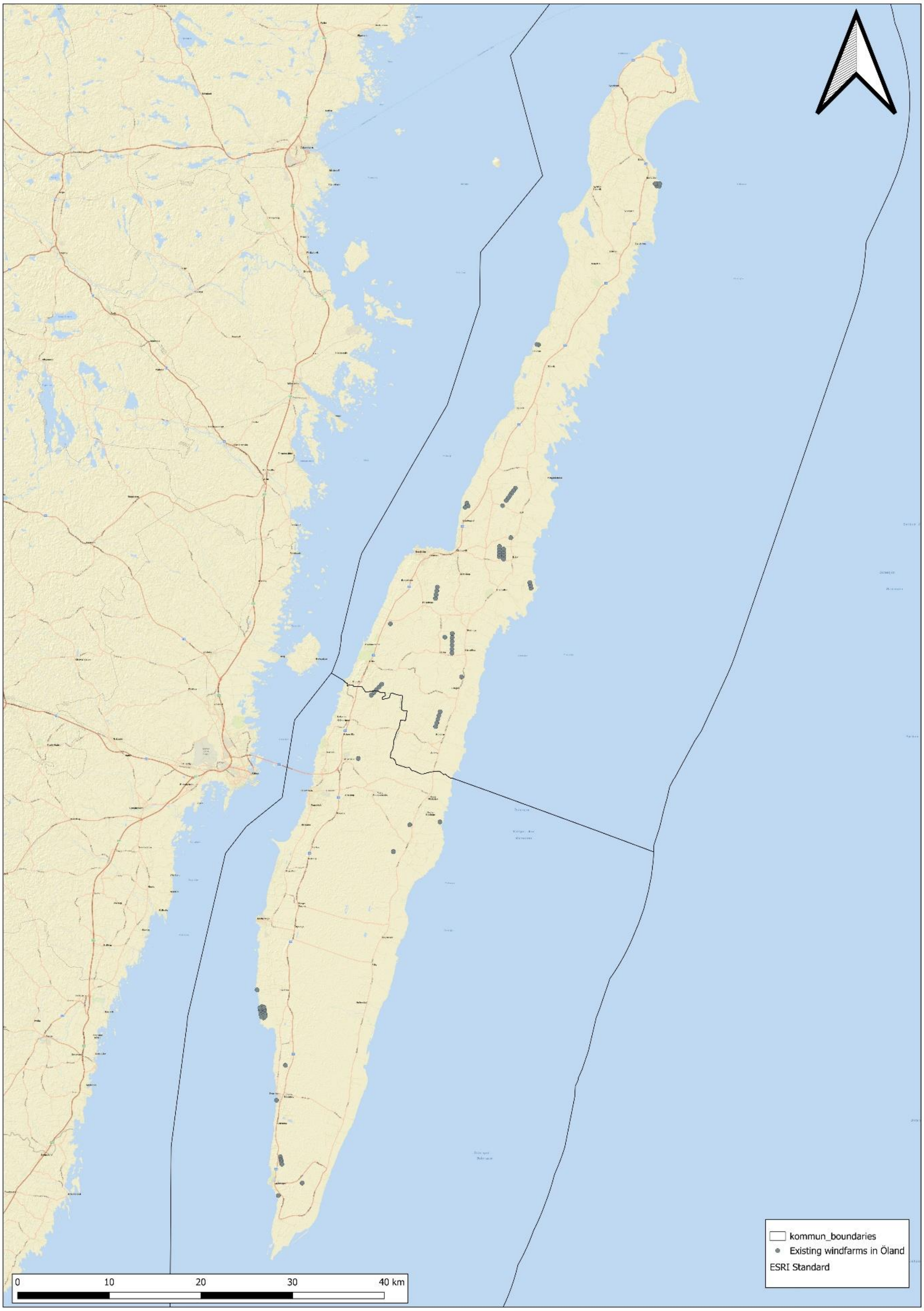

Figure 1: Map with the existing turbines on Öland (Lansstyrelsen, 2024).

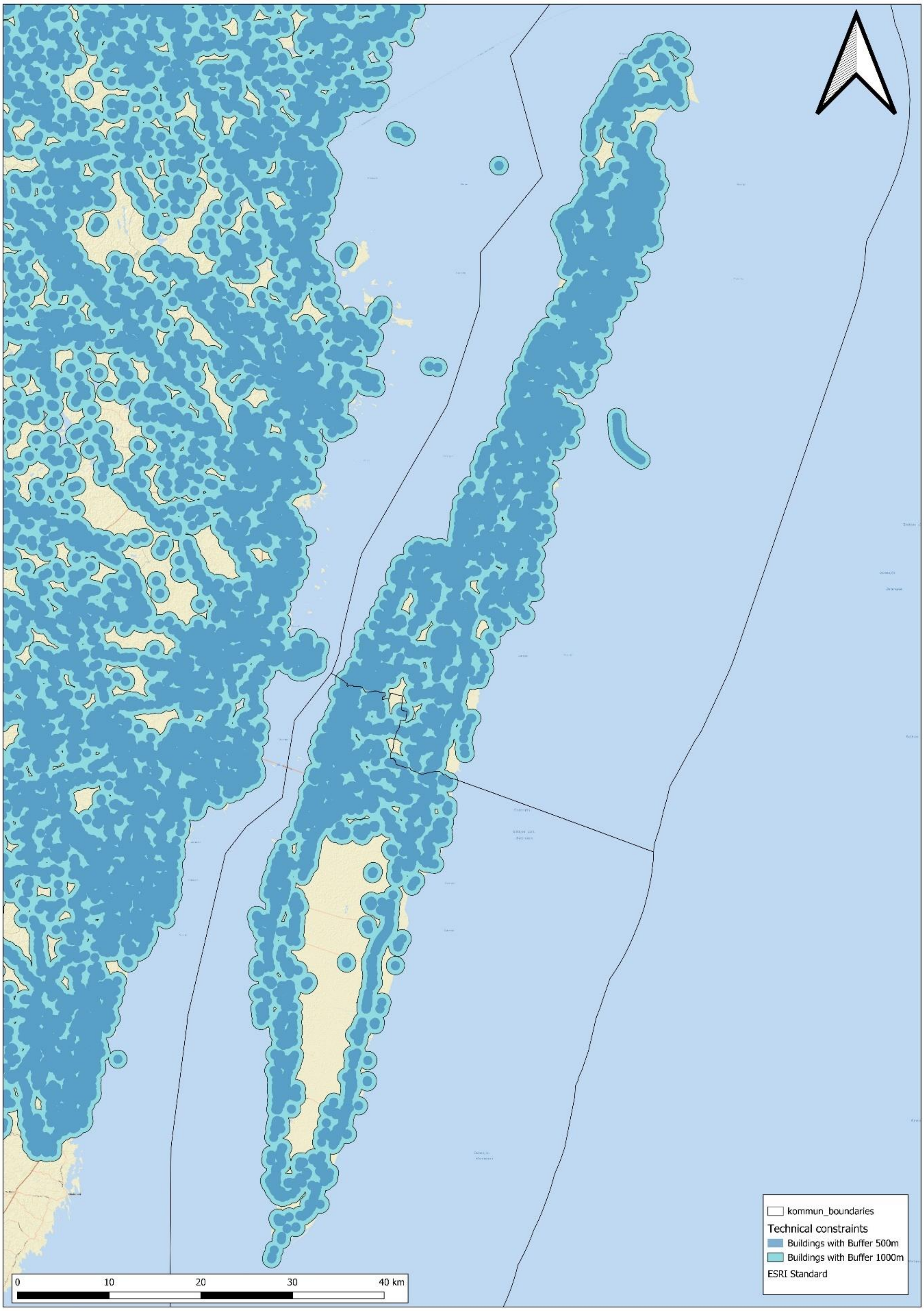

Figure 2: Map with buildings and a buffer of 500 meter and 1000 meter around them (Länsstyrelsen, n.d.).

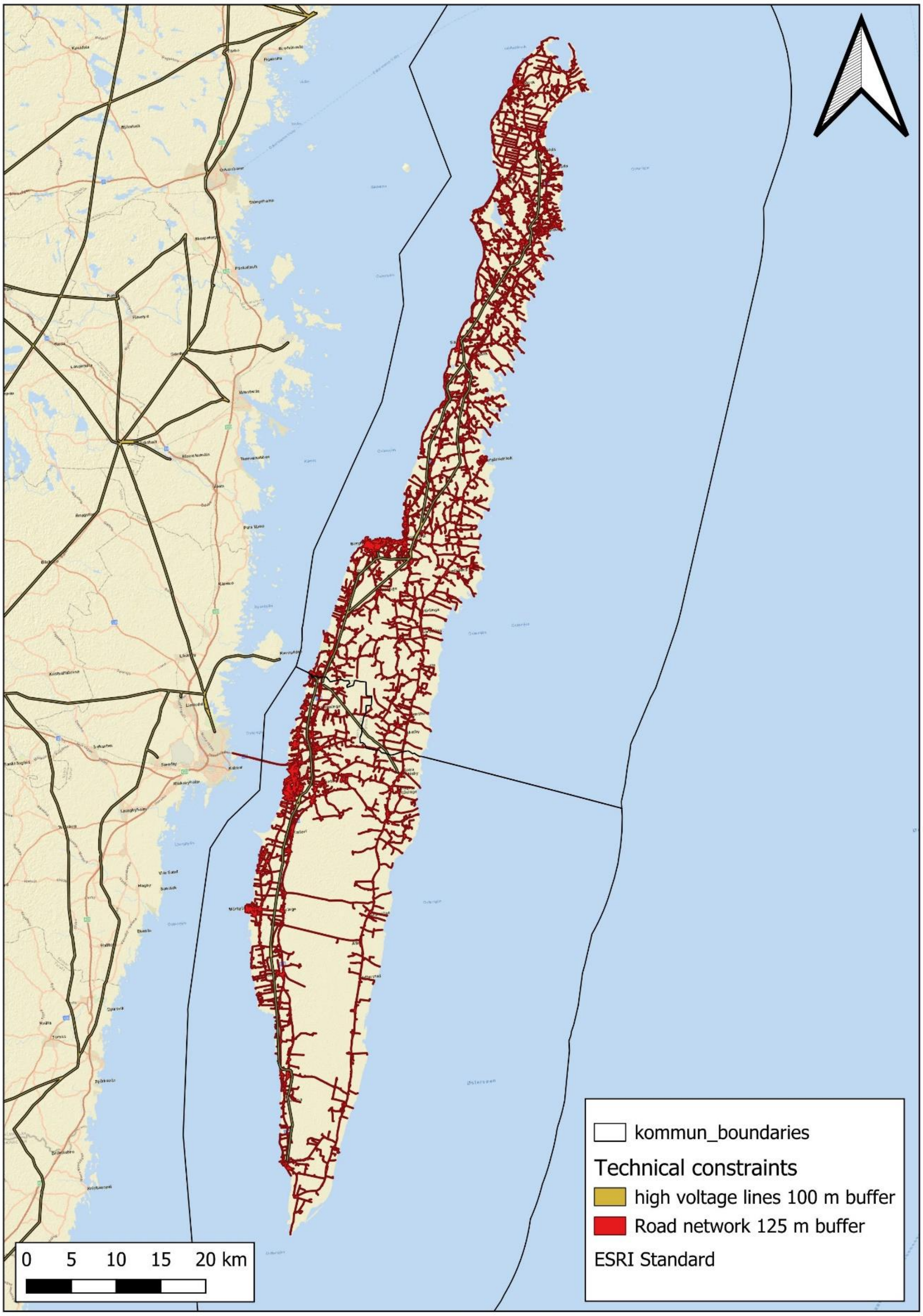

Figure 3: Map with the roads and high voltage lines on Öland (Lantmäteriet, 2023) (Länsstyrelsen, n.d.).

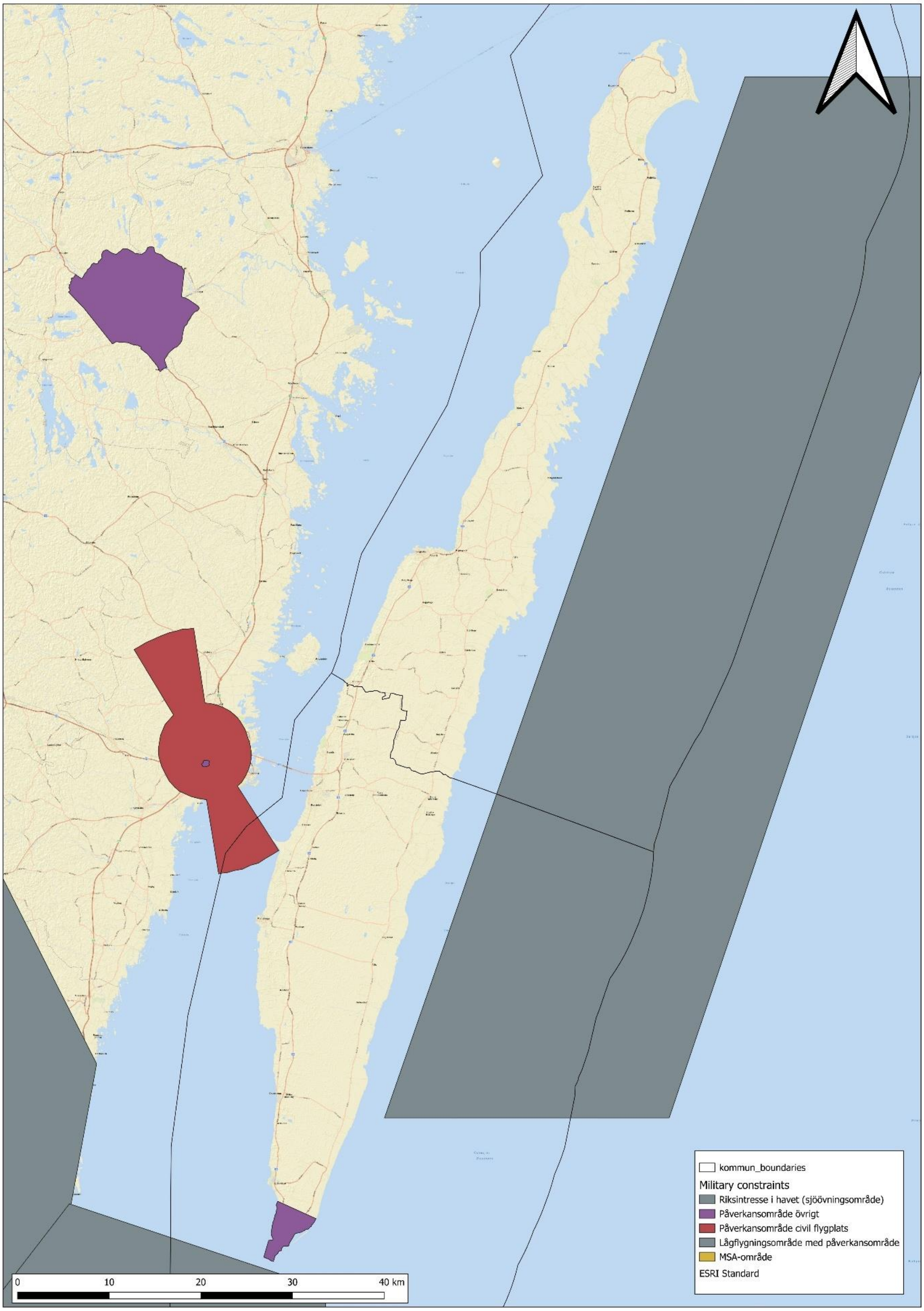

Figure 4: Map with the military constraints on Öland (Länsstyrelsen, n.d.).

3.1.3. Cultural Constraints

Cultural constraints refer to the social, historical, and community-related factors that can limit or influence the development of wind energy projects in a particular area. These constraints often relate to the preservation of cultural heritage, respect for local traditions, and the community's social acceptance of the project. For this preliminary site screening, the cultural constraints that will be taken into account are areas classified as leisure and recreational areas (riksinteresse Friluftsliv), UNESCO World Heritage sites, and registered protected sites. For two of these protected sites, the Karl X Gustavs wall and Borgholm Castle, a buffer of 500 m is also allocated. The other, smaller sites have a buffer of 200 m.

There is no specific permitting required for the development of wind turbines related directly to UNESCO World Heritage sites (UNESCO Svensa Unescoradet, 2012). However, any impact on a World Heritage site might directly affect the general permitting process. In certain cases in Sweden, permits for wind turbines have been refused due to the impact they would have on the UNESCO sites (energimyndigheten, 2024).

Other constraints include the cultural sites of national interest (riksinteresse Kulturmiljövård), but as these cover a large part of the island and were not taken into account in the previous wind development plan, they will not be taken into account during this initial screening. However, the effect of the turbines on these cultural interest areas should be considered in permitting. In accordance with the Environmental Code (Chapter 3.6), these areas of national interest are not the same as World Heritage sites, but they can sometimes overlap.

A summary of these constraints can be found in Table 3. The following map illustrates the cultural restrictions on Öland that are relevant to this report.

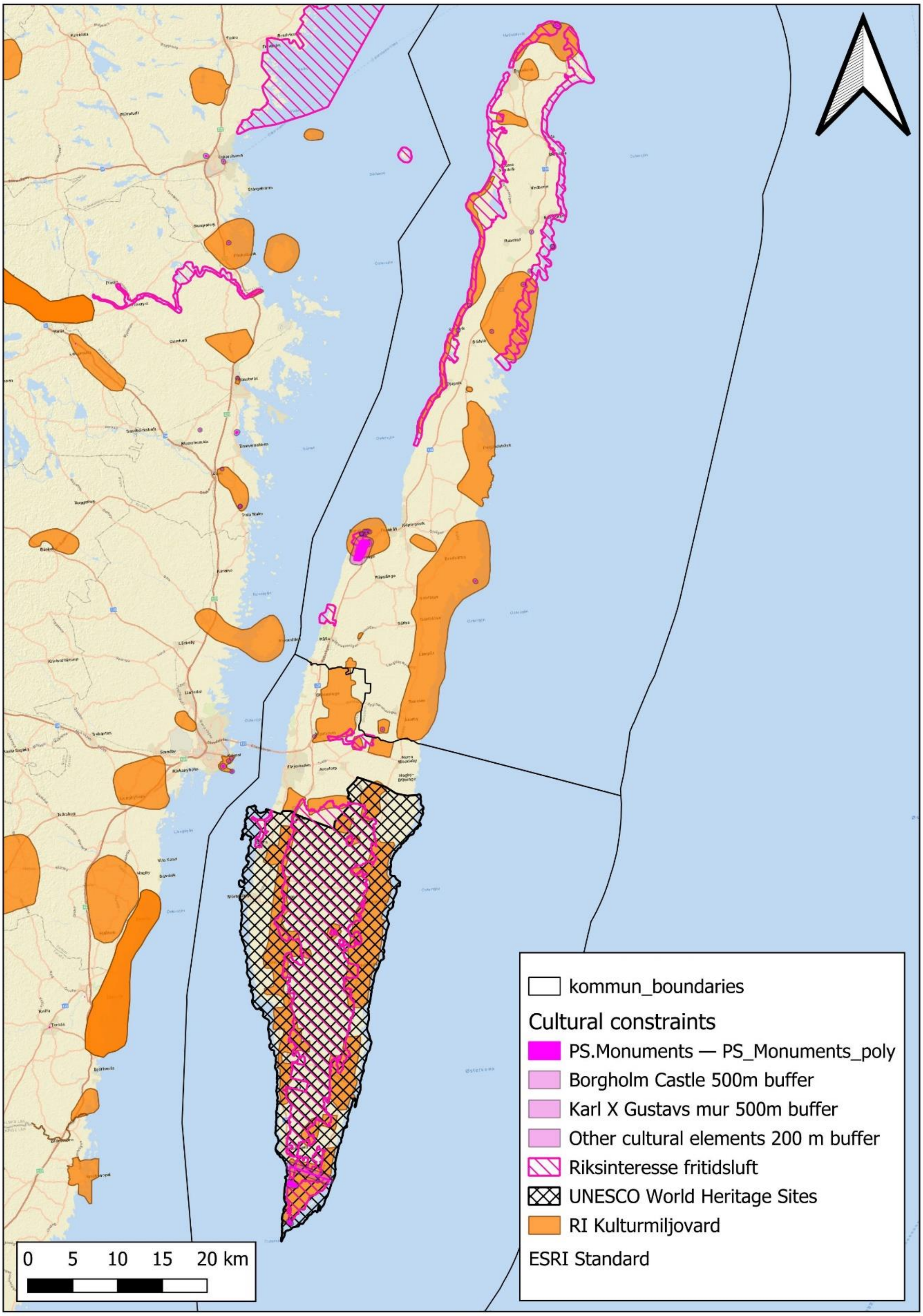

Figure 5: Map with cultural constraints on Öland (UNESCO, n.d.) (European Commission, 2024).

3.1.4. Nature Conservation Constraints

Environmental and natural restrictions are critical factors that must be considered when planning and developing wind energy projects. These restrictions can limit where and how wind farms can be developed to minimise negative impacts on the environment and ensure sustainable use of natural resources. Öland, in particular, has a strong interest in preserving the island's natural value – each year, thousands of tourists visit the island to experience its diverse nature, historical sites, beaches, and UNESCO-listed landscapes.

It should also be considered that:

- These restrictions might evolve and change over time.
- Wind turbines do not necessarily have a negative impact on the fauna and flora in their surroundings. Site studies should be conducted to assess the impact of the turbine.
- In some cases, it could be argued that the development of wind on a particular site is necessary despite it lying in a restricted area due to high resources in that area and limited other sites available.
- The County Administrative Board (Länsstyrelsen) examines permits under the Environmental Code that apply to the location on land when it concerns two or more wind turbines that are higher than 150 metres or seven or more turbines that are higher than 120 meters. If it concerns smaller or fewer wind turbines on land, it is the municipality who decides.

For these reasons, natural conservation constraints are dealt with in the following with a certain level of flexibility in order to support the analysis of different future scenarios.

Figure 6 and Figure 7 illustrate the Natura 2000 and nature conservation areas on Öland, respectively. Figure 8 gives an overview of the other nature-related restrictions. An overview of the constraints can be found in Table 3.

Figure 6: Map with Natura 2000 areas on Öland (eea.europe, 2022)

Figure 6 shows a map with the Natura 2000 protected areas. As illustrated, Natura 2000 encompasses a significant portion of the southern part of the island. A guideline (‘*Wind energy developments and Natura 2000*’) exists on how to best ensure that wind developments are compatible with the provisions of Natura 2000 (Directorate-General for Environment (European Commission), 2010). In this document, we can conclude that, although it is possible to build turbines in Natura 2000 areas, it is highly unlikely that projects will receive permits.

Figure 7: map with areas classified as national interest for natural conservation (Riksinteresse Naturvård)

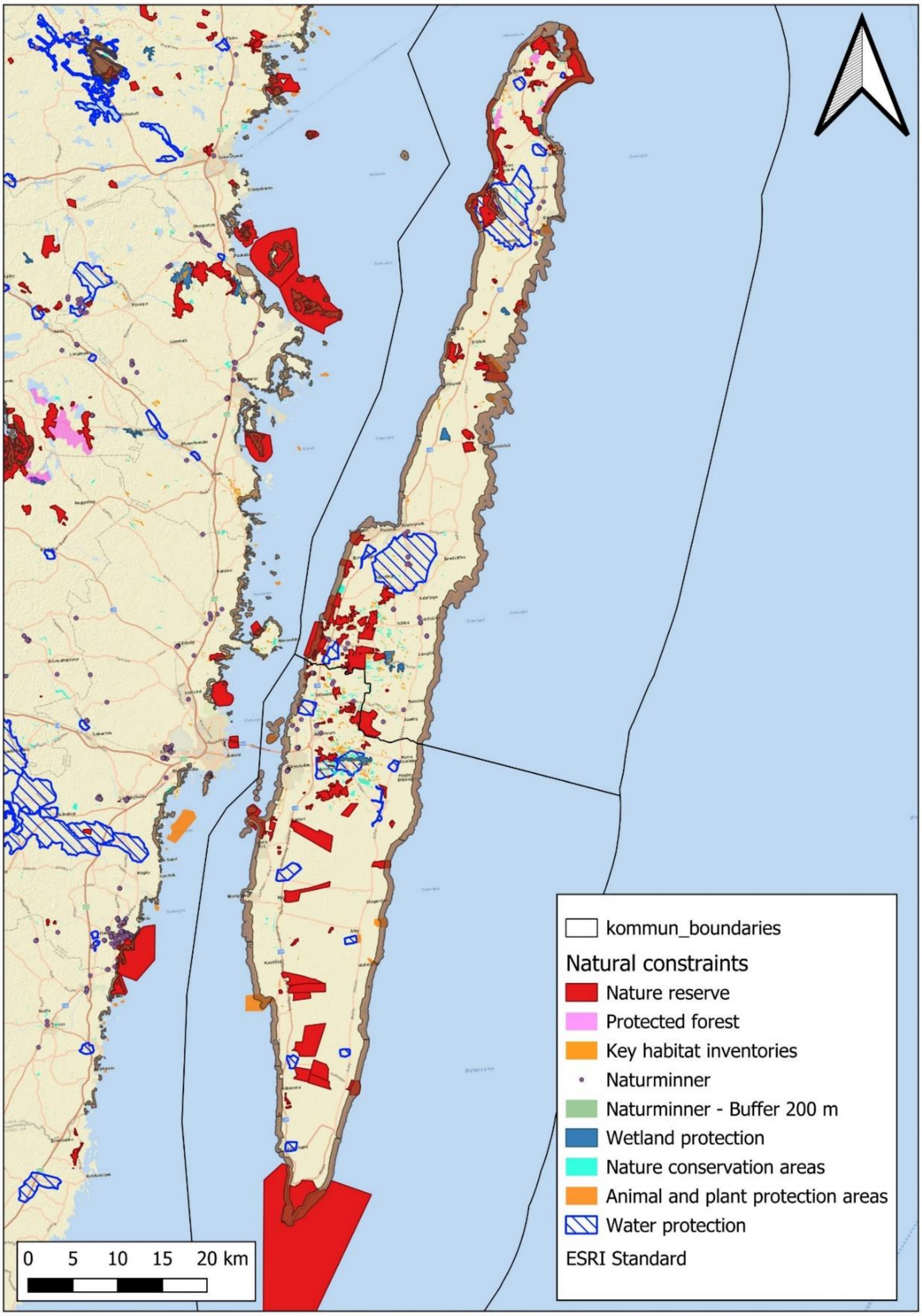

Figure 8: Map with an overview of all other areas with restrictions related to nature on Öland (European Commission, 2024)

3.1.5. Results of the constraint mapping

The results of the constraint mapping are split up into Priority areas, level 1 and level 2, and no priority areas, as illustrated in Figure 9. The level 1 priority areas are those located 1000 meters away from the closest buildings, with no technical constraints, and do not fall within a Natura 2000 or Naturvård area. The level 2 priority areas have a buffer of only 500 meters around buildings and do not fall within a Natura 2000 or Naturvård area. The no-priority zones can either have Natura 2000 or Naturvård restrictions.

Figure 10 and Figure 11 show the detailed versions of the map, focusing on the two municipalities separately.

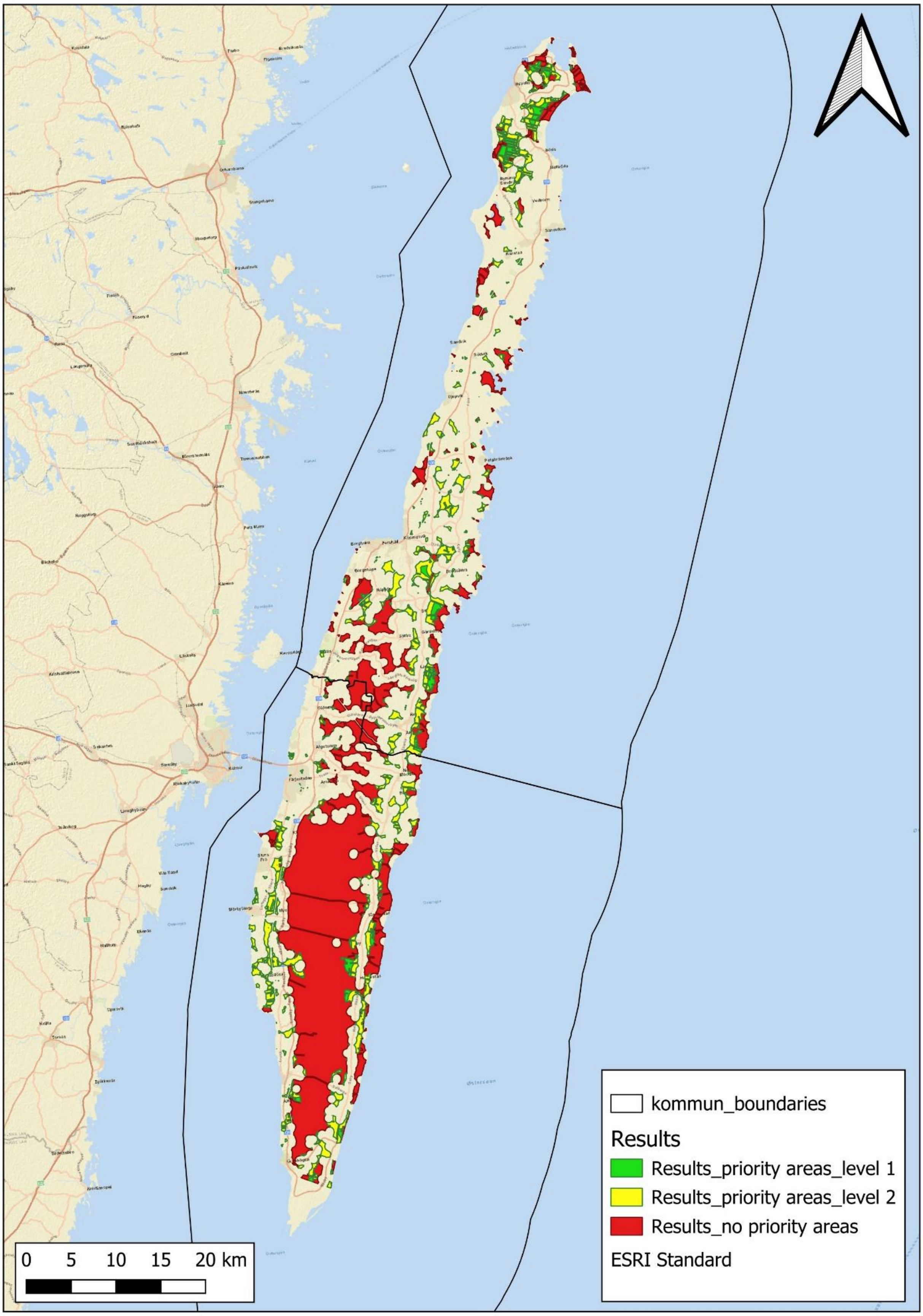

Figure 9: Results of the constraint mapping of Öland

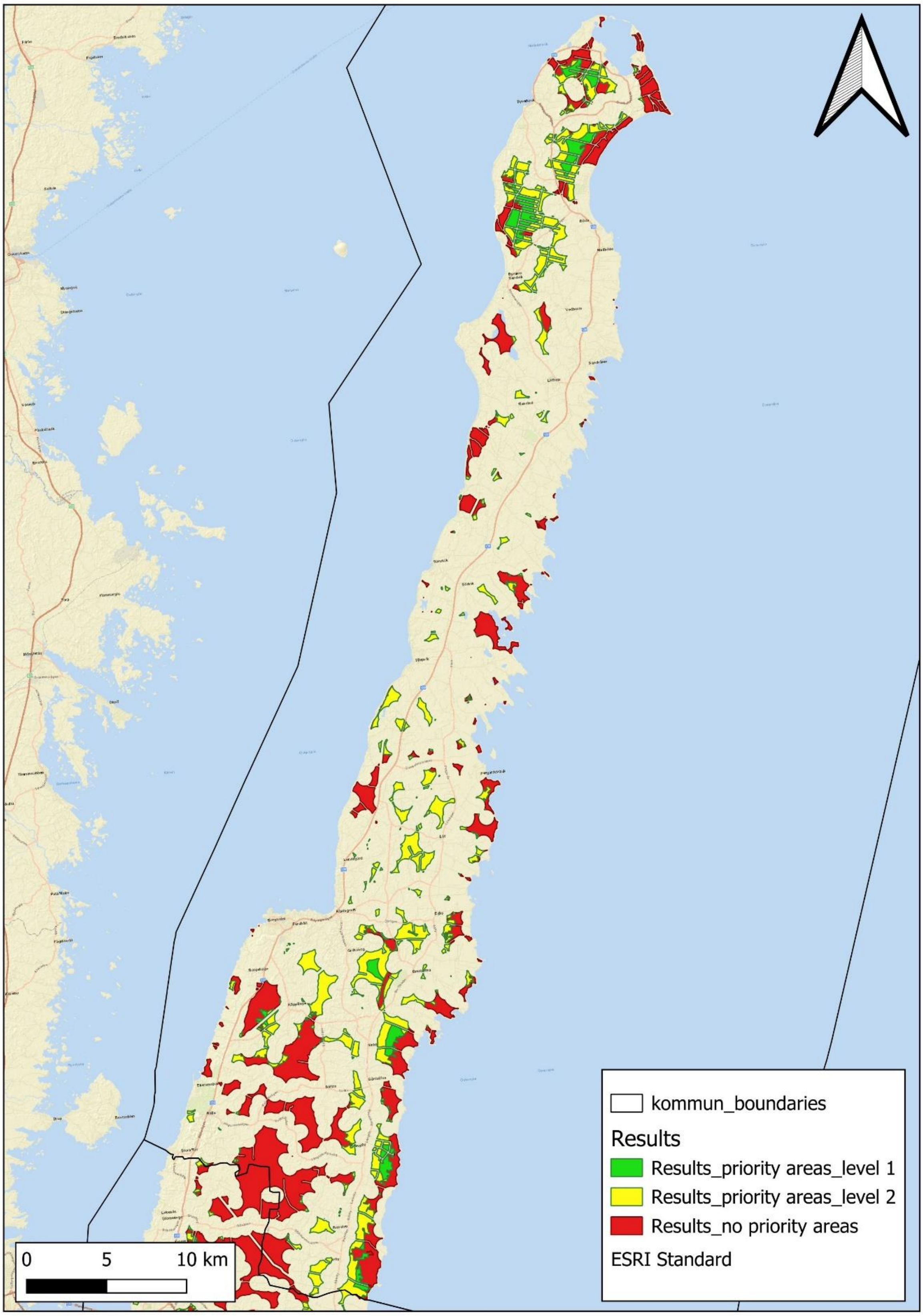

Figure 10: Overview of the potential wind development areas, split into categories of prioritization, Borgholm municipality

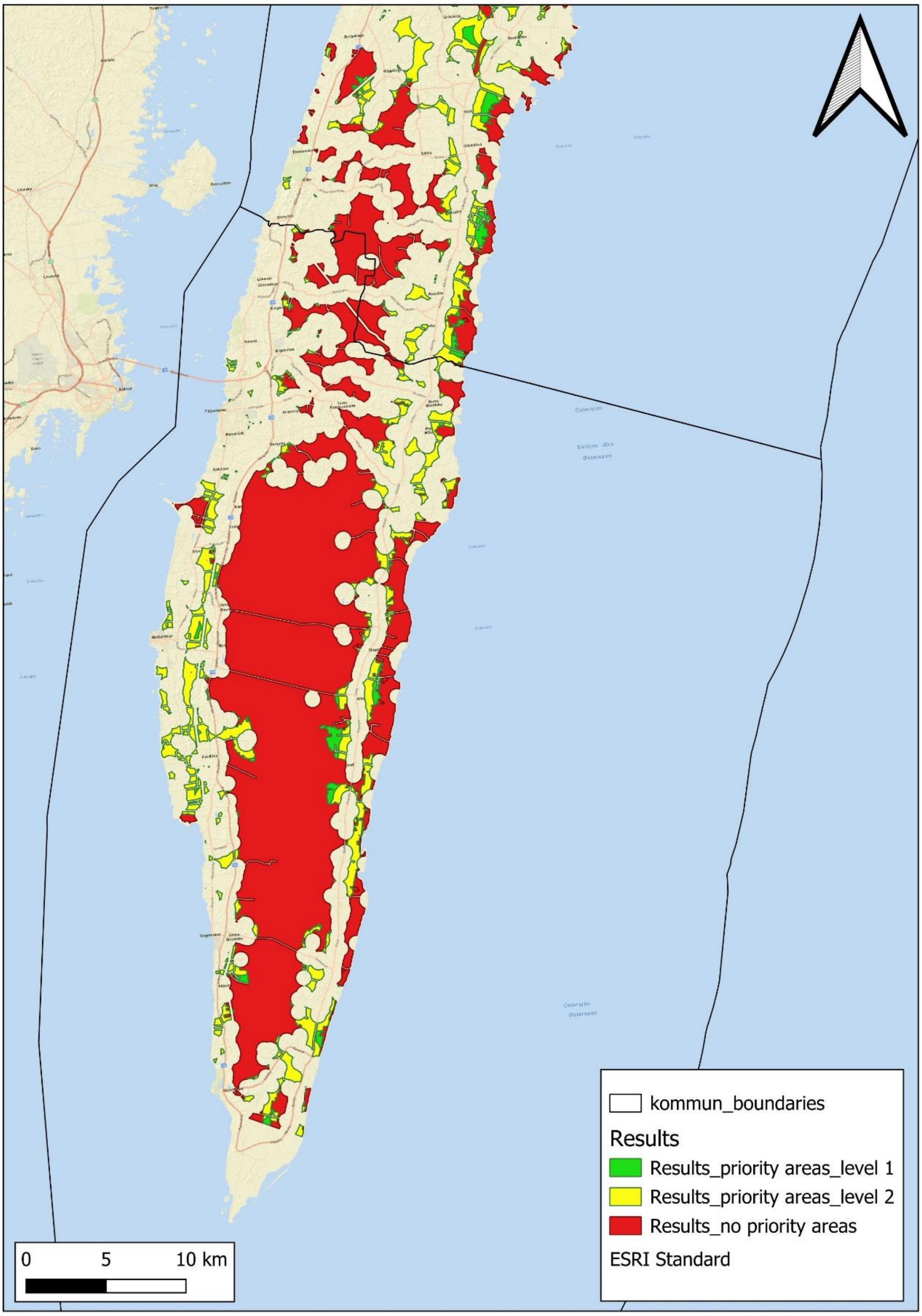

Figure 11: Overview of the potential wind development areas, split into categories of prioritisation, Mörby municipality

3.1.6. Comparing the results with the old development plans

When comparing these results with the old development plans, it is essential to note that the powered turbines are viewed as a constraint during the mapping process. Thus, most areas don't overlap because they already host wind turbines. Figures 12 and 13 present, for

Borgholm and Mörbylånga, respectively, a comparison between the wind development areas identified in the old Wind Development Plan and in this report.

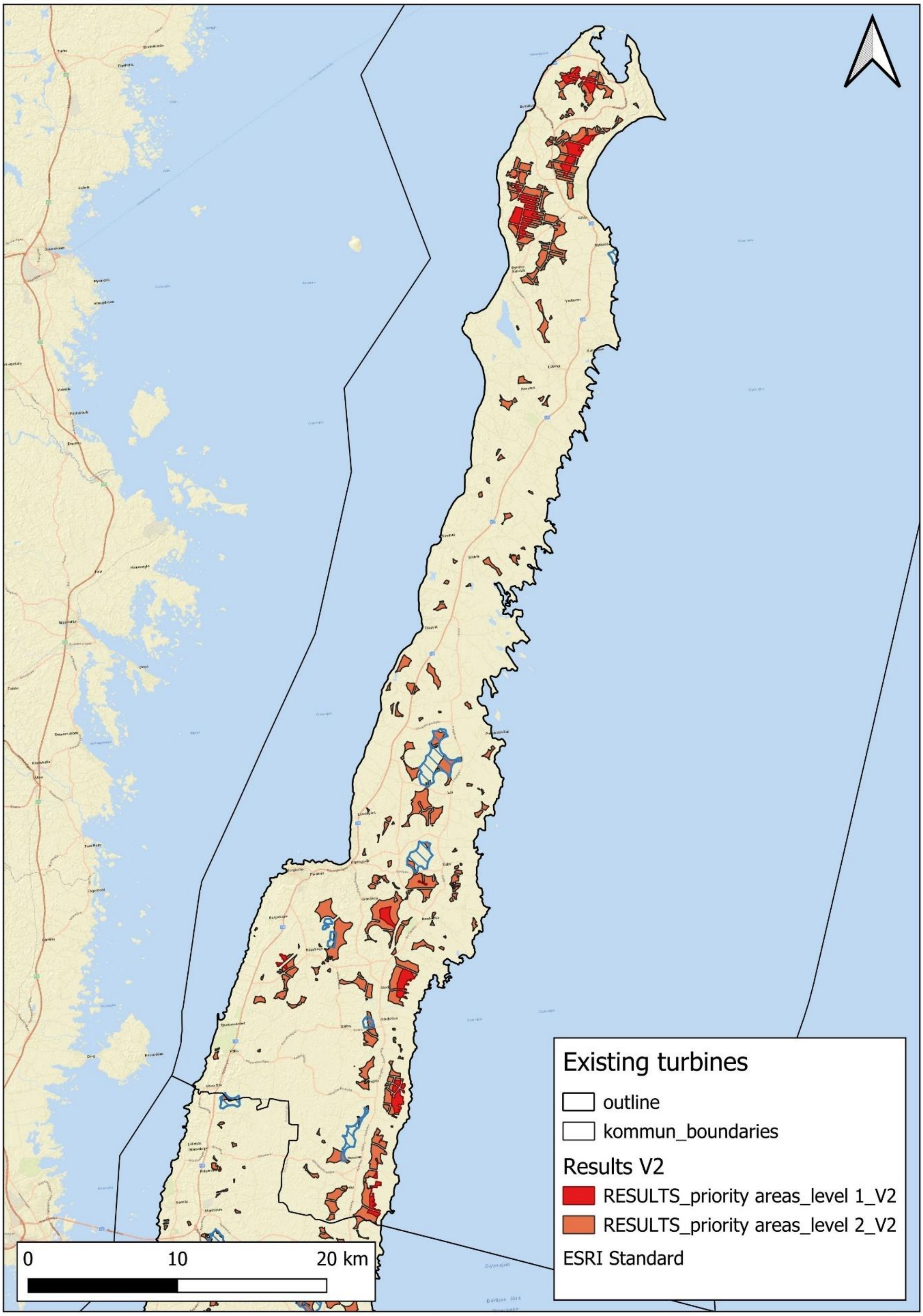

Figure 12: Borgholm municipality map with the old and new wind development areas

Figure 13: Mörbylånga municipality with old and new wind development areas

4. High-level Wind Resource Assessment

In the existing Vindkraftsplan, the resource assessment is based on maps from the Meteorological Institute at Uppsala University (MIUU) model from 2011 (Uppsala University). However, nowadays, more accurate, high-level maps of wind resources are available.
To prioritize the available areas for wind power generation, the New European Wind Atlas (NEWA) was used in this report to find the mean power density in these areas. Mean wind power density (P_m) is a measure of the average wind energy available per unit area over a period, calculated using the formula:

$$P_m = \frac{1}{2} * \rho * v^{3}$$

This formula indicates that the mean power density is dependent on air density (ρ) and the cube of the mean wind speed (v). Since power density increases with the cube of wind speed, even small increases in wind speed can significantly boost the available energy.

When prioritising areas for wind turbine development, mean power density is crucial because it indicates the potential energy yield from the wind. A higher mean power density indicates that more wind energy is available, resulting in increased potential efficiency and energy output from turbines installed in those areas. Therefore, regions with higher mean wind power density are more attractive for wind energy projects, as they promise greater returns on investment.

NEWA utilises the ERA5 dataset, which it downscales using WAsP to create a map with a 50-m grid. The heights available for viewing wind power density are 50, 100, 150, and 200 m.
For the high-level selection of the new wind development sites, the use of NEWA is proficient. However, when moving forward to the design of each site, other models which allow for consideration of local effects must be used.

From this data, the mean wind power density was calculated for each site on the priority and second-priority lists. The results are presented in Figures 15 and 16 for the municipalities of Borgholm and Mörbylånga, respectively.

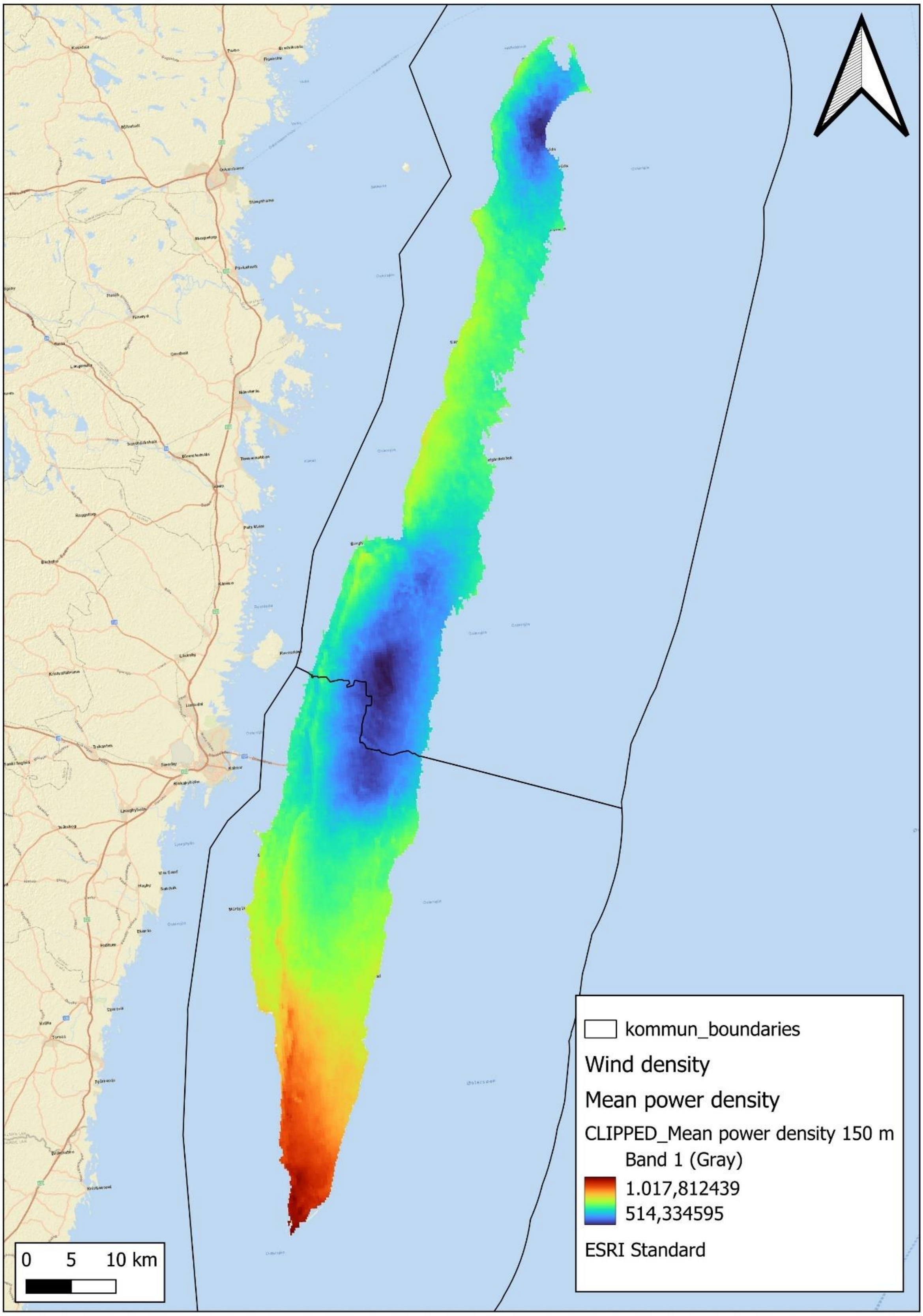

Figure 14: Wind power density of Öland from The New European Wind Atlas

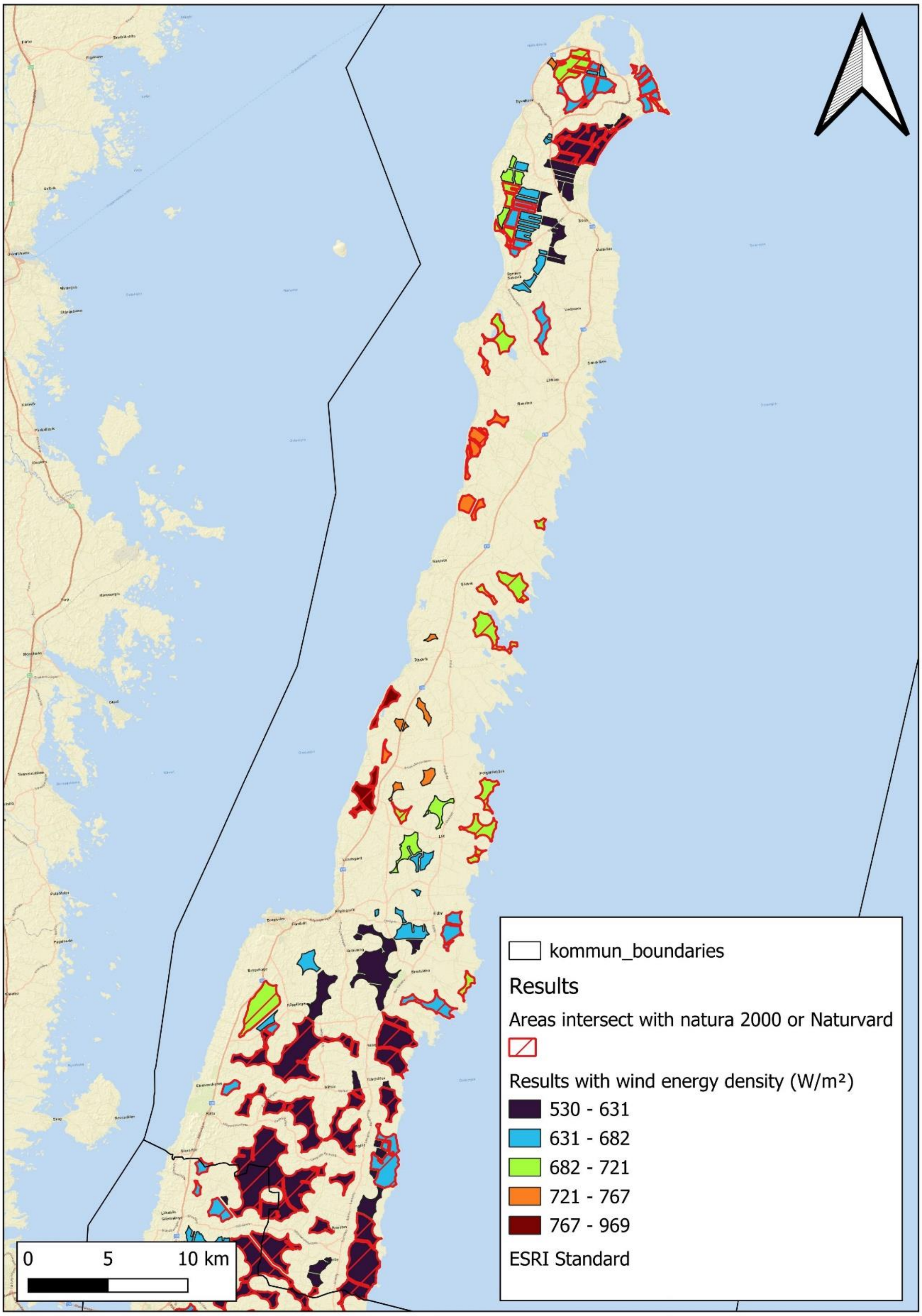

Figure 15: The potential wind development sites and their mean wind power density in the municipality of Borgholm

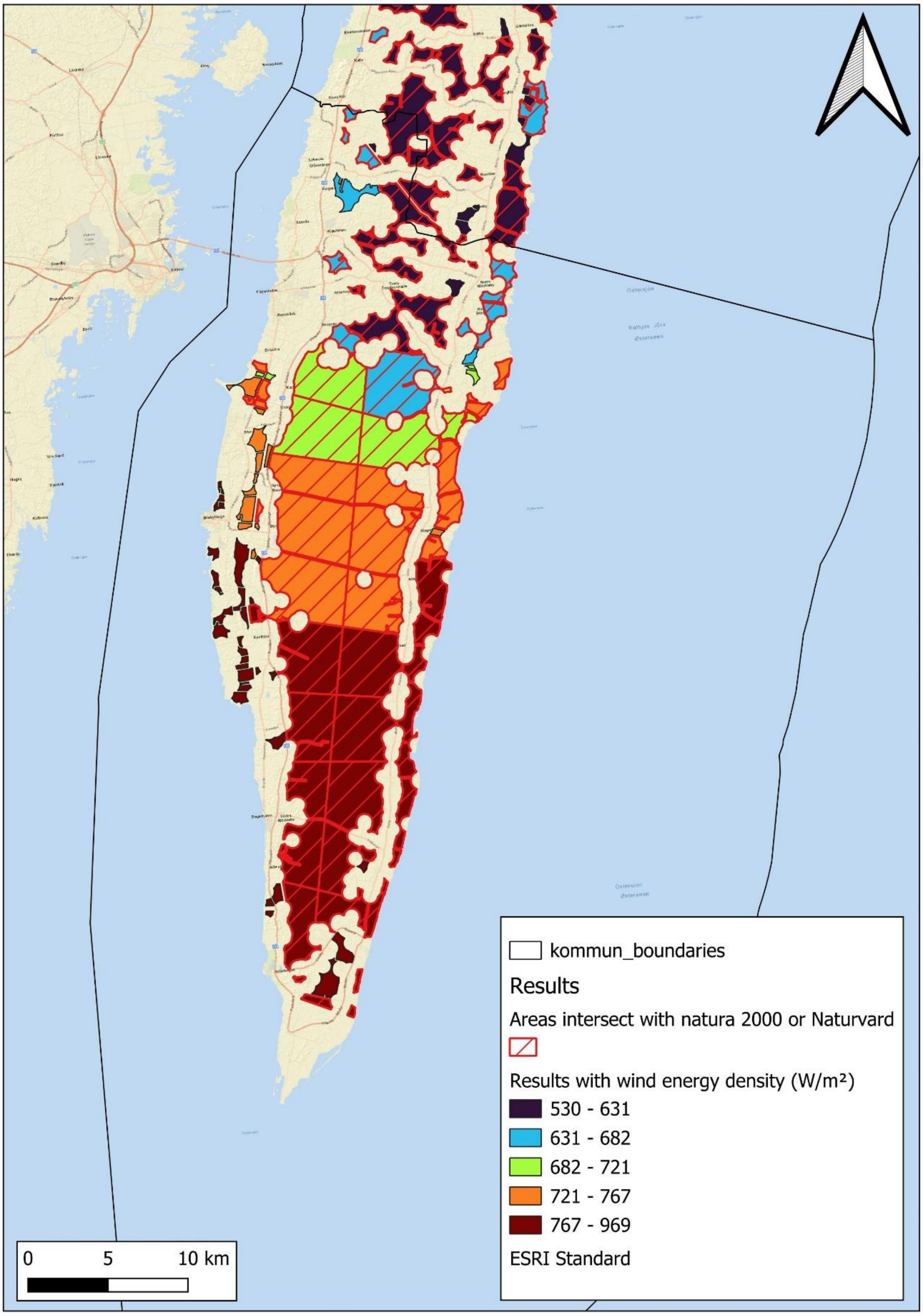

Figure 16: The potential wind development sites and their mean wind power density in the municipality of Mörbylånga

5. Wind Potential

In the previous chapter, the potential areas for wind power development were explored. These areas were divided into different priority levels based on the nature of the restrictions and the proximity of residences. This chapter will explore the yield potential of these areas. It is structured as follows. First, the technological assumptions underlying this analysis are discussed. With this information, a map is created showing the theoretical annual yield of Öland. Afterwards, the potential turbine locations are investigated, and the total annual yield for each scenario is calculated. Lastly, the repowering potential is analysed.

5.1. Technological Assumptions

5.1.1. Terrain limitations

Terrain limitations were not taken into account during the previous chapter's constraint mapping. However, any terrain with a slope higher than 10° should be classified as a no-go zone, and a 50-meter buffer zone should also be considered.

Öland has very flat terrain, with a max height of 51 meters above sea level. The affected areas lie mostly around the main road connecting the northern tip of the island with the south and around Borgholm Castle. The areas identified for wind power development, as outlined in the previous report, remain largely unexplored. Figure 17 shows an example of an area where the no-priority level's results consist of a slope above 10°.

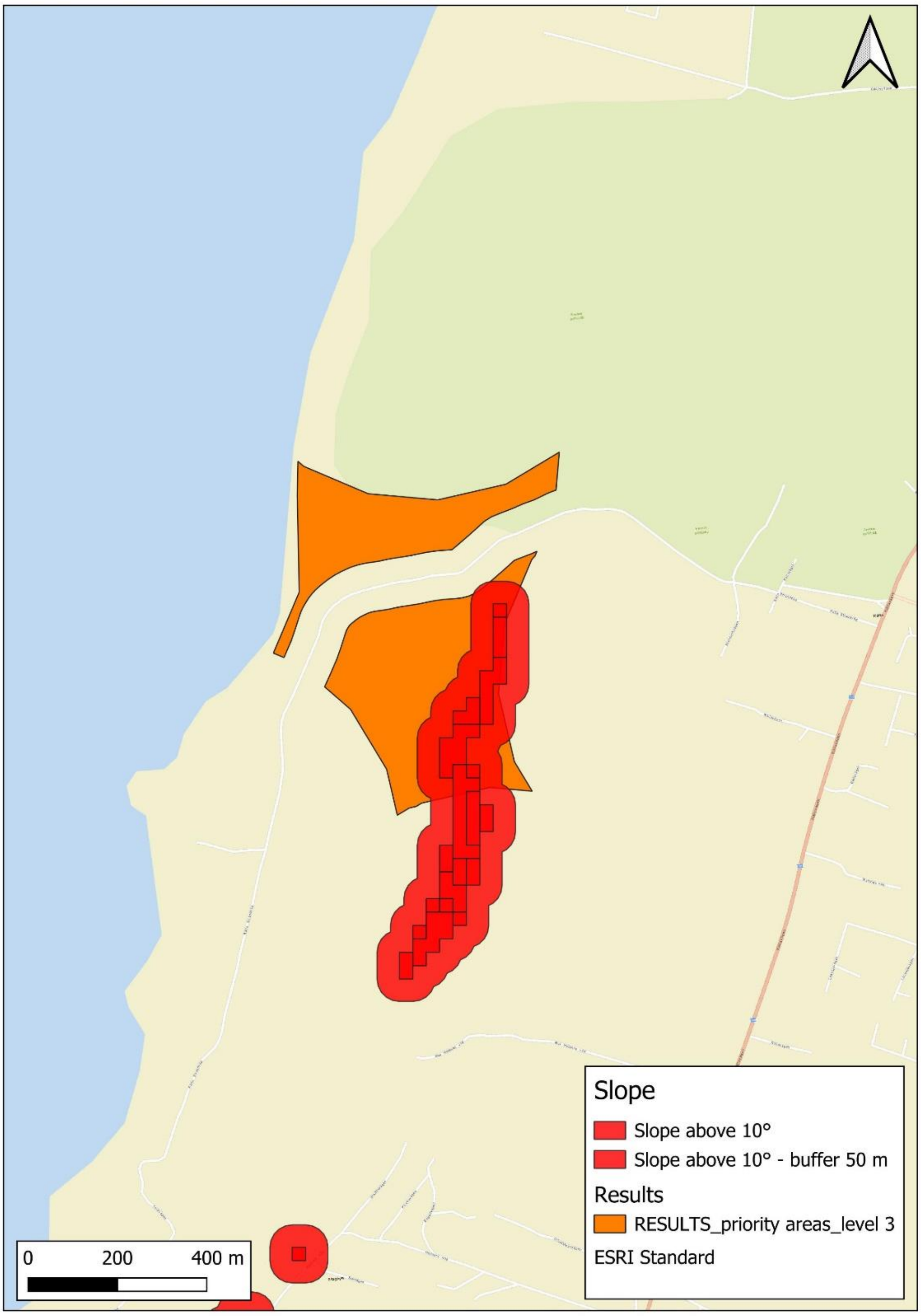

Figure 17: Example of Terrain steepness on Öland and its impact on some areas

5.1.2. Turbine model

A choice of turbine had to be made to determine the minimum distance between turbines when calculating the yield capacity of Öland. Currently, the largest turbine installed on the island has a hub height of only 105 meters and a capacity of 2 MW. Compared to the optimal capacity being installed in mainland Europe, which is around 7 MW, this is relatively small.

For the yield calculations, the Enercon E-138 EP3 E3 4260 model was chosen, which has an installed capacity of 4.26 MW and a hub height of 99 meters. This turbine model was chosen using the following reasoning:

- The recent trends in turbine technology have been to install larger turbines with higher installed capacity. This higher capacity results in better exploitation of the available land and more concentrated/reduced social impact as fewer turbines need to be placed for the same yield.
- As Öland is a popular tourist destination for nature, it's necessary to limit the visual impact of the turbines. Therefore, a turbine with a hub height smaller than the turbine with the tallest hub height operating on Öland has been chosen.

That being said, choosing a larger turbine should not be excluded in the later stages of wind development. A trade-off should be made between fewer larger turbines and more numerous smaller ones. Landscape modification needs to be studied on a case basis and is normally a key part of the Environmental Impact Assessment to be conducted on larger projects.

5.1.3. Losses

Table 4 provides an overview of the losses considered during the yield calculations. They were determined based on expert knowledge within 3E. An explanation of these losses is given below.

Table 4: Losses used for the yield calculations

Loss type	Amount
Unavailability	3%
Performance	1%
Electrical losses	1.5%
Degradation losses	1%
Icing losses	3%
Environmental curtailment losses	1%
Wake losses	5%
Total	**14.5%**

5.1.3.1. Unavailability losses

Unavailability losses are due to downtime of the wind turbines or balance of the plant (maintenance or technical incidents) as well as downtime of the power grid as follows:

- 3E typically evaluates losses due to maintenance and technical incidents on the turbines as 3.0 % of the energy production. This is considered an industry standard, but a conservative estimate based on availability guarantees, typically around 97% in operation and maintenance (O&M) contracts.
- Losses due to maintenance and technical incidents on the Balance of Plant (BoP) are typically evaluated by 3E as 0.2 % of the energy production.
- Grid unavailability loss is assumed to be 1% for this project. This value, which is relatively high compared to standard industry practice, has been assumed in consideration of the additional difficulties in managing and operating insular power systems. It should be noted that the selected value is not the result of a detailed study, and an update might be needed in a later phase of the project.

5.1.3.2. Performance losses

Turbine performance losses are typically due to high wind hysteresis, yaw misalignment, wind flow inclination, turbulence, wind shear and other differences between turbine power curve test conditions and actual conditions at the project site.

Generic power curve losses correspond to expected differences between the effective performance of wind turbines and the manufacturer's power curve in the guaranteed operational envelope. This loss factor is calculated based on the difference between the manufacturer's power curve and a reconstructed power curve in reference climate conditions. The methodology is based on the IEC 61400-12-1 standard for assessing the performance of operational wind turbines and was validated on multiple operational plants. They are estimated to range between 0.0% and 0.2%, depending on the configuration and scenario.

Site-specific performance losses are due to deviations between the power curve operational envelope and the actual wind conditions at the site. The loss factor is calculated based on the actual shear, turbulence, and veer conditions at the site and their deviations from the operational boundaries of the power curve, as recommended by IEC 61400-12-1 for normalising power curves to account for the effect of turbulence and for calculating the rotor-equivalent wind speed (REWS). They are estimated to range between 0.3% and 0.4%, depending on the configuration and scenario.

Suboptimal performance losses correspond to any further deviation in wind turbine performance due to limitations in the wind turbine control system, such as automatic unwind losses, dynamic yaw misalignment, etc. These losses are considered equal to 0.25% regardless of the simplicity of the site. This loss is based on the analysis of operational data from a large number of wind farms.

High wind hysteresis losses are considered to be negligible for this project for two reasons: firstly, because the Vestas turbines are equipped with a control mechanism that does not stop the turbine but gradually reduces the output of the turbine, and secondly because the wind distribution at the site is such that this type of event is not likely to occur very often.

5.1.3.3. Electrical losses

Electrical losses occur in cables and transformers ensuring electrical transmission to the wind farm substation. 3E typically evaluates them as 1.5 % of the energy production for a wind turbine of this size, although this also depends on the wind farm layout. This value is based on the analysis of data from an extensive portfolio of operational wind farms.

5.1.3.4. Environmental losses

Environmental losses contribute to the performance degradation of wind turbines due to adverse environmental conditions. Aerodynamic performance degradation of turbine blades due to dirt accretion (excluding icing) is estimated at 0.95 % for this study. At this stage, 3E does not consider any loss due to potential turbine shutdowns caused by lightning or hail. If specific shutdown rules are enforced, their impact on production should be evaluated separately. No losses due to high temperature are estimated.

5.1.3.5. Curtailment losses

These losses are due to modifications of wind turbine operation for technical or environmental reasons (e.g., related to noise or shadow flicker constraints, bird or bat preservation, etc.). With the information available at this stage and considering the restrictive constraints identified in the available areas within the starting land plots, no curtailment was taken into account.

5.1.3.1. Icing losses

Considering the location of the turbines, turbine shutdowns and aerodynamic performance degradation due to icing conditions are estimated at 3%.

5.1.3.1. Wake losses (Turbine interaction losses)

Turbine interaction losses are due to the mutual influence of the wind turbines downstream as well as upstream. The kinetic energy extraction resulting in losses downstream of the turbines is calculated using the N.O. Jensen (PARK2): 2018 wake model. The induction zone leading to a blockage loss upstream of the turbines is estimated with the Forsting self-similarity model.

5.2. New Wind Farms Yield Calculation

In these calculations, the existing turbines are taken into account, and their locations, as well as a buffer zone around them, have not been considered in the estimated yield calculations. This thus means that the repowering of existing turbines can be added to the powering of new wind farms.

With the use of the Global Wind Atlas, the average annual yield of an E-138 EP3 E3 4260 turbine was calculated at each location on Öland. This resulted in the map visualised in Figure 18. This estimated net annual yield takes into account the losses discussed in the previous chapter.

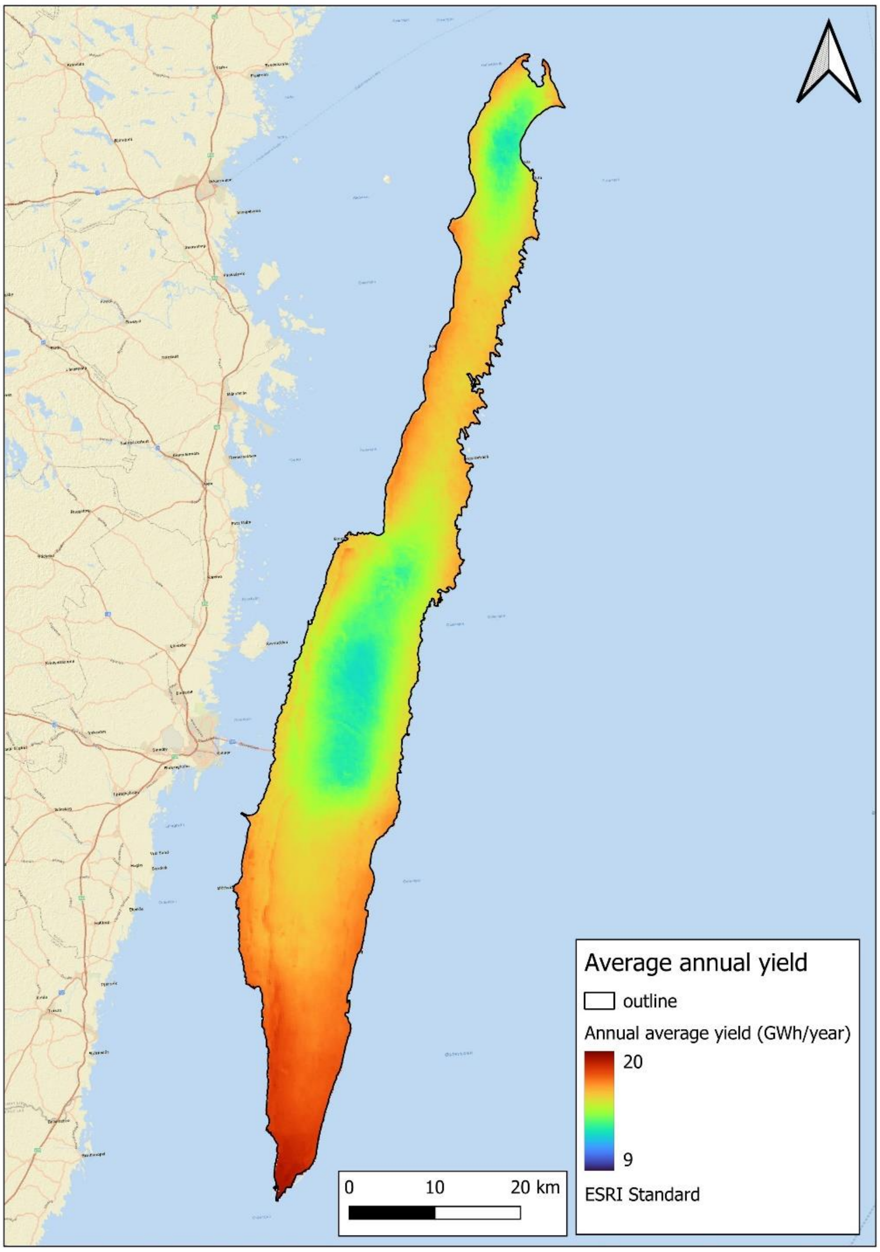

Figure 18: Annual average yield of a E-138 EP3 E3 4260 turbine on Öland.

The yield of the turbines in the new development areas on Öland ranges from 12 to 20 GWh/year. The lower limit is primarily found in the northern tip and the centre part of the island, while the greater limits are found in the southern tip.

5.2.1. Wind turbine placement

Based on the areas identified for wind power development through constraint mapping, potential turbine placements were determined. The resulting areas are categorised by priority levels, where Level 1 represents zones with the fewest constraints and Level 3 the ones with the most constraints. Importantly, Priority Level 2 also includes Level 1 areas, and Priority Level 3 encompasses Level 2 as well.

The placement accounts for optimal inter-turbine spacing—five times the rotor diameter in the primary wind direction (690 m) and three times the rotor diameter in the perpendicular direction (414 m). This spacing will result in minimal wake losses for maximum turbine density. Turbines with a yield of less than 14 GWh/yr are removed from the analysis. An example of how the turbines were placed within the development areas is illustrated in Figure 19. Figures 20, 21, and 22 show the potential placements of turbines in Priority Levels 1, 2, and 3, respectively.

The results of these placements are as follows:

- Priority Level 1: 53 turbines can be placed in the available areas. This yields a total annual production of 847.06 GWh, or an average production of 15.98 GWh per turbine per year.
- Priority Level 1: 352 turbines can be placed in the available areas. This yields a total annual production of 5,632.46 GWh, or an average of 16.00 GWh per turbine per year.
- Priority Level 3: 1303 turbines can be placed in the available area. This yields a total annual production of 21,217.56 GWh, or an average of 16.28 GWh per turbine per year.

A significant number of turbines are located in areas with lower average yields. Figure 23 highlights the best-performing turbines for each priority level, showcasing the top 30 turbines in each category. From this analysis, it's clear that optimal turbine placement is in the southern part of the island. These 'Best 30' turbines can be used to determine the locations which should receive priority treatment.

It is essential to note that these locations are used solely to illustrate the potential yield and require further investigation before turbines can be installed here.

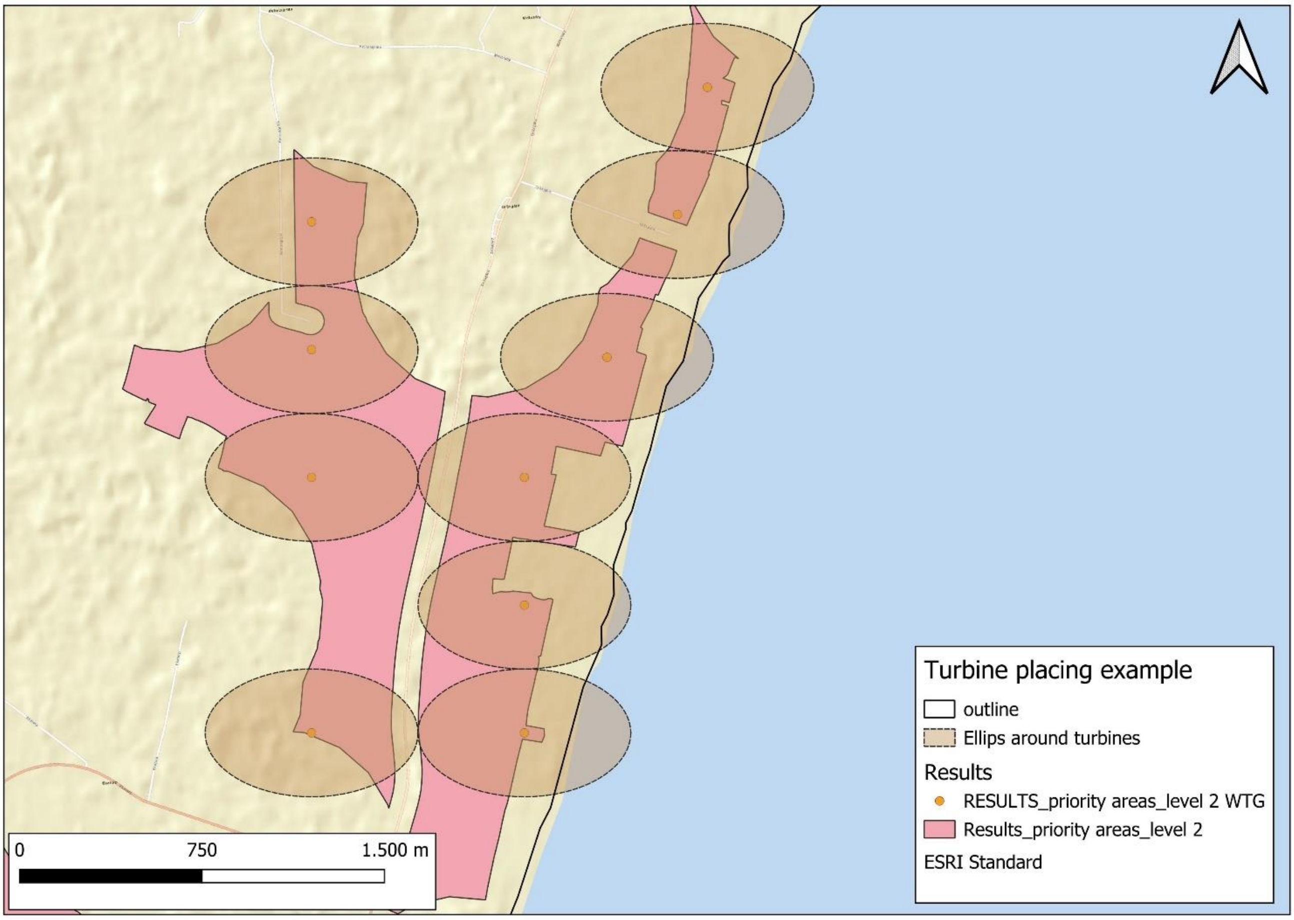

Figure 19: turbine placement example

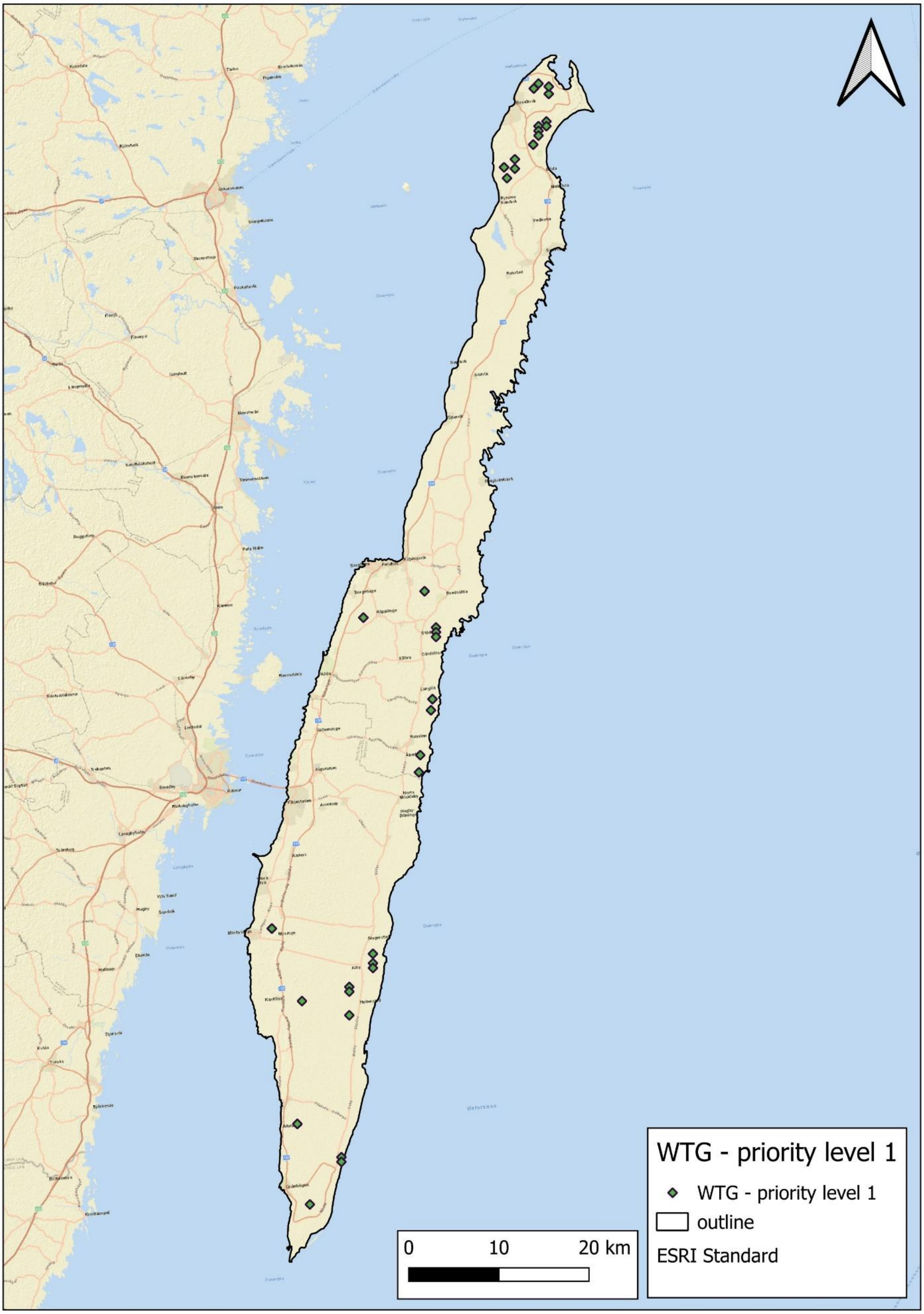

Figure 20: Potential placement of E-138 EP3 E3 4260 turbines on Öland, priority level 1

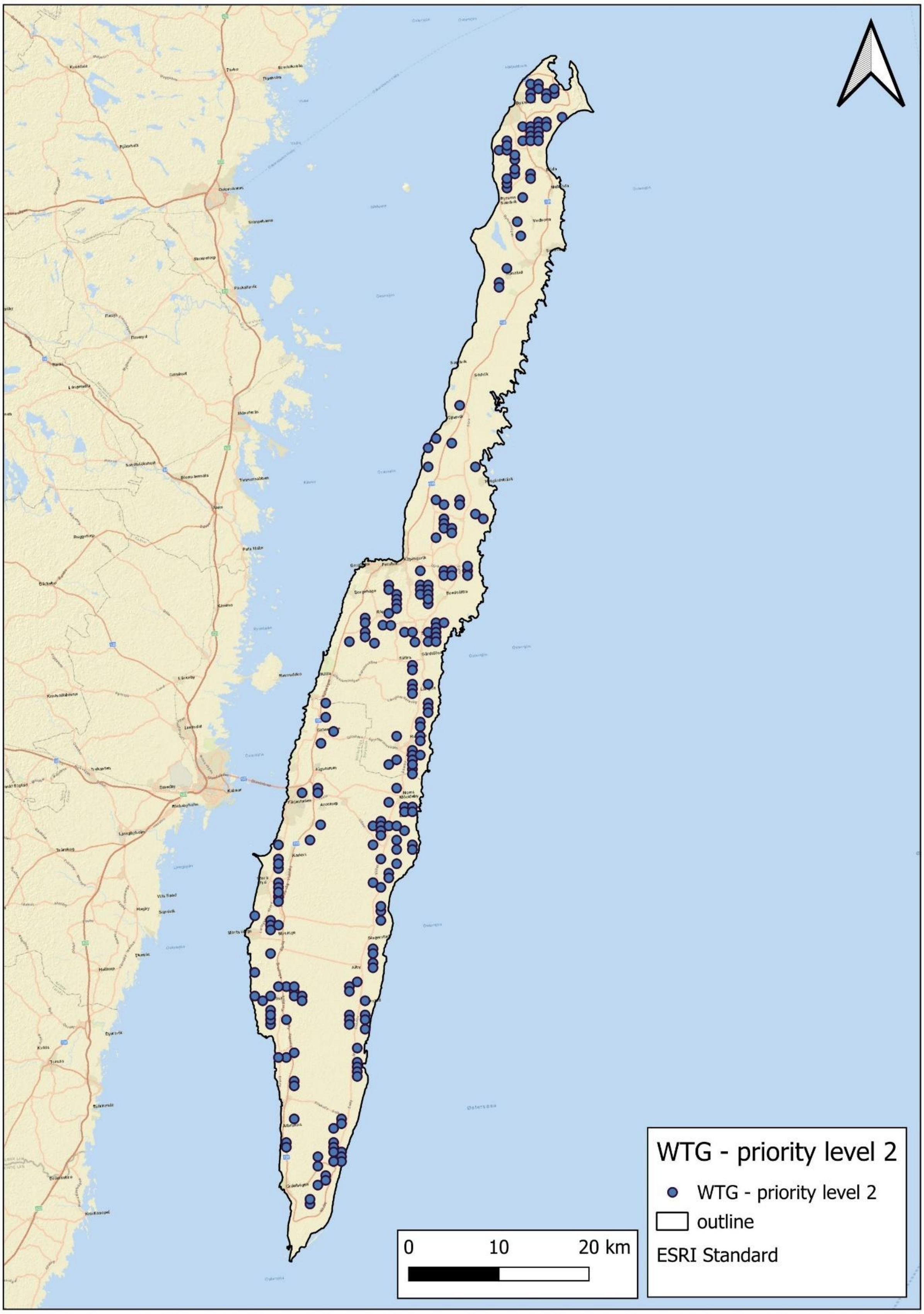

Figure 21: Potential placement of E-138 EP3 E3 4260 turbines on Öland, priority level 2

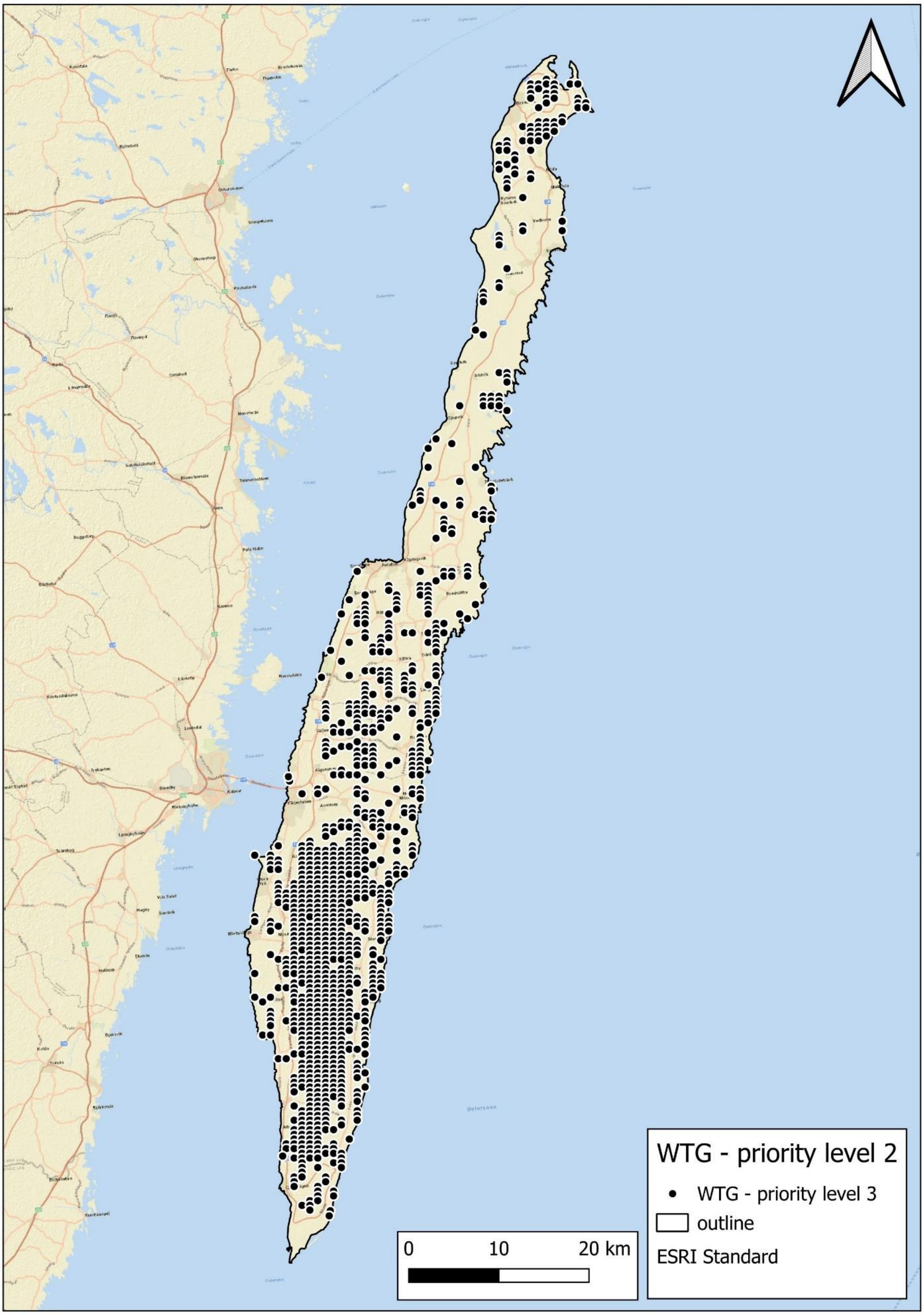

Figure 22: Potential placement of E-138 EP3 E3 4260 turbines on Öland, priority level 3

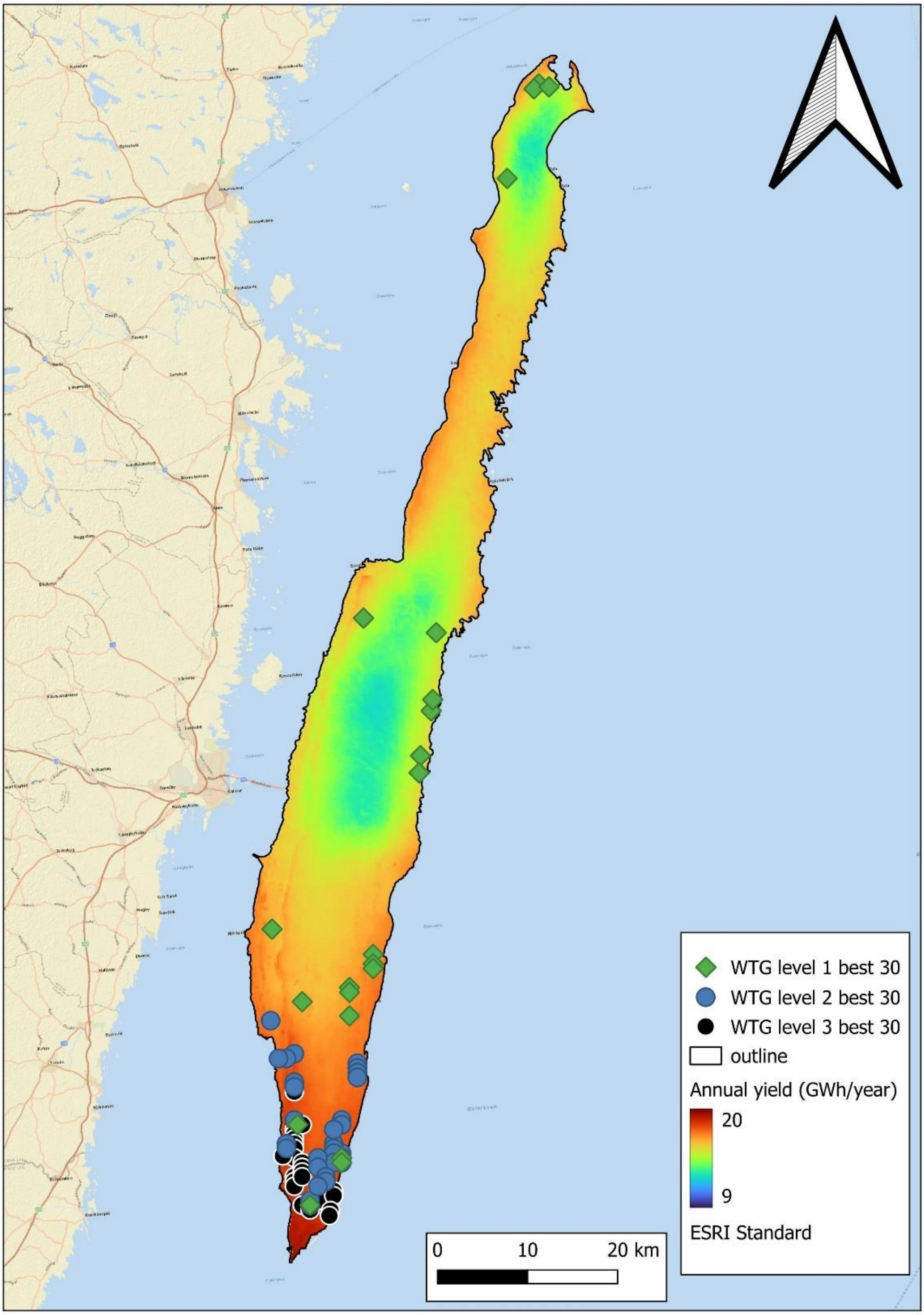

Figure 23: The potential turbine placement of the 30 best performing turbines for each priority level.

5.2.2. Turbine placement limitations

From Figure 23, it would seem that the best solution for Öland is to install all new wind turbines on the southern tip of the island. However, this cannot be done for the following reasons:

1. Grid capacity: With only two parallel 50 kV lines connecting the north to the south, there is a significant risk of overloading the existing infrastructure if too many turbines are installed in the south. The line may not be able to handle the increased power generated, potentially leading to outages or reduced efficiency.

In the Vindkraftsplan of 2013, the following was stated: "*According to calculations made by E ON, it is possible to connect electricity production of up to 90 MW of installed power to the existing pipeline network on the condition that the establishments are distributed over Öland, preferably with 30 MW in the north, 30 MW in the middle and 30 MW in southern Öland.*" (Borgholms kommun och Mörbylånga kommun, 2011)

Moreover, Figure 6 illustrates the population density of the island. As visible, most people live in the central and northern parts of Öland. The number one energy consumer in Öland is households, followed by transport (European Commission, 2024). This means that the load will primarily be in the central and northern parts, and all electricity will need to be transported to these areas.
It is thus suggested to do a study on grid capacity before deciding on the final wind development areas.

Figure 24: MV line across Öland

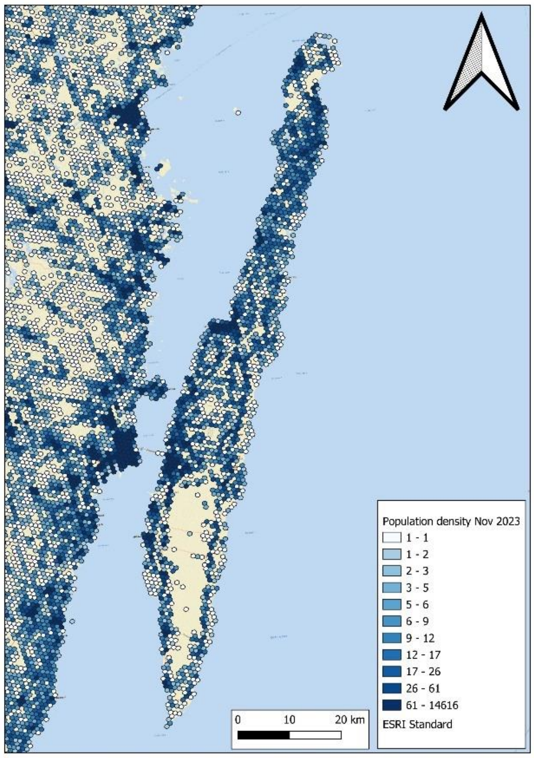

Figure 25: Population density in November 2023

2. Visual impact: Placing all the turbines in the same area would have a significant visual impact on the area. Additionally, the southern part of the island is a UNESCO World Heritage site, attracting numerous tourists each year. The visual effect should be limited here.

5.3. Available areas for repowering

In this chapter the yield that could come from repowering the existing older generation of turbines on Öland is estimated. Information on these turbines was obtained from VindbruksKollen, an open database maintained by Lansstyrelsen, which provides information on turbines in Sweden. Table 5 provides an overview of the parks and individual turbines on Öland that were installed before 2015.

Table 5: Existing turbines on Öland

Name of the Park		# turbines	Year of commission	Total turbine height (m)	Hub Height (m)	Unit capacity (MW)	Turbine model
Kastlösa	Mörbylanga	1	1995	61	42	0.49	Windworld W3700
Ventlinge	Mörbylanga	5	1995	45	31	0.22	Vestas V27/225
Kastlösa Södra	Mörbylanga	16	1998	61	40	0.6	Windworls W4200
Mellböda	Borgholm	5	1998	67	45	0.6	Bonus 600/44
Gregy	Borgholm	1	2001	81	55	0.9	NEG Micon NM52
Långlöt	Borgholm	1	2002	91	65	0.85	Vestas V52
Rogers	Mörbylanga	1	2002	34	24	0.1	Vestas
Rönnerum	Borgholm	3	2002	119	78	2	Enercon E82/2000
Stora Istad	Borgholm	7	2002	119	78	2	Enercon E82-2
Jämjö	Borgholm	1	2003	61	42	0.5	Windworld W3700
Laxeby	Borgholm	1	2003	87	65	0.6	Enercon
Stenninge I	Borgholm	1	2004	75	49	0.9	NEG Micon NM52
Vannborga	Borgholm	2	2004	70	44	0.85	Vestas V52
Degermahn piren II	Mörbylanga	1	2005	73	49	0.8	Enercon E48
Gettelinge	Mörbylanga	1	2006	38	25	0.05	
Hässleby	Mörbylanga	1	2006	53	40	0.15	Windworld
Gårdby	Mörbylanga	1	2007	75	50	0.85	Enercon
Egby	Borgholm	5	2008	100	64	2	Enercon
Långöre	Borgholm	3	2008	100	73	0.8	Enercon E-53
Parboäng Gård	Mörbylanga	1	2009	67	45	0.6	Bonus 600/44
Ryd-Rönnerum	Borgholm, Mörbylanga	2	2010	119	78	2	Enercon E82/2000
Gärdlösa	Borgholm	6	2010	119	78	2	Enercon E-82
Räpplinge	Borgholm	4	2011	125	80	2	Vestas V-90
Svibo	Mörbylanga	1	2011	46	31	0.15	
Egby 2	Borgholm	5	2012	119	78	2	Enercon E-82
Lerkaka	Borgholm	5	2013	150	105	2	Vestas V90-2.0
Nedre Vannborga	Borgholm	1	2013	75	50	0.9	
Skarpa Alby	Mörbylanga	1	2013	27	20	0.45	
Stennige II	Borgholm	1	2015	82	55	1	

The areas currently being used for wind development are assumed to be available for repowering. However, when repowering with larger turbines, the turbines require more space (both physically for safety requirements and to minimise wake), and thus, the wind farm layout needs to be adapted accordingly. Therefore, the turbine placement within these areas is changed to fit the turbines. A distance of five times the rotor in the primary wind direction and three times the rotor diameter in the perpendicular direction was kept between the turbines. This resulted in 44 turbines, and their placement is shown in Figure 27.

In a similar manner, as done for the new development areas, each of these turbine locations was projected to yield an expected annual amount. Using an Enercon E-138 EP3 E3 4260 with an installed capacity of 4.26 MW and a hub height of 99 m, the annual yield per turbine was assessed.

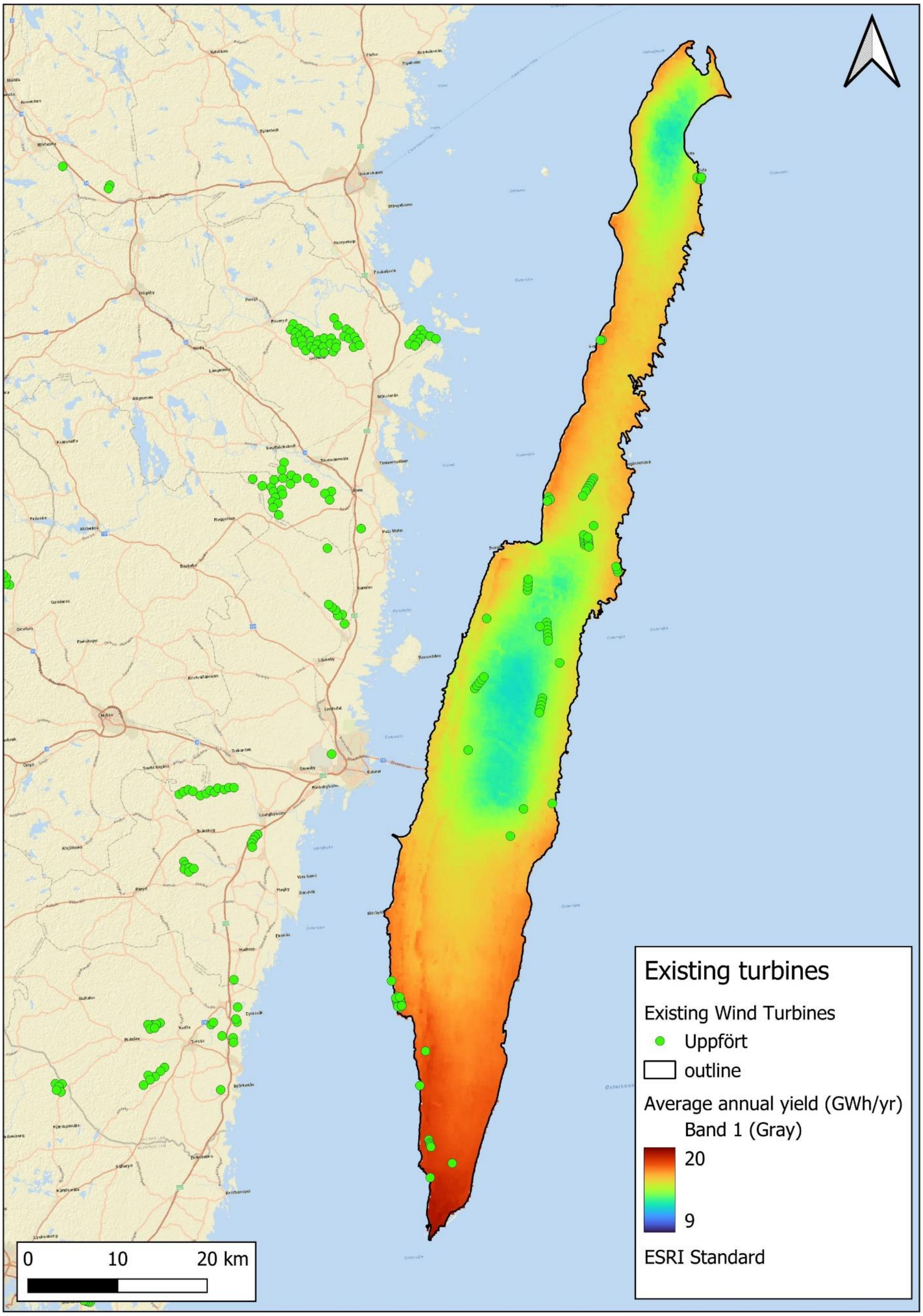

Figure 26: Existing turbines

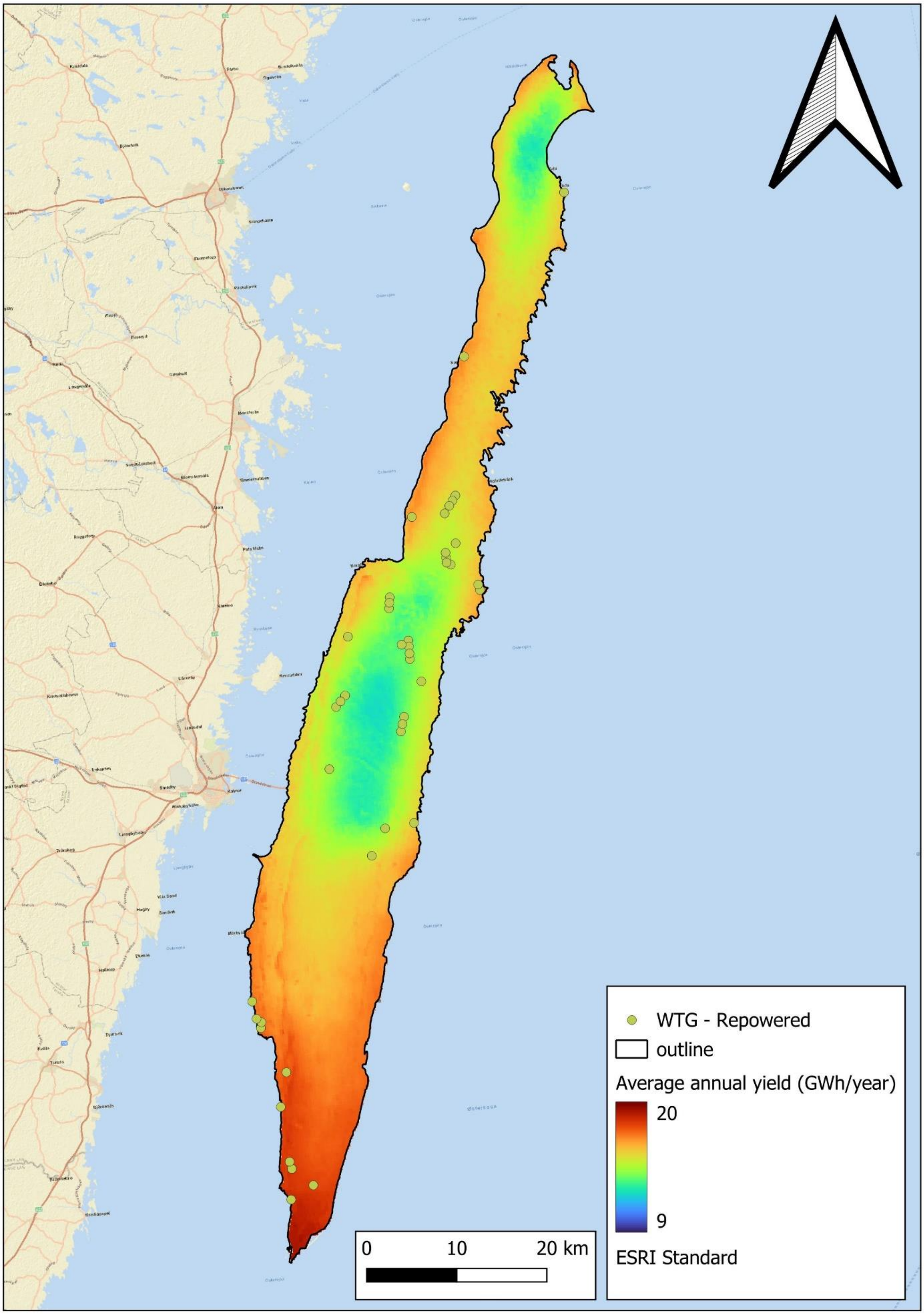

Figure 27: Repowered turbines and their average annual yield based on the E-138 EP3 E3 4260 model

The 30 best-performing repowered turbines, illustrated in Figure 28, should be given priority in the repowering timeline.

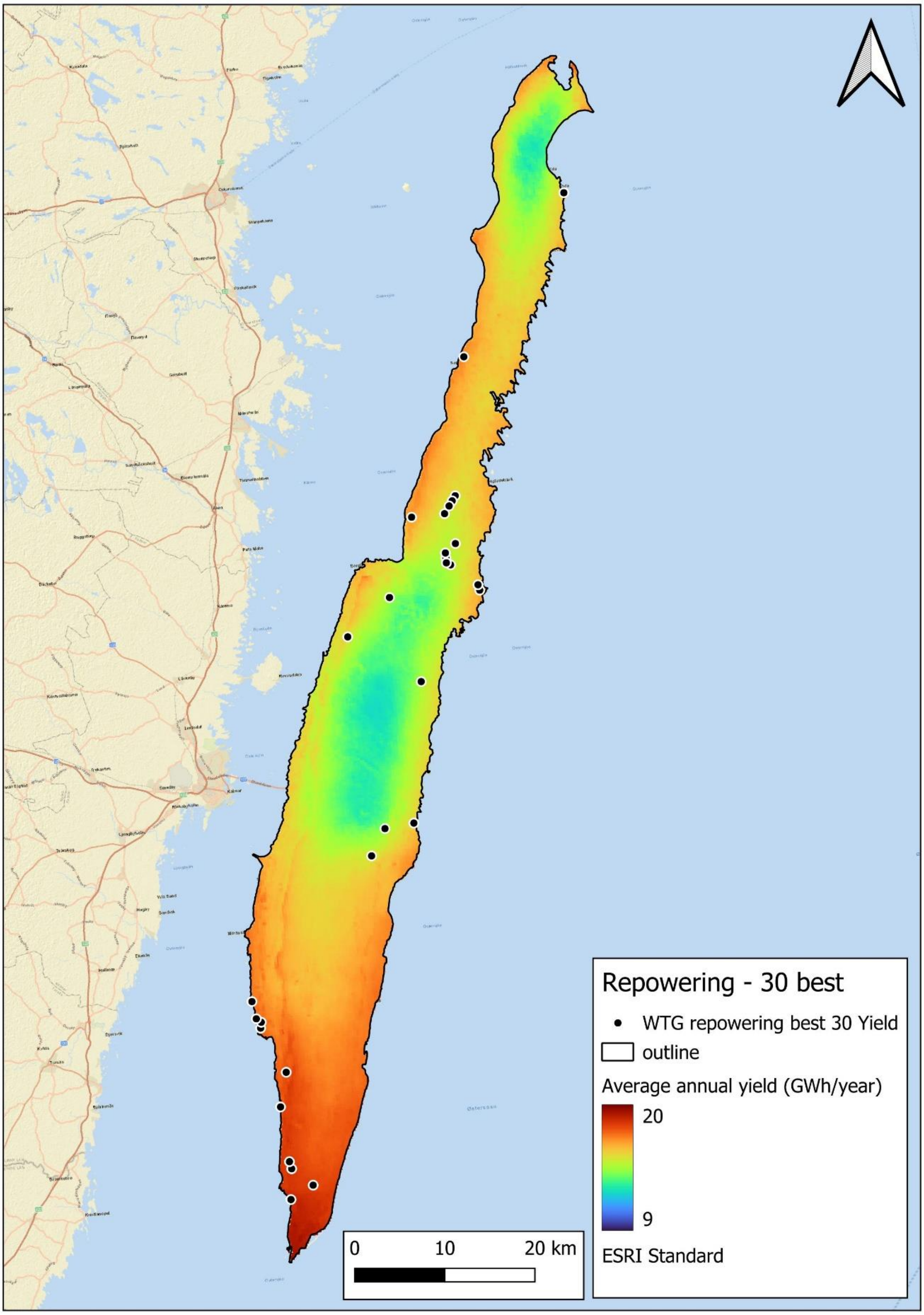

Figure 28: Best 30 performing turbines when repowering.

6. Conclusion and recommendations

In this report, the constraints for wind development on Öland are explained and used to determine new potential development areas around the island. Using the annual average yield estimation, the expected yield per turbine is estimated. The 30 best-performing turbines are identified for each scenario.

Table 6 presents a summary of the results. An estimate of the annual yield is provided per scenario, as well as for the repowering scenario. Although this summary gives a good overview of the available capacity and yield of the different wind development scenarios and can be checked in parallel with the renewable energy goals of Öland, it is not recommended to 'pick' one level as a way forward, but rather to look at the individual turbine locations and their predicted yield when deciding on new development areas on Öland.

Priority Level 1 areas, and especially the 30 best-performing locations, can be seen as the locations to prioritise, although further research is needed concerning noise, grid capacity, shadow flicker, and other studies for local restrictions before issuing permits for wind development. For Priority Level 2 areas, special caution must be exercised regarding noise and shadow flicker, as these locations are closer to residential homes. Priority Level 3 areas can be located in natural reserves, so wind projects in these areas will need to align with more strict environmental regulations.

The average specific yield indicates that the efficiency of the newly developed turbines is expected to exceed that of the turbines already built on the island. This is due to the location of the turbines in places with higher wind power densities and on the type of turbine.

Table 6: Summary of the yield of the different priority area levels

	Existing turbines	Level 1	Level 2	Level 3	Repowering
Area available (km^2)		13.0	107.0	466.9	
# Turbines	92	53	352	1303	44
Total capacity (MW)	115.05	200	1,019	4,274	187.88
Yield (GWh / year)	n/a	847.06	5,632.46	21,217.56	682.90
Average specific yield (MWh/MW)	2,366.7	3,751.2	3,755.9	3,821.6	3,643.2
Average yield per turbines (GWh / year)	n/a	15.98	16.00	16.28	15.52
Yield - Best of 30 (GWh / year)	n/a	503.55	547.07	554.74	488.6

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