Svensson, J., W. Neumann, T. Bjärstig, and C. Thellbro. 2023. Wind power distribution across subalpine, boreal, and temperate landscapes. Ecology and Society 28(4):18. https://doi.org/10.5751/ES-14452-280418

Research

Wind power distribution across subalpine, boreal, and temperate landscapes

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ABSTRACT. Onshore wind power is increasingly expanding to meet global and national goals to increase renewable, clean, and fossil-free energy production. In many countries and regions, however, historical and current land use is extensive, and the expansion of wind power has to be well-tuned to avoid risking irreversible legacy losses of existing and traditional land uses, landscape values, and cultures. Hence, assessments of the siting premises of current and forecasted expansion of wind power are strongly needed as a basis for sustainable planning. We present a study from alpine to temperate biomes in Sweden, where an ambitious onshore wind power expansion strategy has been put in place and will result in Swedish landscapes that are typified by wind power. We explored the existing legal framework—i.e., the national interest for wind power according to the Swedish Environmental Code—concerning the spatial interaction with other national interests for nature conservation, landscape values, and other land uses, and the land cover, landowner, and formally protected areas distribution within wind power sites and in their proximity. We found that the national interest framework does not provide sufficient guidance for locating wind power to avoid spatial overlap with conflicting interests and values. Furthermore, our analysis revealed that wind power is located mainly in forest-dominated landscapes, and on lands where private forest companies are the dominant owners but where the proportion of public and non-industrial private ownership increases in the near surroundings. Finally, we found that large areas of formally protected areas are within the proximate areas influenced by wind power. As an extensive onshore wind power expansion is already going on, and an even more extensive expansion is projected, the ways forward toward a sustainable wind power expansion calls for integrated landscape planning approaches that are based on comprehensive assessments of existing interests and values.

Key Words: *human–nature interactions; land sharing; land sparing; land cover; landowner; land use conflict; landscape planning; national interests; nature conservation; protected areas; renewable energy; sustainability; Sweden*

INTRODUCTION

With the production of clean energy as a high-level energy policy ambition and a fast-growing technology worldwide (e.g., UN 2019, IRENA 2021), the footprint of wind power on landscapes is increasing (Northrup and Wittemyer 2013, Eichhorn et al. 2017, Pasqualetti and Stremke 2018, Diógenes et al. 2020). Accordingly, there are arguments about the opportunities and needs on the one hand, and on the negative consequences and threats on the other, not the least in the context of the UN sustainable development goals (e.g., Nilsson et al. 2016, Bali Swain and Yang-Wallentin 2020, Kati et al. 2021). Among the opportunities and needs, climate change and green house carbon emissions are examples of core arguments (e.g., Poggi et al. 2018, Qin et al. 2021). Undoubtedly, a transition from carbon-based electricity production to zero or minor carbon release to the atmosphere is essential to mitigate continued rising global temperatures. Among the negative consequences and threats, one core argument concerns the consequences on other important natural resources, values, and land uses (e.g., Eichorn and Drechsler 2010, Scherhaufer et al. 2017). Wind power establishments require and affect considerable areas, directly at the wind power sites, with the infrastructure in their immediate surrounding, and at a distance due to visual, noise, light, and vibration disturbances (e.g., Wolsink 2007, Rudolph et al. 2017, Szumilas-Kowalczyk et al. 2020). Thereby, assessments of the consequences of existing and forecast expansion of wind power are strongly needed for outlining opportunities for integrated "least cost" (i.e., minimizing the negative impact on other resources and values) landscape planning (Liljenfeldt 2015, Zaunbrecher and Zeifle 2016, Arts et al. 2017, Zerrahn 2017, Betts et al. 2021, Oliveira and Meyfroidt 2022) and for mitigating "collateral damage" (Pasqualetti and Stremke 2018).

As a late-arriving and major land use, onshore wind power commonly expands in landscapes that already have a pronounced land use footprint (e.g., Bar-On et al. 2018, Pasqualetti and Stremke 2018, Stoessel et al. 2022)—in other words, in anthropogenic landscapes with existing losses and degradation of ecosystems, ecological functionality, and opportunities for traditional land uses (Northrup and Wittemyer 2013, Perrow 2017, Avila 2018, IPBES 2018, Skarin et al. 2018, Rosqvist et al. 2021). Arguments are raised that an expansion of wind power may overshoot land use carrying capacity and generate tipping point turnover and cascade effects that are arduous to recover from, from both an ecological and a traditional land use perspective (Barnosky et al. 2012). Hence, to be recognized and supported by society, such an expansion needs to be well-tuned to the existing landscape values and land use premises, as well as to the context of local attitudes of policymakers and stakeholders (Ryberg et al. 2020).

To meet rising global, regional, and local energy demands, many countries rely on expanding wind power electricity production (e.g., Xu et al. 2019); for Europe, this is equal to a forecast production share of 50% by 2040 (Ahmad and Zhang 2020). Regions and countries—e.g., Europe and Asia— differ in the way they promote wind power development (Lema et al. 2015). At present, wind power is the dominant form of energy production in many regions and is approaching dominance in others (Newell 2018, IRENA 2020). In 2021, the global installed capacity of wind power totaled 825 GW (whereof 93% was from onshore), of which 222 GW was in Europe (87% onshore) alone (IRENA 2022). After Asia, Europe holds a top position in installed wind power capacity globally (IRENA 2021), and the share of onshore wind power is expected to remain high in the future. Commonly, this expansion is manifested by large-scale establishments with many turbines clustered in restricted areas (Perrow 2017).

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Throughout the anthropogenic landscapes of Europe, however, onshore wind power expansion faces constraints in land eligibility due to sensitivity to wind speed, terrain, and long distances between the areas of energy production, distribution, and consumption (Ryberg et al. 2020). Whereas land for wind power is more available in counties such as Spain and France, a wind energy potential model for Sweden indicated that close to 70% of the national territory excluded wind power due to various constraints (Siyal et al. 2015). The complex barriers and opportunities for defining suitable and unsuitable areas for onshore wind power have since long been framed in "windscape," "energy landscape," and corresponding approaches (e.g., Pasqualetti and Stremke 2018, Mauro 2019).

In Sweden, wind power has been developed on a larger scale since the 1990s, with a slow increase up to the beginning of the 21st century (Anshelm and Simon 2016; Bjärstig et al. 2022) and since then with a more rapid expansion rate. From a national production level of less than 0.5 TWh at the beginning of the millennium, the production increased to 3.5 TWh in 2010 and to approximately 20 TWh and 13% of the gross energy production in Sweden in 2019 (Statistics Sweden 2021a). Furthermore, Sweden has ratified very ambitious environmental goals; the national strategy for a sustainable development of wind power (ER 2021) is very determined to foster further expansion. This strategy forecasts a 100-TWh production capacity by the year 2040, whereof 80 TWh will be onshore, and directs future wind power to large-scale sites with multiple turbines clustered (ER 2018, 2021). Such an expansion will claim large areas and even larger impact areas, and will require the use of technical advances such as taller turbines to reach into air layers that have higher and more consistent wind conditions (ER 2021). For onshore electricity production, it is estimated that 150–500 wind power sites with 4600–12,000 turbines will be required (ER 2018).

The pressure on land use and competition among different interests is already high in Sweden, like in most European countries. In a previous study (Svensson et al. 2020a), we showed that the multiple land use claims in northern Sweden represent an area two and four times the available land surface, and Stoessel et al. (2022) reported that 60% of the surface of northern Norway, Sweden, and Finland is affected by multiple land use pressures. Therefore, the "more of everything" (Beland Lindahl et al. 2017) paradigm will be further challenged as wind power increases.

The national strategy for a sustainable development of wind power (ER 2021) directs extensive wind power expansion into more rural areas, with specific obstacles associated with such areas (Jefferson 2018, Poggi et al. 2018). The northern rural areas in Sweden have low human population density and are used extensively for hydro-electric power generation, forest biomass production, mineral extraction, etc., while still providing vast areas of high-value nature conservation, recreation, socio-cultural, and tourism values (Fredman and Emmelin 2001, Statistics Sweden 2021b). The many competing land use claims affect the local society and, in particular, the Indigenous Sámi people who have cultural rights to land and rights to self-determination in their traditional territories (Bjärstig et al. 2020). In addition to the already existing land use claims and rights in Sweden, wind power expansion relies on well-developed decision-making routines to achieve local and regional legitimacy (Bergek 2010, Saglie at al. 2020). Furthermore, it requires careful dialogue, consultation, and planning based on risks for conflicts but also on opportunities for integration and synergy (Zachrisson et al. 2021). This translates into an immediate need for strategic spatial planning with integrative, cross-sectoral landscape approaches (e.g., Arts et al. 2017, Solbär et al. 2019) that puts the forecast increase in wind power production in the context of the social-ecological landscape attributes (Pacheco-Romero et al. 2020). The present small share of Environmental Court permits for new onshore wind power applications (22% in 2021) (Svensk Vindenergi 2022) clearly also speaks for a need for such a landscape approach.

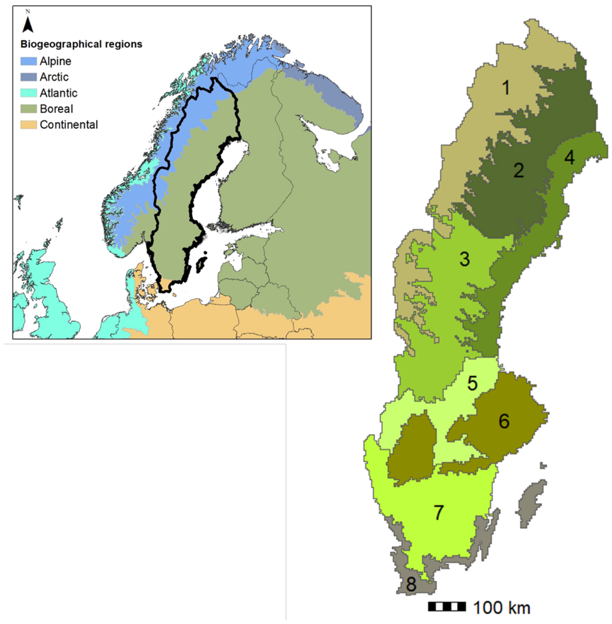
Our overall study objective was to analyze attributes of anthropogenic landscapes in Sweden, as a northern European case, that are or will be typical sites for wind power. Data were derived from actual wind power site locations, attributes of landscapes in their geographical proximity, and the legal claim for wind power as recognized as a national interest (hereafter NI) according to the Swedish Environmental Code (Swedish Environmental Code 1998). The NI policy is aimed at safeguarding public interests to ensure sustainable use of land and water (Solbär et al. 2019), and represents a legal claim to safeguard the current land use priority (Svensson et al. 2020a). The NI policy further seeks to combine sectoral steering with decentralized land use planning (Söderholm et al. 2007, Solbär et al. 2019). The NI framework includes wind power production (hereafter NI wind power) but also other major land uses as well as landscape and nature conservation values. On national and subnational scales, we explored the following research questions: (1) What is the spatial distribution and overlap of NI wind power relative to other NI categories that concern landscape and nature conservation values and other land uses? (2) What is the spatial distribution and overlap of wind power sites relative to NI wind power and other NI categories? (3) What land cover types and land ownership characterize the wind power sites and their surrounding geographical areas? (4) What is the overlap among different formal protection of landscape and nature conservation values? We discuss our results with reference to NI wind power as a strategic spatial planning basis for locating wind power sites, and to other important landscape attributes as represented by other NI categories, landscape and nature conservation values, land cover types, landowners, and formal protection.

MATERIALS AND METHODS

The study region and its stratification

To account for gradients in biogeographic regions, we stratified the Swedish land base data into eight strata based on the National Inventory of Landscapes in Sweden (Ståhl et al. 2011) monitoring scheme (Fig. 1; Appendix 1). This stratification covers alpine mountains and their foothill zones, the interior boreal inland and coastal forestlands, and interior forestlands as well as plains and agricultural regions in the temperate south. Alpine and subalpine environments of the Scandinavian mountain range bordering Norway dominate in stratum 1, which also harbors the vast majority of formally protected nature in Sweden (Statistics Sweden 2021b). Sápmi, the land of the Indigenous Sámi people, covers a very large share of strata 1–4, with reindeer husbandry as a core cultural phenomenon and type of land use that co-occurs with other land uses regardless of landowner (Sandström

Fig. 1. The study region covers the land base of Sweden, and is divided into eight strata developed from the National Inventory of Landscapes in Sweden (Ståhl et al. 2011) national stratification system (Appendix 1): 1: mountains and foothills, 2: far north interior forestlands, 3: north interior forestlands, 4: north coasts, 5: south interior forestlands, 6: south interior plains, 7: far south interior forestlands, 8: far south coasts. Biogeographical regions are according to the official delineations used in the Habitats Directive (European Environmental Agency 2019).



et al. 2016). Swedish forests generally have an extensive industrial forestry footprint except above the mountain forest border, where more intact forest landscapes occur (e.g., Angelstam et al. 2020). Certain distinct characteristics are reflected in the stratification, such as the transition from the southern temperate to the northern boreal and subalpine and alpine biomes, and the transition from coastal sedimentary areas (strata 4, 5, 6, 8) to moraine and bedrock regions above the postglacial highest coastline (strata 2, 3, 7). Agriculture land, urban characteristics, and developed infrastructure dominate in strata 5, 6, and 8 and partly in 4 and 7, whereas rural characteristics dominate in strata 2 and 3 and partly in stratum 4 (Anonymous 2021).

National interests

The Swedish Environmental Code (1998) is a comprehensive legal framework for environmental policy that came into force in 1999 (Hysing 2014). The code encompasses national interests (NIs) as a legally recognized claim for securing public interests and access to terrestrial and aquatic areas, and includes both specific and general aspects of conservation and land use. The framing of the NIs emphasizes sustainable use of land and water systems, with a focus on one specific value or interest (Swedish Environmental Code 1998, Chapter 4), and if possible, given sustainable development, on co-occurring values and interests (Swedish Environmental Code 1998, Chapter 3). The NI framework represents a "soft" land use direction instrument, which favors current land use and regulates if and how other land uses should be given priority or allowed to occur simultaneously (Svensson et al. 2020a). As such, it provides the basis of municipal comprehensive planning as a default landscape planning instrument in Sweden (Thellbro et al. 2017). The local municipal comprehensive planning and the corresponding regional County Administrative Board planning define both the synergies and trade-offs in a landscape where NIs overlap, which is generally the case in northern Sweden (Solbär et al. 2019, Svensson et al. 2020a). Moreover, given the variety of NI types, from nature conservation (e.g., NI Natura 2000 Species and Habitat Directive) to strongly exploitative activities (e.g., NI mining), the likelihood for synergies or conflicts varies depending on overlapping NIs and the actual local situation. In an international perspective, NIs could be incorporated into current spatial planning philosophy, which would lead to an integrated holistic approach and avoid policies that might lead to partiality and/or fragmentation or favor one particular interest (Solly 2021).

In this study, NIs are used to bring perspectives on landscape multifunctionality into strategic spatial planning based on the legal, administrative, socioeconomic, geographical, historical, or cultural contexts in which the spatial planning systems are embedded. For further details of the NI framework and how it is implemented in Sweden, see, for example, Söderholm and Pettersson (2007), Bergek (2010), Siyal et al. (2015), Solbär et al. (2019), and Svensson et al. (2020a). Wind power energy production (NI wind power) is included as one of the NIs in the Swedish Environmental Code, Chapter 3. All NIs included in this study and the NI categorization are defined in Appendix 2.

Data

Wind power

We used two different data sets on onshore wind power. The first was on the actual wind power sites as defined by the location of individual turbines, which we grouped into clusters (wind power parks, farms) based on their site identifier and status, following the public national wind power database (Vindbrukskollen 2021). To identify the current status of the sites and allow us to examine temporal trends, we used the following classes: (1) established sites, (2) sites that have been approved, and (3) sites in the process of approval. The latter class includes sites where withdrawals as well as appeals may delay or halt establishment. We analyzed the three classes separately. In combination, we consider these three classes to represent the present situation in terms of wind power sites that typify or will typify Swedish landscapes in the near future. The second data set was the NI wind power polygons—i.e., the entire polygon area without considering a buffering area (800-m radius in the revised NI wind power data; see Appendix 3)—for settlements within the polygon circumference. The decision to use the entire area was to ensure consistency given that such buffers are not applied to any other landscape attribute.

This approach allowed us to address three different aspects: (1) the spatial interactions following geographical overlap with areas also claimed by NIs other than NI wind power, (2) the geographical overlap between wind power sites and NIs, including NI wind power, and (3) the geographical overlap of wind power sites along a chronosequence (established, approved, and in process).

Other national interests

The first set of landscape attributes were NIs other than NI wind power; i.e., a set of NIs that recognize landscape and nature conservation values or other important land use types, mainly in rural settings outside urban and other developed areas on terrestrial surface. We considered NI wind power as the primary category; the other NIs were organized into five secondary categories (see Appendix 2): (1) landscape values, including six different NIs that either directly protect general or specific landscape values or restrict certain types and aspects of land use to protect such values; (2) nature conservation values, including three different NIs that focus on protecting biodiversity; (3) reindeer husbandry; (4) national defense (strict protection category only; see Appendix 4); and (5) mineral and material. We refer to Svensson et al. (2020a) for the analytical background to this categorization. The data were extracted from the Swedish Environmental Protection Agency (2020).

Land cover, landowner, and formal protection

The second set of landscape attributes consisted of data on land cover, landowner, and existing formal protection of landscape and biodiversity values. To define which land cover types characterize wind power sites, we applied the 10- x 10-m raster national land cover database (Swedish Environmental Protection Agency 2019) using the following categories: (1) forestland, (2) open wetland, (3) agriculture land, (4) other open land (mainly alpine, and bedrock surfaces), (5) artificial surfaces, and (6) inland waterbodies. Category definitions are provided in Appendix 5.

Landowner data were provided by the Swedish Environmental Protection Agency, as applied by Henriksson and Olsson (2020). The landownership distribution was organized into three categories: (1) public, (2) private forest companies, and (3) non-industrial private owners (NIP owners). These three categories broadly represent the main ownership distribution on land and inland water outside urban and developed areas in Sweden (Anonymous 2021). Category definitions are provided in Appendix 6.

Data on formal protection were extracted from the Swedish Environmental Protection Agency (2020) and Swedish Forestry Agency (2021) databases. Formal protection includes nature reserves, biotope protection areas, fauna and flora protection areas, nature conservation areas, national parks, nature heritage areas, and cultural reserves according to the Swedish Environmental Code, Chapter 7 (1998), and nature conservation agreements according to the Swedish Land Code (1970).

Analyses

Given the large geographical scale of our analyses, we applied all geospatial data in the condition they were published; i.e., without correcting minor border-drawing inaccuracies. During analyses, we noticed that some spatial layers had missing data in some counties, but this was to such a minor extent that it did not affect our findings. To avoid double counting any area due to overlapping polygons within a given layer, we dissolved each layer in its level of analyses.

First, we quantified the spatial co-occurrence and frequency of overlap among the NI categories using a fishnet grid of 1- x 1-km cell size and tabulated the intersection between each cell for each NI category. Second, we assessed the percentage overlap between NI wind power and each of the other NI categories by quantifying their spatial intersection. Third, to calculate the percentage of wind power sites distributed in a given NI category, we intersected the wind site layer with the layer of each NI category. Fourth, we calculated wind power site area as a minimum convex polygon (MCP) with a 100-m buffer. For sites with less than three turbines of the same temporal class (established, approved, in process), we calculated a 100-m distance buffer around each turbine (since the MCP requires at least three points). Fifth, for each wind power class, we calculated the percentage overlap with the NI categories. Sixth, we calculated a 1-km and a 10-km buffer around each wind power site to retrieve the landscape attributes in close proximity and at distance from the site. To avoid double counting any area, we dissolved each layer in its level of analysis. The spatial scales of wind power impacts vary depending on the actual research question addressed. Given the scope of our study and the variety of environmental topics, we considered the buffers of 1 km and 10 km as representing generic direct local impacts and landscape impacts, respectively.

We quantified the frequency of occurrence, area, and percentage overlap of land cover, landowner, and formal protection at three nested spatial scales: the site area with a 100-m buffer, within a 1-km buffer, and with a 10-km buffer. We applied tabulate intersection to assess the spatial overlap among vector data (analysis toolbox, wind power sites, NI polygons, and formal protection) and tabulate area (zonal statistics toolbox) to assess the overlap between vector and raster data (landowner and land cover). All analyses were performed per strata and for the national total.

We used two statistical tests to control for differences in occurrence of landscape attributes between wind power sites and the 1-km buffer, the 1-km and 10-km buffers, and the wind power sites and strata; Chi-square tests to compare observed proportions to expected probabilities of landownership and land cover types within wind power sites across strata; and proportion tests for differences in the percentage share of landownership and land cover types among different geographical scales within a given stratum. This allowed us to evaluate differences across strata as well as differences in 1-km and 10-km distances from wind power sites. We used ESRI ArcGIS Desktop 10.6, R 3.6.3 and QGIS 3.18 for data preparation, spatial analyses, and visual presentation. All data sources are provided in Appendix 7; the statistical test is included in Appendix 8.

RESULTS

The NI wind power covers a total area of 4657 km^2 (Table 1). Excluding an 800-m radius buffer around settlements, which corresponds to a net NI wind power area, the area is 3671 km^2 (Appendix 3). Both the NI wind power area and its share within a given stratum vary largely across strata; e.g., 113 km^2 and 0.2% in the south interior plains, and 1331 km^2 and 1.6% in the north interior forestlands. Generally, NI wind power is most abundant in the far north, north, south, and far south interior forestlands and the north coasts strata, but it covers considerably less area and shares than the other NI categories except NI mineral. The NI landscape values cover a large share of the national land surface (42.5%), whereas NI nature conservation, including approximately 87,000 km^2 of EU Directive Natura 2000 area, and NI reindeer husbandry have the largest areas and shares in the mountains and foothills stratum. Reindeer husbandry occurs only

Table 1. Total area (km^2) and area proportion (%) of national interest (NI) categories per stratum and nationally.[†]

	Wind power[‡]		Landscape values		Nature conservation		Reindeer husbandry		National defense[§]		Mineral	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Mountains and foothills	189	0.2	76,004	83.1	61,305	67.0	37,493	41.0	4,723	5.2	310	0.3
Far north interior forestlands	959	1.2	19,204	24.3	8,913	11.3	26,767	33.9	11,647	14.7	359	0.5
North interior forestlands	1,331	1.6	30,620	37.8	6,322	7.8	15,940	19.7	2,403	3.0	18	<0.1
North coasts	646	1.3	13,947	28.2	7,172	14.5	5,778	11.7	4,831	9.8	18	<0.1
South interior forestlands	398	1.0	7,731	20.0	3,650	9.5	–	–	3,454	9.0	218	0.6
South interior plains	113	0.2	24,692	43.1	11,606	20.2	–	–	13,831	24.1	61	0.1
Far south interior forestlands	843	1.3	21,187	33.2	11,001	17.3	–	–	7,044	11.1	17	<0.1
Far south coasts	179	0.8	12,102	53.5	5,848	25.8	–	–	2,781	12.3	46	0.2
National total	4,657	1.0	205,487	42.5	115,819	24.0	85,978	17.8	50,714	10.5	1,046	0.2

[†] Polygons that cross strata were separated per stratum for area calculations. The area cover of national interest (NI) categories are the net area; i.e., without overlapping area within the different NIs included in the category. A dash (–) indicates zero occurrence. The single NI and the NI categorization are presented in Appendix 2. The gross area—i.e., the area cover of any single NI within the categories, the number of polygons for each NI category, and the number of polygons and area of single NIs, are presented in Appendix 7.
[‡] For wind power, we applied the areas without buffering for settlements inside the original NI polygons (Appendix 3).
[§] For national defense, we included the following types: stop for high constructions, stop for wind power construction, areas of importance for national defense, and areas formally defined as NI national defense (Appendix 4).

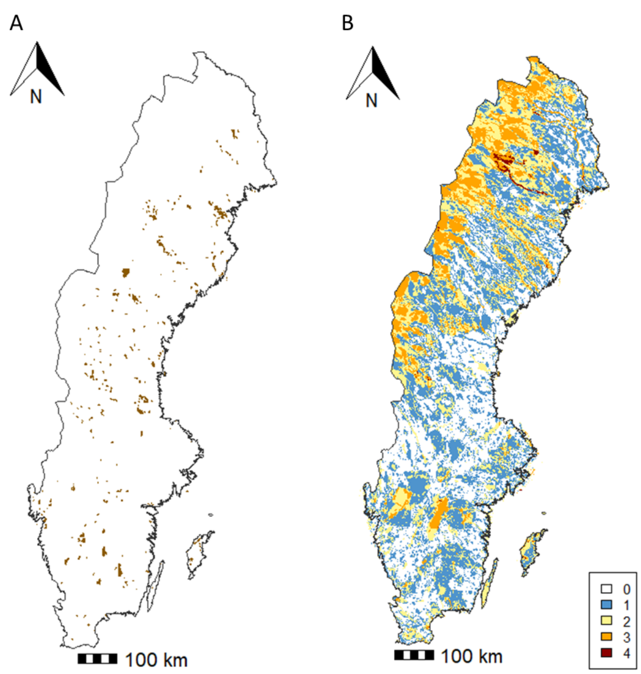
in the four northern strata, where it holds a large share; NI national defense covers the largest areas and shares both in the south interior plains and the far north interior forestlands strata.

The distribution of NI wind power is scattered across Sweden. There is a low frequency of occurrence mainly in the mountains and foothills and the south interior plains strata, in particular in proximity to the capital region in south-central east Sweden (Fig. 2). The overlap among the different NI categories is concentrated in the mountains and foothills stratum, with up to four of six categories overlapping. Given their larger areal coverage, the most evident overlap is between NI categories other than NI wind power. However, in parts of the north coasts, north interior forestlands, and far north interior forestlands strata, NI wind power contributes to a large extent to the overlap.

NI wind power overlaps geographically mainly with NI nature conservation in the mountains and foothills stratum and with NI landscape values in the far south coasts stratum (Table 2; Appendix 9). The overlap with NI reindeer husbandry and NI national defense is greatest in the mountains and foothills stratum. The total overlap is far greater in the mountains and foothills and the far south coasts than in the other strata, which indicates an overall greater complexity in these strata.

Wind power sites occur mainly outside any NI category, and outside areas designated as NI wind power (Fig. 3). Moreover, there is an evident trend between the classes of wind power sites toward an even more pronounced temporal location outside any NI category, particularly in the far north interior, north interior, and south interior forestlands. The wind power sites that are located within any NI categories are mainly within NI wind power and NI landscape values. In the mountains and foothills stratum, there are only established wind power sites, which are located mainly within NI nature conservation and to some extent in NI reindeer husbandry, NI landscape values, and NI mineral; hence, there are no sites that are approved and or in process.

Fig. 2. The distribution of (A) national Interest wind power, and (B) the frequency overlap of co-occurring national interest categories within 1- x 1-km pixels, from zero to a maximum four out of six categories.



Land cover composition varies among strata (Table A8.4). Forestland is the dominant land cover in all strata at all scales and has a greater share within wind power sites compared to forestland distribution across the strata, except in the mountains and foothills stratum (Fig. 4; Table A8:2). There, open land

Table 2. Overlap (%) between national interest (NI) wind power and other national interest categories, separately and in total.[†]

Stratum	Landscape values	Nature conservation	Reindeer husbandry	National defense	Mineral	Total overlap
Mountains and foothills	6.3	71.5	21.2	28.9	0.6	128.5
Far north interior forestlands	26.5	10.4	11.9	7.0	0.4	56.2
North interior forestlands	17.8	2.0	11.9	1.2	–	32.9
North coasts	22.3	5.6	11.3	1.6	–	40.8
South interior forestlands	10.3	4.0	–	9.7	2.5	26.5
South interior plains	24.5	26.6	–	9.0	–	60.1
Far south interior forestlands	25.2	8.6	–	13.0	0.2	47.0
Far south coasts	86.3	26.5	–	14.9	1.1	128.8

[†] Polygons that cross strata were separated per stratum for area calculations. The area cover of national interest (NI) categories are the net area; i.e., without overlapping area within the different NIs included in the category. A dash (–) indicates zero occurrence. Total area (km^2) and area proportion (%) of the individual national interests in the landscape and nature conservation values NI categories, as well as their overall overlap (%) with NI wind power, per subregion and nationally, are presented in Appendix 9.

dominates within the sites, at both the 1-km distance and 10-km distance, but with forestland at a greater share at the 10-km distance. The forestland share at the 10-km distance is also greater than within the stratum. Agricultural land dominates at the 1-km distance in the south interior plains and far south coasts strata, and has a larger share within the sites than within the strata. Wetland is present at low levels in the four northern strata but has a greater share within sites than within the strata. Artificial surface cover is present at low levels in all strata. Waterbody cover increases with distance from the wind power sites, particularly in the north coasts and far south coasts strata.

Wind power sites occur on land within all three landowner categories in all strata, but with unequal composition of ownership (Tables A8.1 and A8.3); e.g., there is a decreasing share of forest company and increasing share of NIP ownership from north to south (Fig. 5). Public ownership dominates in the mountains and foothills stratum, whereas forest company ownership dominates in the far north interior forestlands, north interior forestlands, north coasts, and south interior forestlands strata. In contrast, NIP ownership is most common in the south interior plains, far south interior forestlands, and far south coasts strata. The share of ownership also differs between the wind power sites at 1-km and 10-km distances, and the strata (Table A8.2). On forest company ownership, the share is higher on wind power sites compared with the entire strata in all strata except the far north interior forestland and the far south coasts strata, and in particular, is higher in the south interior forestlands, the north coasts, the north interior forestlands and the mountains and foothills strata. On NIP land ownership, the share is lower on wind power sites compared with the entire strata in the south interior forestlands, the north coasts, and the north interior forestlands strata, but is higher in the far south coasts and far north interior forestlands strata. Thus, the largest proportional differences were found in the north coasts and south interior plains strata. In the mountains and foothills stratum, NIP ownership share increases within 1 km, whereas both public and NIP ownership increases within a 10-km distance. In all other strata, public ownership shares increase mainly at the 10-km distance, although at low levels. NIP ownership increases in the immediate distance in all strata, except in the far north interior forestlands. In contrast, the share of forest company ownership decreases from wind power site to 1 km, 10 km, and the entire stratum in the far north interior forestlands, north coasts, and south interior forestlands strata.

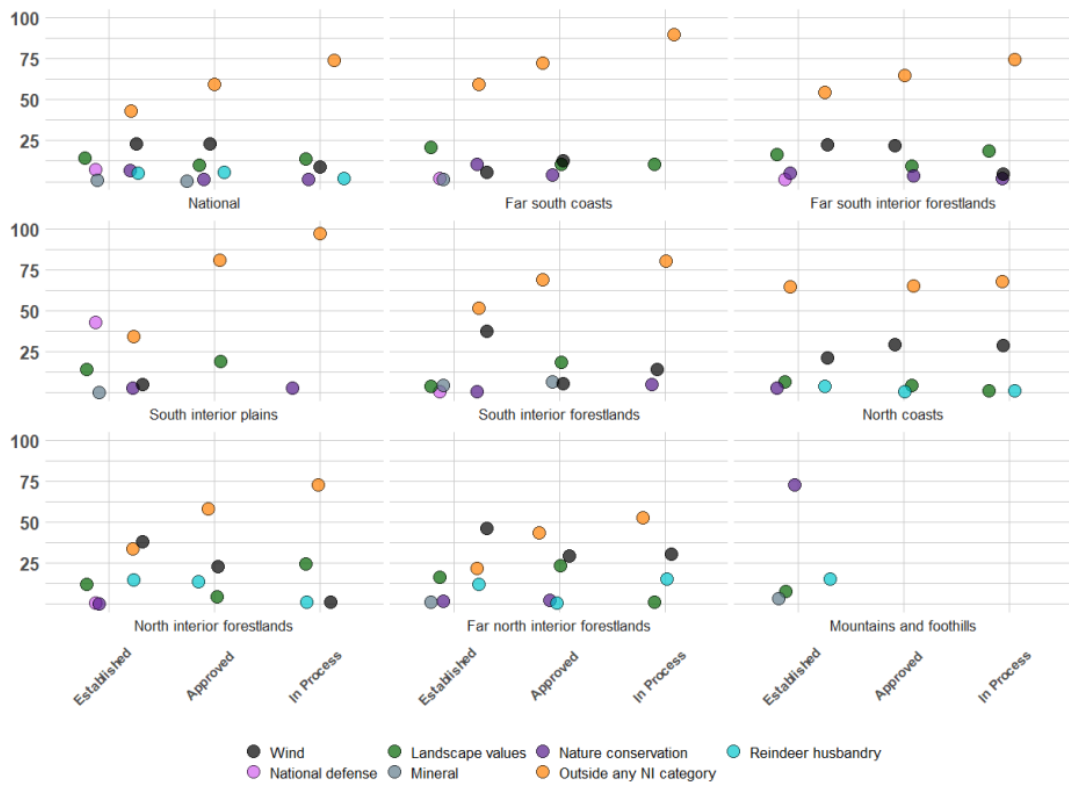
A large number of formal protection areas occur close to wind power sites. Within 1 km, there are 640 single protected areas covering more than 200 km^2; within 10 km, there are 9719 areas covering 7600.5 km^2 (Table 3). Within both buffer scales, the number and area of protected areas are greatest in the far south coasts, far south interior forestlands, and south interior plains strata; i.e., in the three southernmost strata. However, by far, the largest proportion of protected areas within both the 1-km and 10-km distances occurs in the mountain and foothills stratum, with close to 26% and 34%, respectively, for, by comparison, a low number of protected areas that cover a very large area. The proportion of total protected area per stratum and on national scale is small within 1 km but high within 10 km. On a national scale, more than 13% of all protected areas are within a 10-km distance, and there is a higher proportion in the south than in the north. In the far south coasts stratum, more than 71% of all protected areas are within 10 km of wind power sites. Artificial surfaces close to wind power sites are more common in southern Sweden—i.e., in the three southernmost strata—but also by area within the 10-km distance in the north interior forestlands stratum (Table 4; Table 10.1).

DISCUSSION

Large-scale expansion of onshore wind power is a planning challenge

Large-scale expansion of onshore wind power comes with consequences in both anthropogenic and more natural landscapes. There is a rich literature globally and from various countries and regions that supports this (e.g., Perrow 2017, Zerrahn 2017, Ryberg et al. 2020, Kati et al. 2021). Clearly, the realization of the ambitious Swedish strategy for sustainable development of wind power (ER 2021) will strongly transform the Swedish landscape. In addition to the land claim for wind power sites and their immediate surrounding planning area, various impacts on other land use claims and values appear nearby and at a distance. To find and balance "least cost" solutions and mitigate damage on other conflicting values and interests thus becomes critically needed (Zerrahn 2017). "Energy landscape" (e.g., Pasqualetti and Stremke 2018) planning will have to be done with care based on solid data and knowledge on the cumulative consequences in addition to existing land use pressures on natural resources, biodiversity, ecosystem services,

Fig. 3. The proportion (%) of individual wind power sites separated into established, approved, and in process, in the different national interest (NI) categories and outside any NI category, presented on national scale and for each stratum.



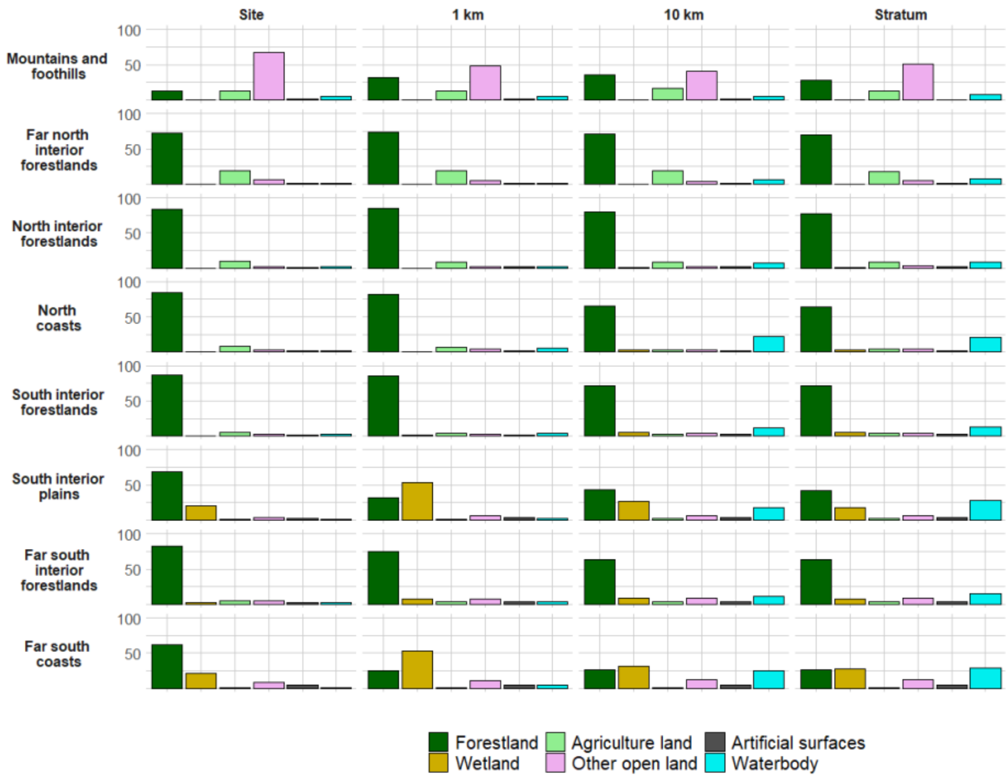
and traditional values. The strong focus on clustering turbines in large sites, which is a clear trend for wind power establishment (Vella 2017), further emphasizes the need to differentiate suitable from unsuitable locations and balance between different environmental and climate goals in specific locations (e.g., Kati et al. 2021).

Our approach to analyzing the presence of onshore wind power across very different landscape conditions and geographical scales shows that the location of wind power in accordance with the NI framework (Swedish Environmental Code 1998) is not particularly conclusive in terms of geographical placing. Onshore wind power sites are established outside the designated wind power NIs, and moreover are overlapping conservation and landscape values as well as other land uses, including where co-existence will cause conflict and where adaptation and mitigation is difficult, if even possible. Our results also indicate that this trend in establishing wind power sites outside NI wind power has been increasing over time.

The Swedish mountain region has particularly important NI reindeer husbandry, and regions in south Sweden have particularly important NI landscape values. Thus, both rural hinterland and urban regions pose challenging conflicts for strategic spatial planning on the landscape level. Further, our study shows that wind power currently occurs and will occur in the future mainly on forestland in the north and agricultural land in the south, across public, private forest company, and NIP landownership, with forest company land dominating on sites and NIP ownership increasing at close distance. Therefore, planning needs to undertake dynamic and adaptive approaches to facilitate transparent and fair compensation on sites and at distance from wind power. Finally, our study also shows that the occurrence of formally protected areas is extensive in the proximity of wind power sites. Clearly, a sustainable expansion of onshore wind power requires well-tuned and informed planning based on solid landscape data.

Successful and sustainable development of wind power requires inclusive and integrated planning (Liljenfeldt 2015, Zaunbrecher and Zeifle 2016, Diogenes et al. 2020, Lauf et al. 2020, Saglie et al. 2020). Trade-offs, mitigation, and compensation must be explored, and wind power locations must be selected to avoid constraining, counteracting, or canceling other values and interests (Nilsson et al. 2016). Our analysis reveals that currently, NI wind power does not provide much support to achieve this. Instead, NI wind power provides limited or even poor guidance for wind power entrepreneurs, planning authorities, and landowners. In short, our analysis indicates that NI wind power and the NI framework in general do not currently have the capacity to mitigate land use conflicts, exhaustive negotiations, and decision-making processes, nor does the framework promote

Fig. 4. The proportion (%) of land cover categories at the scale of the wind power site and within both 1-km and 10-km distances from the site boundaries, presented on a national scale and for each stratum, and with the proportions for the entire stratum for comparison. The data combine wind power sites that are established, approved, and in process. The land cover types are defined in Appendix 5.

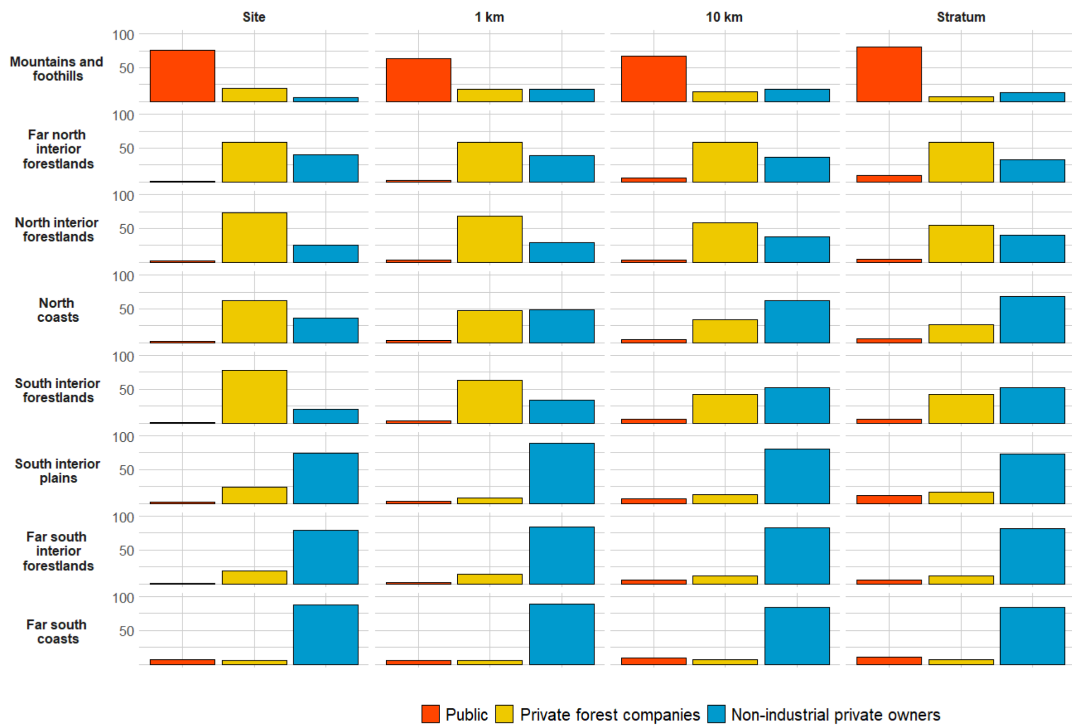


a mutual solution-oriented dialog, which is needed for sustainable development as intended with the NI framework (Bergek 2010, Siyal et al. 2015, Solbär et al. 2019, Darpö 2020, Svensson et al. 2020a). To fine-tune awareness of conflict risks and integration and synergy opportunities within both the actual wind power sites and at a distance, there is a need for multiple-scale planning that specifically addresses other focal values and interests. Furthermore, the planning needs to be sensitive to negative and positive effects more broadly in the context of sustainable development (e.g., Bali Swain and Yang-Wallentin 2020) as well as to the local conditions and site-specific environmental impacts at any site being evaluated for wind power establishment (e.g., Siyal et al. 2015).

In addition to redefining NI wind power relative to other values and interests that are not spatially compatible, there is a need to reassess suitable wind power locations, given, for example, the use of taller turbines, a more efficient power line infrastructure, and reduced overall energy distribution constraints (Antonini and Caldeira 2021). Our results indicate a temporal trend in recent and future wind power establishment outside designated NI wind power areas at a larger share than existing installations. This suggests that the delineated NI wind power areas are outdated and need revision. Revising only NI wind power, however, is of little use in establishing a sustainable strategy for extensive wind power expansion, since there will still be competition with other public interests and land uses (Bergek 2010) if they are not integrated simultaneously (e.g., Perrow 2017). The NI framework is thus a deficient strategic, tactical, and operational planning basis that does not facilitate sustainable use of land and water area in a holistic and multifunctional perspective, as intended. Similar conclusions have been reached on a more local scale (four municipalities) in northern Sweden, where Solbär et al. (2019) argued that the vagueness in the NI framework adds dysfunctionality to local spatial planning, and that integrative approaches on wider landscape scales are needed for functional planning.

We suggest that to advance sustainable wind power expansion, a conceptual development following a triad approach (e.g., Grumbine 1994) is needed. In a triad approach, conservation core areas (typically understood as formally protected areas) are recognized in an inner zone along with NIs oriented toward conservation and/or landscape value protection, and NIs oriented toward land use restriction are in an outer zone. If possible, wind power is located outside both zones but strictly not in the inner zone (cf exclusion zones; Siyal et al. 2015). Such a triad approach underscores a stronger focus on avoidance and minimization of wind power in the inner zone, and on compensation in the outer zone, following, for example, the Business and Biodiversity Offsets

Fig. 5. The proportion (%) of landowner categories at the wind power site and within both 1-km and 10-km distances from the site boundaries, presented for each stratum with the proportions for the entire subregion for comparison. The data combine wind power sites that are established, approved, and in process. The landowner categories are defined in Appendix 6.



Programme (2012) mitigation hierarchy. Hence, this approach builds on a focus on planning based on avoiding conflict risks in the inner zone and promoting integration and synergy opportunities in the outer zone. The extensively overlapping land claims and the resulting cumulative impacts, as is the case particularly in northern Sweden (Svensson et al. 2020a, Rosqvist et al. 2021, Stoessel et al. 2022), requires informed planning and sharing–sparing approaches that more strictly separate areas for specific or combined goals (Betts et al. 2021). In this context, a no-go for onshore wind power needs to be incorporated and implemented to achieve a fully functional planning system. In order to not further intensify the current levels of stress on important landscape attributes while at the same time allowing sustainable wind power expansion, planning new wind power will have to be sensitive and potentially even include removing existing wind power as an option in a compensation framework.

Our analyses of NI wind power focus on the circumference of the delineated polygons. In the revised version of NI wind power, 800-m radius buffers around settlements have been withdrawn from the polygons (Swedish Energy Agency 2013). We argue, however, that since this modification concerns only the aspect of closeness to settlements and does not consider the spatial co-occurrence with other land use interests (e.g., nature conservation, landscapes values, or pastoral herding system), our approach of applying the entire polygons is the most reasonable.

Landscape attributes

In addition to landscape and biodiversity values, reindeer husbandry, mines, and national defense, as analyzed in this study, are other land uses that occupy large areas that are important at a national level or to the national economy. The Swedish Environmental Code (Chapter 3; 1998) recognizes both forestry and agriculture as of national importance, although they are not formally recognized as NIs (Svensson et al. 2020a). To be effective in municipal comprehensive planning as well as in regional land use planning and decision-making, the NI framework needs to reflect updated areas for wind power, other land uses, and landscape and nature conservation values simultaneously. Since the NIs encompass such diverse interests and values, categorizing them by similar purposes as done in this study is a way to explore the potential in this direction. This categorization approach allowed us to move away from the specific Swedish scheme into a more general assessment that, to our understanding, is more general and thus potentially applicable to other countries and regions that experience a similar expansion of onshore wind power in landscapes with multifunctional land use.

National interests other than wind power

The extensive overlap between NI wind power and NI category landscape values is challenging, for example, with respect to landscape view impact (e.g., Szumilas-Kowalczyk et al. 2020). We included six types of NIs in this category. The NIs that by far dominate by area and overlap with NI wind power are those that

Table 3. Area (km^2), number, and proportion (%) of total formally protected area per stratum and nationally within both 1-km and 10-km buffer distances from wind power site boundaries.†

Stratum	1-km distance				10-km distance			
	Area (km^2)	Number	Buffer (%)	Total (%)	Area (km^2)	Number	Buffer (%)	Total (%)
Mountains and foothills	32.5	2	25.7	0.1	1,161.2	31	33.6	3.0
Far north interior forestlands	33.0	43	2.7	1.0	504.9	316	3.8	15.0
North interior forestlands	41.5	81	1.6	2.4	516.3	1,001	1.8	29.4
North coasts	8.4	45	1.0	0.4	642.8	633	3.9	30.5
South interior forestlands	18.9	72	1.9	1.0	547.6	1,116	3.7	28.0
South interior plains	20.3	112	1.4	0.4	1,308.8	2,047	5.3	27.8
Far south interior forestlands	19.6	155	1.0	0.6	1,618.4	2,815	4.7	48.8
Far south coasts	36.6	130	2.4	2.0	1,300.5	1,760	6.8	71.4
National	210.9	640	2.0	0.4	7,600.5	9,719	4.9	13.2

† To reveal temporal trends, the data combine wind power sites that are established, approved, and in process. Formal protection includes nature reserves, biotope protection areas, fauna and flora protection areas, national parks, nature heritage areas, and cultural reserves according the Swedish Environmental Code, Chapter 7 (1998), and nature conservation agreements according to the Swedish Land Code (1970).

Table 4. Area (km^2) and proportion (%) of artificial surface per stratum and nationally within both 1-km and 10-km distances from wind power site boundaries.†

Stratum	1-km distance		10-km distance	
	km^2	%	km^2	%
Mountains and foothills	2.1	1.7	37.6	1.1
Far north interior forestlands	13.9	1.1	161.7	1.2
North interior forestlands	37.2	1.5	460.7	1.6
North coasts	14.9	1.7	341.9	2.1
South interior forestlands	20.9	2.1	412.4	2.8
South interior plains	52.9	3.7	898.4	3.6
Far south interior forestlands	62.8	3.4	1,285.8	3.7
Far south coasts	74.6	4.9	838.4	4.4
National	279.5	2.6	4,437.1	2.9

† To illustrate temporal trends, the data include wind power sites that are established, approved, and in process. Artificial surface was calculated by pixels (10- x 10 m) from the national land cover map (Swedish Environmental Protection Agency 2019). "Buildings and urban areas" include pixels that indicate constructions (i.e., roofs). "Roads and railways" include pixels classified as roads and railways. "Other built infrastructure" includes pixels classified as artificial open surface that are not buildings, roads, or railways. The area of these subcategories of artificial surface are presented separately in Appendix 10.

protect general landscape values rather than those that restrict other land uses. This is particularly evident in southernmost Sweden (the far south coasts stratum), where itinerant recreation and tourism strongly dominates. The negative visual impacts of turbines are well studied (e.g., Wolsink 2007, Szumilas-Kowalczyk et al. 2020.) Likewise, the overlap with the nature conservation NI category (consisting of three NIs that are oriented toward conservation of biodiversity, ecosystems, and landscapes) is extensive, particularly in the mountain and foothills stratum, where the largest overlap occurs both by absolute area and share of stratum area, and in the south interior plains and the far south coasts strata. The overlap between wind power and the nature conservation NI category is less pronounced in forest-dominated strata. Both the nature conservation and landscape value NI categories contain slightly different NI types, and the specific conservation aspects also vary between different NI areas within each type. Hence, it should be assumed that the direct effects of wind power will vary among both NI types and NI areas (cf. Northrup and Wittemyer 2013, Perrow 2017, Kati et al. 2021).

Generally, Indigenous and local rural cultures are sensitive to wind power expansion (Ek and Matti 2015, Avila 2018, Skarin et al. 2018, Stefanelli et al. 2018, Rosqvist et al. 2021). We argue that the traditional nomadic Indigenous Sámi people' reindeer husbandry and culture is currently being pushed toward a tipping point. Hence, even existing wind power is challenging, and any additional wind power establishment in the reindeer husbandry area needs to be carefully balanced. Cumulative impacts from other land uses leave small (i.e., 4% of the surface) and fragmented "free space" land in northern Sweden, Norway, and Finland (Stoessel et al. 2022). Reindeer husbandry is a pastoral herding system. The reindeer husbandry area covers much of the north Sweden territory—i.e., 55% of the Swedish land base (Sandström et al. 2016)—and overall, grazing by semi-domesticated grazers covers 40% of the land base of northern Norway, Sweden, and Finland (Stoessel et al. 2022). As a result, wind power overlap with NI reindeer husbandry occurs across all of northern Sweden and is the greatest in the mountain and foothills stratum, which is also the area in which reindeer husbandry can occur year-around (Stoessel et al. 2022). Since the transhumance nomadic reindeer husbandry includes annual long-distance migration from the mountains to the coast and back (Pape and Löffler 2012), the negative disturbance is spatiotemporal but also more general since wind power disturbs the migration route biannually. This calls for certain attention in landscape planning (e.g., Bjärstig et al. 2020), including a no-go for wind power or a removal of existing wind power if the consequences become too severe. Furthermore, since reindeer husbandry and central aspects of the Sámi culture are evidently nature-based (Svensson et al. 2020a), a functional construction of NI reindeer husbandry has to be dynamic and include both current and future favorable areas for reindeer. As such, the high dynamic nature of reindeer husbandry emphasizes the relevance of considering adaptive planning approaches. Given a changing climate and the cumulative impact of other land uses such as forest management, tourism, and recreation along with other disturbances such as predators (e.g., Skarin et al. 2018, Rosqvist et al. 2021), large-scale wind power establishment in the reindeer husbandry areas becomes particularly challenging and a potential threat to sustainable reindeer husbandry and to a vital Sami culture.

The NI national defense encompasses different types of restrictions. The strict regulations, as applied in this study, hinder wind power, as also recognized in the national strategy (ER 2021).

The NI mineral occupies small and scattered mining areas, and has a pronounced local impact and strong legal support (Raitio et al. 2020). Although co-existence on the exact area used for surface mines is not possible, we argue that wind power, national defense facilities, and mines may benefit from coordinating neighboring locations by using the same road networks and other infrastructure; i.e., reflecting integration and synergy opportunities.

Land cover

Forestland is the dominating land cover both within wind power sites and at distance for all strata where forest is a dominating land cover. Forestlands and woodlands together cover approximately 75% of Sweden (Anonymous 2021). However, forests occur at a higher percentage within wind power sites than in the corresponding strata. This indicates that there is a choice for wind power and an ongoing land use conversion from forestry to energy production, albeit on comparable small areas. The dominance of wind power in forests differs from situations in other countries where wind power in forests can be more restricted despite having high wind power capacity (e.g., in Germany; Bunzel et al. 2019). In Bunzel et al.'s (2019) study, it was shown that 24% of more than 27,000 turbines were located in forests but with a large concentration in the southern federal states. This is a reflection of a stronger federal state policy control than in Sweden, where a national strategy (ER 2021) is promoted. In Germany, forests are seen as more natural lands than in Sweden where production forestry dominates, where wind power establishment risks causing further stress on valuable ecosystems and habitats but also as a land use that is as economically important as forestry (Bunzel et al. 2019).

Forestland cover is greater, in particular, at a 10-km distance from wind power sites in the mountains and foothills stratum compared with at sites and the entire stratum, which indicates that the sites are located in proximity to the alpine treeline and mountain forest border. This implies that there are lesser negative effects on alpine environments and the values associated with these open landscapes (Hedblom et al. 2019) but greater negative effects on the mountain foothill forests that are recognized as national and international core assets for biodiversity conservation and intact forest landscape characteristics (Kuuluvainen et al. 2017, Curtis et al. 2018, Svensson et al. 2020b). The Scandinavian mountain foothills region is also a focal area for reindeer grazing (Pape and Löffler 2012) and generally harbors high social and cultural values (e.g., Fredman and Emmelin 2001, Lundmark 2005, Josefsson et al. 2010, Blicharska et al. 2017). We foresee that further wind power expansion will risk disrupting the intact characteristics and inherent multifaceted values associated with the mountain region in Scandinavia. This is recognized in the recommendation of avoidance (BBOP 2012) of new wind power in the national strategy (ER 2021) in this region.

In contrast to the mountain region, the wind power strategy proposes a large expansion in the remaining part of northern Sweden. The ambition for the boreal forest region (i.e., the north coasts, and far north and north interior forestlands strata) is to have more than 2300 new turbines producing 47.5 TWh (equal to approximately 55% of total expected electricity production capacity). This will require more than 2000 km^2 of land surface for the sites and 6500 km^2 for the surrounding infrastructure area (defined as three times the site area) (ER 2021). On forestlands used for active forestry, somewhat less land will be available for forestry. On the other hand, a more developed road infrastructure in these remaining forestry lands will improve accessibility. Hence, forestry and wind power production may be combined with a certain mutual integration and synergetic gain (Bunzel et al 2019). In this context, it should be stressed that the forest landscape in Sweden outside the mountain region is already heavily modified by decades of modern clearcutting forestry practices (Kuuluvainen et al. 2017, Swedish Forest Agency 2020) and does not represent natural or even near-natural conditions (Josefsson et al. 2010, Svensson et al. 2019). Thus, wind power generally does not interfere with exclusive natural forest ecosystem conditions. Still, the expansion of wind power adds an additional type of land use to landscapes that have already multiple, overlapping uses. This challenges sustainability and potentially contributes to enforced loss of intrinsic ecological and socio-cultural values and ecosystem services (e.g., Angelstam et al. 2020). Further, aspects such as how to mitigate cumulative disturbances by wind power in addition to other exploitative land use, such as mining and industrial wood biomass-oriented plantation forestry, which is dominating in Sweden and Finland (e.g., Kuuluvainen et al. 2017), contest the identification of eligible locations for wind energy production and distribution (Ryberg et al. 2020).

Landowner

Our results on landowner composition on-site and at distance from wind power underscores two points. First, the dominant landowner category on-site differs between north and south Sweden, and second, it differs between on-site and at the 10-km distance. We found a predominance of public land in the mountain region, forest company land in the forest-dominated northern inland strata, and NIP land in the south. Particularly in the forest-dominated strata, forest company land dominates within the wind power sites, whereas the share of NIP land increases at distance. Thus, although wind power is built mainly on forest company land, the impact also affects NIP owners. The different on-site and close-distance effects will have to be addressed in wind power expansion. It should be assumed that different types of negotiation and communication routines, compensation frameworks, conflict management, licensing practices, etc. (Inderberg et al. 2019, Saglie et al. 2020, Gulbrandsen et al. 2021) will have to be applied to different types of landowners in different parts of the country.

In addition to land ownership, however, there are other rights holders to consider; i.e., those with rights to use the land without formal ownership. In the case of northern Sweden, the most important example is the Sámi people's rights to the land (Sandström et al. 2016). Furthermore, the Swedish right of public access to land outside private housing properties and arable land is an important traditional customary rule (Sandell and Fredman 2010) and is vital to many businesses (Andersson Cederholm and Sjöholm 2021). The same can be argued for hunting rights (Saito et al. 2023). Taken together, this makes the fairness aspects of onshore wind power expansion even more spatially complex (Avila 2018, Bjärstig et al. 2022).

Formal protection

Protected areas (Swedish Environmental Code 1998, Chapter 7) cover a small share of the within 1-km distance but a large share of the within 10-km distance. At the latter distance, our estimate (7600 km^2; 13.2%) is similar to the national share of all formally protected terrestrial and inland water surface in Sweden (Statistics Sweden 2021b); hence, this must be considered as very substantial. Furthermore, the share of protected area is particularly large in south Sweden (far south interior forestlands and far south coasts strata), which has a more urban character. The claim of approximately 12,000 km^2 land surface for the wind power sites and their immediate surrounding infrastructure areas according to the national wind power strategy (ER 2021) equals approximately 3.5% of the total national land surface. Although it represents a moderate land share, 3.5% is comparable to the share of all formally protected forestlands in Sweden below the mountain forest border (3.7%) (Statistics Sweden 2021b). This share of protected forests is seriously questioned by the forestry industry due to the loss of forestland used for wood biomass production (e.g., Angelstam et al. 2020).

It is recognized that the protected areas need to be increased and their ecological functionality needs to be improved (Statistics Sweden 2021b). Presently, sufficient area and spatial configuration for functional ecosystems, representative habitats, and suitable habitat for threatened species is far from secured in Sweden outside the mountain region (Orlikowska et al. 2020, Mikusiński et al. 2021). Given the extensive evidence of the negative effects of wind power on biodiversity, various species, intact landscape characteristics, landscape views, and socio-cultural aspects (e.g., Oles and Hammarlund 2011, Sandgren et al. 2013, Perrow 2017, Szumilas-Kowalczyk et al. 2020, Kati et al. 2021), national strategies on protection and wind power are not compatible. Obviously, this discrepancy represents actual and potentially deepened conflicts, ultimately between the Sustainable Development Goals 7 (affordable and clear energy) and 15 (life on land) (Nilsson et al. 2016). Precedence in priorities and decision-making for negative impact mitigation is not clarified or supported by the NI framework or by an integrated planning basis. If not well-tuned, establishment of 80 TWh or more (ER 2021) onshore wind power will risk further landscape overuse and result in critical loss of biodiversity, ecosystem services, and traditional values.

CONCLUSIONS

Using the land base in Sweden as a case, this study provides a comprehensive assessment of northern European anthropogenic landscapes that will become increasingly typified by wind power. We explored the extent to which the existing legal national interest framework facilitates sustainable planning of the expected expansion of onshore wind power. We assessed the spatial interaction between wind power establishments and legal claims with other conservation and landscape values and land uses, which land cover types and landowners provide the land needed for this, and to what extent formal protection is affected. We conclude that the current NI framework for locating wind power sites does not provide sufficient support for placing wind power in a spatial context with other land use interests and landscape and conservation values. We conclude that an overall revision of the NI framework is critically needed to allow holistic, strategic, and sustainable landscape planning. We also conclude that wind power in Sweden most likely will expand in forest-dominated landscapes and mainly on land owned by forest companies, while the negative impacts will affect other land covers, landowners, and rights holders. The substantial share of private ownership of land in Sweden poses a challenging situation compared with countries that have predominantly state forest ownership. Finally, we conclude that substantial areas that are important for Indigenous Sámi people reindeer husbandry and formal protection of biodiversity and landscape values are within close distance of wind power sites. This "overcrowded" situation is to be seen as a general obstacle in countries that experience a similar extensive development of a major land use actor such as onshore wind power. Ways forward toward sustainable onshore wind power development will require a well-developed mitigation strategy but also a focus on possible integration and synergy effects. This calls for integrated planning approaches that are not yet in place.

Author Contributions:

JS was the PI and developed the conceptual approach together with WN. JS drafted all text. WN made all data collections and performed all calculations in cooperation with JS. JS and WN developed tables, figures, and appendices. TB and CT contributed continuously to the approach. WN, TB, and CS provided input into the text, interpretations of results and context.

Acknowledgments:

We acknowledge funding from the Swedish Energy Agency and Swedish Environmental Protection Agency in-common Vindval program (grant P47419-1) and assistance with the landowner data by Birgitta Olsson of the Swedish Environmental Protection Agency. We also acknowledge valuable comments from anonymous reviewers and the editorial board, and the contribution by John P. Ball, PhD, on language and overall clarity of the content and study approach.

Data Availability:

All data are referenced to original sources. We provide appendices that contain further information on data and data categorization.

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APPENDIX 1. SUB REGIONS

Table A1.1. The eight sub regions are based on the 10 strata that are applied in the National Inventory of Landscapes in Sweden (NILS; Ståhl et al. 2011) biodiversity, land use, and landscape change program, with sub region 8 combining NILS strata 1 and 2, and sub region 6 combining NILS strata 3 and 4.

Sub regions		NILS strata in Swedish	Description
1	Mountains and foothills	Fjällen och fjällnära området (10)	The area above the mountain forest border that includes subalpine coniferous forests, mountain birch (*Betula pubescens ssp. Czerepanovii*) tree-line forests and open sub alpine and alpine environments.
2	Far north interior forestlands	Norra Norrlands inland (9)	Forest-dominated landscapes mainly with Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) plantations and with a transition into subalpine and arctic tundra landscapes to the west and north. Extensive wetlands and bedrock- or other dry habitats, open or with sparse tree coverage, occurs in both strata.
3	North interior forestlands	Södra Norrlands inland (8)	As sub region no. 2
4	North coasts	Norrlands kustland (7)	The Gulf of Bothnia coastline in boreal Sweden below the highest post-glacial highest coastline. The landscapes are plantation forest-dominated with intermixed open areas including large wetlands in particular in the central and north parts.
5	South interior forestlands	Mellersta Sveriges skogsbygder (6)	Plantation forest-dominated landscapes in the transition from boreal to hemi-boreal and temperate conditions.
6	South interior plains	Götalands norra och Svealands slättbygder (3, 4)	Plains and other agriculture-dominated and open landscapes of south-central Sweden. This sub region is the most rich in amount of inland water bodies.
7	Far south interior forestlands	Götalands skogsbygder (5)	Hemi-boreal (boreonemoral) plantation forest-dominated landscapes, with intermixed but not dominating open agricultural areas and plains.
8	Far south coasts	Götalands slätt- och mellanbygder (1, 2)	Plains, agriculture-dominated and other open landscapes and transition to temperate forest-dominated areas in vicinity of the coasts of south Sweden.

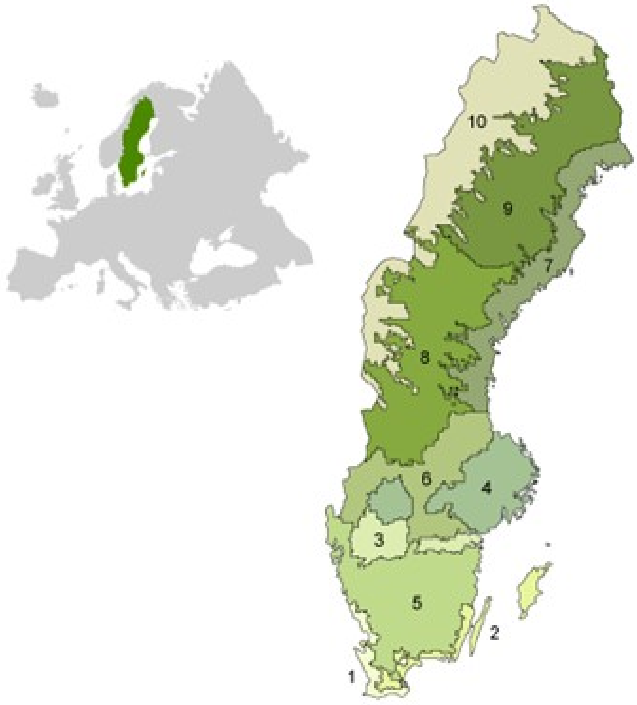

Fig. A1.2. Stratification according the National Inventory of Landscapes in Sweden (Ståhl et al. 2011)

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APPENDIX 2. NATIONAL INTEREST CATEGORIES

The national interest (NI) categories in this study concern wind power energy production, landscape values, nature conservation values, reindeer husbandry, national defense, and material and minerals (mining). The specific values and qualities are not explicitly expressed in the Swedish Environmental Code (1998), whereby categorization is not straightforward. In this study, we have based the categorization on the generic type of protection and land-use value that the national interest is supposed to deliver and protect. Only NIs on terrestrial area and outside urban centers are included. The Swedish Environmental Code also include other national interests that are not considered in this study: In chapter 3 (5-9 §§) hydro-electrical energy production, drinking water supply, energy distribution, communication (physical and digital/electronic), industrial production, waste treatment, nuclear waste storage, commercial fishing. In chapter 4 (2-8 §§) the national city park in Stockholm (Swedish: "Nationalstadsparken").

Table A2.1. Categories of national interests and the various NIs employed in this study, with their chapter and definition according to the Swedish Environmental Code (following Svensson et al. 2020a).

Wind power	Wind power energy production, 3:8. Land and water areas that are in particular suitable for installations for energy production, should as far as possible be protected against measures that substantially may hinder such establishment and use.
Landscape values	Contiguous mountains, 4:5. A defined mountain area in which buildings and installations can be approved only if they are needed for reindeer husbandry, local inhabitants, scientific purposes or for itinerant recreation. Measures not needed for the above purposes are approved only if it is without impact on the natural and semi-natural landscape characteristics of the areas.
	Coastal and archipelago areas protected from exploitation, 4:3-4. Land use and exploitation is restricted within defined coastal and archipelago areas, either for exploitative land use, which requires a Parliamentary decision, or for general land use for building or expanding existing secondary home installations. In the latter case, buildings that support facilities for recreational purpose may be permitted if certain reasons can be presented, and mainly for recreational areas close to larger urban centers.
	Watercourses protected from hydro-electrical installations, 4:6. Installations for hydro-electrical energy production is not allowed. This includes also regulation of water level and channeling of water away from the watercourse. Land use and land-use installations should not at all, or only temporarily and at low degree, affect the environmental qualities negatively.
	Cultural environment, 3:6. Land and water areas, and the physical environment in general, that in a public opinion are important for their cultural values, should as far as possible be protected against measures that substantially may harm the natural- or cultural environment.
	Recreation, 3:6. Land- and water areas, and the physical environment in general, that in a public opinion are important for their recreational values, should as far as possible be protected against measures that substantially may harm the natural- or cultural environment.
	Itinerant recreation and tourism, 4:2. A defined geographical area in which the tourism and recreation interests, in particular for itinerant recreation, should be especially considered in the approval of exploitive or other impacts and measures on the environment.
Nature conservation	Nature conservation, 3:6. Land and water areas, and the physical environment in general, that in a public opinion are important for their natural values, should as far as possible be protected against measures that substantially may harm the natural- or cultural environment.
	Natura 2000 Species and Habitat Directive, 4:8. Use of land and water in a nature area that has been assigned according to the EU Species and Habitat Directive (2006/105/EG), that in

	a substantial way will impact the environment, requires a formal permission. Measures that are directly necessary for management and governance of the natural values are allowed. Natura 2000 Birds Directive 4:8. Use of land and water in a nature area that has been assigned according to the EU Bird directive (2009/147/EG), that in a substantial way will impact the environment, requires a formal permission. Measures that are directly necessary for management and governance of the natural values are allowed.
Reindeer husbandry	3:5. Land and water areas that are important to reindeer husbandry, should as far as possible be protected against measures that may hinder reindeer husbandry. Reindeer husbandry is allowed land use within the defined reindeer husbandry area (Reindeer Husbandry Act 1971)
National defense	Military and other national defense, 3:9: Land and water areas that are important to the national defense, should as far as possible be protected against measures that, noticeable, may hinder the national defense interests. Areas that are needed for the national defense, are protected against measures that, noticeable, can limit access and use of national defense installations.
Mining	Material and minerals, 3:7. Land and water areas that harbor known resources of valuable substances and materials, should be protected against measures that substantially may hinder their excavation.

LITERATURE CITED

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APPENDIX 3. NATIONAL INTEREST WIND POWER WITH BUFFER FOR SETTLEMENTS

To avoid or reduce direct impact on settlements, the polygons and areas for national interest (NI) for wind power energy production includes buffer areas inside and along the boundaries of the original NI-polygons, set systematically at a 800 m radius from settlements (http://mdp.vic-metria.nu/miljodataportalen/, date 24 October 2019). For consistency with the other NIs included in this study, this buffering has not been accounted for in the analyses.

Table A3.1. Total area (km^2) and area proportion (%) of national interest wind power with reduction of 800 m radius around settlements.

	km^2	%
1 Mountains and foothills	179	0.2
2 Far north interior forestlands	893	1.1
3 North interior forestlands	1,104	1.4
4 North coasts	550	1.1
5 South interior forestlands	314	0.8
6 South interior plains	87	0.2
7 Far south interior forestlands	385	0.6
8 Far south coasts	160	0.7
National total	3,671	0.8

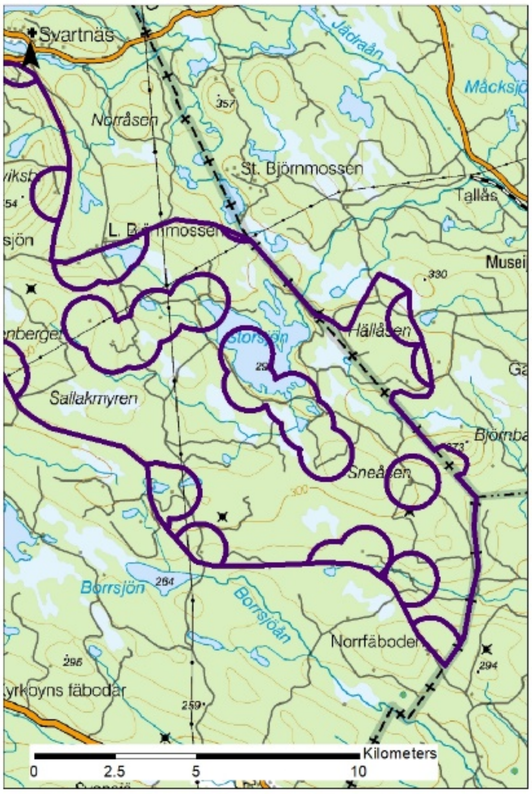

Fig. A3.2. An example of a national interest wind power polygon with systematic 800 m buffers around settlements.

APPENDIX 4. NATIONAL INTEREST NATIONAL DEFENSE

The national defense national interests (NI) occur in the Swedish Environmental Code (1998) in sets with different degree of protection and restrictions for other use:

1. Includes areas of national interest and special needs for limiting tall constructions on terrestrial surface, i.e. it is prohibited to build high buildings and installations, including wind power turbines. Set 1 was employed in the analyses.
2. Includes low flying airfare, safety areas (55 km buffer) around airports to guarantee obstacle clearance for air traffic, civil airports, and risk of other impact on air traffic.
3. Includes risk of noise and other danger, and weather radar clearance.

In this study, only category 1 was used as NI national defense.

Table A4.1. Occurrence (km^2) and overlap share (%) of National defense categories 1 and 2 combined and 1, 2 and 3 combined, presented on national scale and for each stratum.

	Categories 1 + 2				Categories 1 + 2 + 3			
	Occurrence		Overlap		Occurrence		Overlap	
	km^2	%	km^2	%	km^2	%	km^2	%
Mountains and foothills	21,728	23.8	77	40.5	22,695	24.8	80	42.3
Far north interior forestlands	32,082	40.6	275	28.6	33,163	42.0	331	34.5
North interior forestlands	17,868	22.1	249	18.7	33,337	41.2	474	35.6
North coasts	10,575	21.4	28	4.3	22,943	46.5	336	52.0
South interior forestlands	8,198	21.3	57	14.2	9,510	24.7	57	14.2
South interior plains	25,394	44.3	32	28.2	29,862	52.1	32	28.3
Far south interior forestlands	20,607	32.3	310	36.7	27,545	43.2	350	41.5
Far south coasts	6,853	30.3	118	65.9	11,134	49.2	137	76.5
National total	143,304	29.7	1,145	24.5	190,190	39.4	1,796	38.6

APPENDIX 5. LAND COVER CATEGORIES

Definitions according to NMD (Swedish Environmental Protection Agency 2018, 2019) of these land-cover types:

Forestland:	Tree-covered areas outside and on wetland with a total crown cover of >10%. Trees are higher than 5 meters. We also included temporarily non-forest areas with were at the time of the map open or re-growing with trees less 5 meters, reflecting clear-felled, storm-felled or burnt areas.
Wetland:	Open land where the water for a large part of the year is close by, in or just above the ground surface.
Agriculture land:	Agricultural land used for plant cultivation or kept in such a condition that it can be used for plant cultivation. The land should be able to be used without any special preparatory action other than the use of conventional farming methods and agricultural machinery. The soil can be used for plant cultivation every year. Exceptions can be made for an individual year if special circumstances exist.
Other open land:	Land that is not wetland, arable land or exploited vegetation-free surfaces and has 10% or less vegetation coverage during the current vegetation period. The ground can be covered by moss and lichen.
Artificial surfaces:	Durable infrastructure constructions consisting of roofs or roofs and walls, roads, railways, and artificial open and vegetation-free surfaces that are not buildings, roads or railways.
Waterbody:	Inland and marine waters.

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Swedish Environmental Protection Agency. 2018. Naturvårdsverket. Nationella marktäckedata 2018 basskikt. Produktbeskrivning. Utgåva 2.2. 2020-07-07. Available at: Nationella marktäckedata 2018 – basskikt (naturvardsverket.se). (In Swedish)

Swedish Environmental Protection Agency. 2019. Naturvårdsverket. Nationella Marktäckedata. Available at https://www.naturvardsverket.se/Samar-miljon/Kartor/Nationella-Marktackedata-NMD/ (In Swedish) (accessed March 16, 2020); un-generalized raster, 10x10 m, June 18, 2021. (In Swedish)

APPENDIX 6. LANDOWNER CATEGORIES

Landowner data were provided by the Swedish Environmental Protection Agency, as applied by Henriksson and Olsson (2020). We analyzed ownership distribution for three categories:

1) Public, including the National Property Board, the Fortification Agency, other state agencies including the Swedish Environmental Protection Agency, regional and municipal authorities;
2) Private forest companies (Billerud-Korsnäs, Stora Enso, Holmen, SCA, Sveaskog state forest companies), other incorporates, the Swedish Church, and forest commons (i.e. land owned by share by a community);
3) Non-industrial private owners, defined as ownership polygons up to 1000 ha owned by private persons and households.

LITERATURE CITED

Henriksson S., and B. Olsson. 2020. Kunskapssammanställning fjällnära skog. Redovisning av underlag till Skogsutredningen 2019. Naturvårdsverket och Skogsstyrelsen, 2020-02-14. Dnr. NV-07994-19. (In Swedish)

APPENDIX 7. DATA AVAILABILITY

Table A7.1. Sources, type and date of assessment of the spatial data applied in the analysis to quantify the spatial distribution and overlap among wind power establishment, national interests, protected areas in Sweden.

Data	Data type	Source	Address	Accessed
Wind power turbines (established, approved, in process)	Vector (point)	Vindbrukskollen	https://vbk.lansstyrelsen.se/en	18 May 2021
National Interests				
Wind power energy production, 3:8.	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	24 Oct 2019
Reindeer husbandry 3:5.	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Material and minerals, 3:7.	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Military and other national defense, 3:9:	Vector (polygon)	Swedish Armed Forces	https://www.forsvarsmakten.se/en	14 May 2020
Nature Conservation Values				
Nature conservation, 3:6.	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Natura 2000 Birds Directive 4:8	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Natura 2000 Species and Habitat Directive, 4:8	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Landscape Values				
Contiguous mountains, 4:5	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Coastal and archipelago areas protected from exploitation, 4:3-4	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	21 May 2021
Watercourses protected from hydro-electrical installations, 4:6.	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	24 Oct 2019
Cultural environment, 3:6	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Recreation, 3:6	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018

Itinerant recreation and tourism, 4:2	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	13 Nov 2018
Protected Areas				
National Park, 7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	10 Apr 2019
Nature Reserve, 7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	10 Apr 2019
Biotope Protection Areas, 7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	10 Oct 2019
		Swedish Forest Agency	https://www.skogsstyrelsen.se/en/	06 Jul 2021
Fauna and flora protection areas, 7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	27 Aug 2019
Nature conservation areas,7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	27 Aug 2019
Nature conservation agreements according to the Land code (1970)	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	28 Aug 2019
		Swedish Forest Agency	https://www.skogsstyrelsen.se/en/	06 Jul 2021
Nature heritage areas, 7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	10 Apr 2019
Cultural reserves,7	Vector (polygon)	Swedish Environmental Protection Agency	https://miljodataportalen.naturvardsverket.se/miljodataportalen/	10 Apr 2019
Other				
National Land cover	Raster (10x10m)	Swedish Environmental Protection Agency	https://www.naturvardsverket.se/en/services-and-permits/maps-and-map-services/national-land-cover-database/	18 Jun 2021
Land Owner	Vector (polygon)	Swedish Environmental Protection Agency	https://www.naturvardsverket.se/en	10 Jun 2020

APPENDIX 8. STATISTICAL TESTS

Table A8.1. Proportion test on the occurrence of different landowner categories between scales across regions. Significant greater proportions on the first-named scale compared to the second-named one in bold. X^2 = X squared statistic, p = p-value (0 < 0.05, 1 = non-significant).

		Proportion in 1km-buffer compared to wind power sites			Proportion in 10km-buffer compared to 1km-buffer			Proportion in wind power sites compared to strata		
Owner	Region	X^2	Percentage difference	p	X^2	Percentage difference	p	X^2	Percentage difference	p
Public	Mountains	2,090,635	-0.117	1	**542,098**	**0.031**	**0**	594,276	-0.045	1
Public	Far north forests	**1,570,683**	**0.008**	**0**	**26,808,426**	**0.035**	**0**	45,811,779	-0.079	1
Public	North forests	**1,024,644**	**0.006**	**0**	**2,545,466**	**0.006**	**0**	14,403,727	-0.023	1
Public	North coasts	**2,651,071**	**0.020**	**0**	**443,929**	**0.005**	**0**	7,242,406	-0.036	1
Public	South forests	**4,477,793**	**0.021**	**0**	**9,709,568**	**0.023**	**0**	13,391,899	-0.043	1
Public	South plains	**256,281**	**0.010**	**0**	**40,224,981**	**0.045**	**0**	6,921,417	-0.092	1
Public	Far south forests	**970,458**	**0.007**	**0**	**39,914,218**	**0.033**	**0**	15,873,321	-0.046	1
Public	Far south plains	888,212	-0.019	1	**33,017,269**	**0.045**	**0**	1,346,693	-0.030	1
Company	Mountains	28,449	-0.011	1	1,188,637	-0.035	1	**10,961,931**	**0.122**	**0**
Company	Far north forests	**48,968**	**0.005**	**0**	124,648	-0.005	1	9,606	-0.002	1
Company	North forests	8,611,546	-0.049	1	76,225,697	-0.090	1	**134,315,717**	**0.173**	**0**
Company	North coasts	16,640,459	-0.139	1	69,794,504	-0.141	1	**178,316,231**	**0.351**	**0**
Company	South forests	29,550,521	-0.153	1	167,995,486	-0.212	1	**201,999,596**	**0.361**	**0**
Company	South plains	22,237,959	-0.156	1	**20,212,220**	**0.041**	**0**	**3,654,418**	**0.078**	**0**
Company	Far south forests	7,866,189	-0.054	1	8,762,657	-0.023	1	**17,341,750**	**0.068**	**0**
Company	Far south plains	60,585	-0.005	1	**1,432,376**	**0.008**	**0**	31,253	-0.004	1
NIP	Mountains	**4,387,484**	**0.128**	**0**	**8,916**	**0.003**	**0**	2,380,141	-0.077	1
NIP	Far north forests	326,687	-0.014	1	4,225,018	-0.029	1	**18,357,487**	**0.081**	**0**
NIP	North forests	**7,058,511**	**0.043**	**0**	**68,596,238**	**0.084**	**0**	103,296,019	-0.149	1
NIP	North coasts	**12,358,314**	**0.119**	**0**	**62,149,009**	**0.137**	**0**	129,653,077	-0.315	1
NIP	South forests	**23,160,546**	**0.132**	**0**	**130,696,816**	**0.188**	**0**	153,972,921	-0.318	1
NIP	South plains	**15,371,259**	**0.146**	**0**	61,861,652	-0.086	1	**78,481**	**0.014**	**0**
NIP	Far south forests	**5,405,828**	**0.047**	**0**	1,400,323	-0.011	1	1,315,396	-0.022	1
NIP	Far south plains	**735,871**	**0.024**	**0**	29,147,874	-0.053	1	**1,118,188**	**0.034**	**0**

Table A8.2. Proportion test on the occurrence of different land cover types between scales across regions. Significant greater proportions on the first-named scale compared to the second-named one in bold. X^2 = X squared statistic, p = p-value (0 < 0.05, 1 = non-significant).

		Proportion in 1km-buffer compared to wind power sites			Proportion in 10km-buffer compared to 1km-buffer			Proportion in wind power sites compared to strata		
Land cover	**Region**	**X^2**	**Percentage difference**	**p**	**X^2**	**Percentage difference**	**p**	**X^2**	**Percentage difference**	**p**
Forest	Mountains	**5,670,427**	**0.181**	**0**	**1,130,264**	**0.046**	**0**	4,789,166	-0.144	1
Forest	Far north forests	**466,774**	**0.015**	**0**	6,681,197	-0.035	1	**3,150,237**	**0.033**	**0**
Forest	North forests	**788,413**	**0.011**	**0**	42,204,640	-0.054	1	**26,669,458**	**0.065**	**0**
Forest	North coasts	686,519	-0.021	1	99,620,620	-0.163	1	**48,847,470**	**0.196**	**0**
Forest	South forests	465,728	-0.014	1	93,135,320	-0.140	1	**45,442,770**	**0.155**	**0**
Forest	South plains	46,343,091	-0.366	1	**63,275,549**	**0.106**	**0**	**24,441,260**	**0.269**	**0**
Forest	Far south forests	13,663,201	-0.085	1	89,816,707	-0.108	1	**71,262,814**	**0.200**	**0**
Forest	Far south plains	80,877,442	-0.368	1	**511,382**	**0.008**	**0**	**87,301,784**	**0.360**	**0**
Arable	Mountains	**1,954**	**0.000**	**0**	**3,171**	**0.000**	**0**	525	0.000	1
Arable	Far north forests	**1,572**	**0.000**	**0**	**1,541,663**	**0.002**	**0**	885,558	-0.002	1
Arable	North forests	**1,129,768**	**0.001**	**0**	**11,666,267**	**0.006**	**0**	9,311,370	-0.008	1
Arable	North coasts	**1,426,825**	**0.006**	**0**	**14,784,652**	**0.022**	**0**	10,495,725	-0.036	1
Arable	South forests	**3,412,697**	**0.011**	**0**	**34,659,773**	**0.043**	**0**	18,821,182	-0.048	1
Arable	South plains	**34,377,776**	**0.332**	**0**	482,243,456	-0.267	1	**306,168**	**0.023**	**0**
Arable	Far south forests	**19,168,896**	**0.059**	**0**	**2,433,458**	**0.010**	**0**	18,261,207	-0.054	1
Arable	Far south plains	**48,418,021**	**0.316**	**0**	315,408,318	-0.220	1	3,005,075	-0.068	1
Wetland	Mountains	**6,894**	**0.005**	**0**	**1,089,773**	**0.035**	**0**	4,525	-0.003	1
Wetland	Far north forests	198,296	-0.009	1	58	0.000	1	**1,172,048**	**0.017**	**0**
Wetland	North forests	1,719,487	-0.013	1	14,078	-0.001	1	**1,423,940**	**0.010**	**0**
Wetland	North coasts	1,407,270	-0.020	1	16,202,319	-0.027	1	**12,585,008**	**0.042**	**0**
Wetland	South forests	471,455	-0.008	1	1,365,326	-0.007	1	**2,229,302**	**0.014**	**0**
Wetland	South plains	261,157	-0.007	1	**6,173,026**	**0.010**	**0**	2,897	-0.001	1
Wetland	Far south forests	1,271,172	-0.011	1	**190,657**	**0.002**	**0**	**1,222,204**	**0.010**	**0**
Wetland	Far south plains	99,405	-0.003	1	**1,315,515**	**0.004**	**0**	1,426	0.000	1
Open	Mountains	4,719,475	-0.186	1	2,911,356	-0.076	1	**4,637,484**	**0.158**	**0**
Open	Far north forests	759,546	-0.010	1	12,948,049	-0.020	1	**5,512,106**	**0.019**	**0**
Open	North forests	1,420	0.000	1	7,231	0.000	1	954,865	-0.005	1
Open	**North coasts**	**93,763**	**0.004**	**0**	19,505	-0.001	1	227,287	-0.005	1
Open	**South forests**	**197,895**	**0.004**	**0**	**4,244,740**	**0.013**	**0**	1,875,917	-0.013	1
Open	**South plains**	**509,884**	**0.019**	**0**	**1,297,244**	**0.008**	**0**	721,053	-0.023	1
Open	**Far south forests**	**3,147,922**	**0.025**	**0**	**2,091,324**	**0.010**	**0**	4,409,166	-0.028	1
Open	**Far south plains**	**542,413**	**0.021**	**0**	**4,062,424**	**0.018**	**0**	1,474,519	-0.035	1
Artificial	**Mountains**	**51,077**	**0.005**	**0**	424,874	-0.006	1	**2,669,540**	**0.010**	**0**
Artificial	Far north forests	7,840	0.000	1	**68,790**	**0.001**	**0**	2,794	0.000	1
Artificial	North forests	**2,314**	**0.000**	**0**	**304,329**	**0.001**	**0**	294,343	-0.002	1
Artificial	North coasts	**7,788**	**0.001**	**0**	**609,113**	**0.004**	**0**	442,751	-0.006	1

		Proportion in 1km-buffer compared to wind power sites			Proportion in 10km-buffer compared to 1km-buffer			Proportion in wind power sites compared to strata		
Land cover	**Region**	**X^2**	**Percentage difference**	**p**	**X^2**	**Percentage difference**	**p**	**X^2**	**Percentage difference**	**p**
Artificial	South forests	**5,183**	**0.001**	**0**	**1,769,251**	**0.007**	**0**	667,674	-0.007	1
Artificial	South plains	**79,701**	**0.006**	**0**	2,429	0.000	1	24,446	-0.003	1
Artificial	Far south forests	**368,888**	**0.006**	**0**	**670,713**	**0.004**	**0**	944,293	-0.009	1
Artificial	Far south plains	10,143	-0.002	1	821,900	-0.005	1	**356,548**	**0.010**	**0**
Water	Mountains	12,625	-0.004	1	**1,903**	**0.001**	**0**	295,246	-0.021	1
Water	Far north forests	**626,358**	**0.004**	**0**	**55,102,524**	**0.052**	**0**	40,000,619	-0.067	1
Water	North forests	**15,776**	**0.001**	**0**	**85,392,848**	**0.048**	**0**	53,443,603	-0.059	1
Water	North coasts	**4,827,333**	**0.031**	**0**	**137,199,437**	**0.165**	**0**	63,506,460	-0.191	1
Water	South forests	**346,237**	**0.007**	**0**	**63,835,145**	**0.084**	**0**	34,087,710	-0.101	1
Water	South plains	**606,908**	**0.015**	**0**	**201,401,904**	**0.143**	**0**	28,632,805	-0.265	1
Water	Far south forests	**432,687**	**0.006**	**0**	**120,034,913**	**0.082**	**0**	46,618,857	-0.118	1
Water	Far south plains	**3,546,773**	**0.037**	**0**	**306,090,210**	**0.196**	**0**	46,432,882	-0.267	1

Table A8.3. Chi square test on the equal percentage share of landowner categories in wind power sites across regions. X^2 = X squared statistic, p = p-value (0 < 0.05, 1 = non-significant).

Region	X^2	Degrees of freedom	p-value
Mountains	38,538,833	2	0
Far north forests	313,220,562	2	0
North forests	874,802,656	2	0
North coasts	157,643,412	2	0
South forests	374,109,978	2	0
South plains	66,747,653	2	0
Far south forests	414,391,898	2	0
Far south plains	170,324,585	2	0

Table A8.4. Chi square test on the equal percentage share of land cover type in wind power sites across regions. X^2 = X squared statistic, p = p-value (0 < 0.05, 1 = non-significant).

Region	X^2	**Degrees of freedom**	**p-value**
Mountains	89,570,110	5	0
Far north forests	1,474,685,638	5	0
North forests	3,723,760,749	5	0
North coasts	965,767,469	5	0
South forests	1,394,564,153	5	0
South plains	174,031,677	5	0
Far south forests	1,323,116,539	5	0
Far south plains	218,716,957	5	0

APPENDIX 9. SINGLE NATIONAL INTERESTS IN THE LANDSCAPE VALUES AND NATURE CONSERVATION CATEGORIES.

Table A9.1. Total area (km^2) and area proportion (%) of the single national interests (NI) in the landscape values NI-category, per sub region and nationally.

Stratum	Contiguous mountains		Coastal and archipelago areas protected from exploitation		Watercourses protected from hydro-electrical installations *		Cultural environment		Recreation		Itinerant recreation and tourism	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Mountains and foothills	48,497	53.0	-	-	15,093	16.5	2017	2.2	61,439	67.2	30,597	33.5
Far north interior forestland	107	0.1	-	-	14,322	18.1	1,253	1.6	5,495	7.0	1,959	2.5
North interior forestlands	16	<0.0	-	-	17,219	21.3	4,207	5.2	9,615	11.9	8,919	11.0
North coasts	-	-	1,624	3.3	4,450	9.0	1,307	2.6	6,939	14.1	6,857	13.9
South interior forestlands	-	-			393	1.0	843	2.2	4,962	12.9	4,542	11.8
South interior plains	-	-	99	0.2	102	0.2	5,990	10.4	12,219	21.3	18,119	31.6
Far south interior forestland	-	-	3,872	6.1	8,238	12.9	2,815	4.4	9,263	14.5	7,256	11.4
Far south coasts	-	-	2,455		239	1.1	2.656	11.7	3,474	15.4	9,038	39.9
Nation	48,620	19.3	8,051	4.2	60,057	12.4	21,089	4.4	113,406	23.5	87,289	18.1

Footnote: Polygons that cross sub regions were separated per sub region for area calculations. The area cover of natural interest (NI) categories are the net area, i.e. without overlapping area within the different NIs included in the category. Dash (–) indicates no occurrence. The single NI and the NI-categorization are presented in appendix 2. * Data for Norrbotten county, concerning Torneälven, Kalixälven and Piteälven river watersheds are missing in the public available data on protected watercourses, which implies an underestimate of area and share for the far north interior forestland strata.

Table A9.2. Overlap (in %) between national interest (NI) wind power and the single NI in the landscape values NI-category.

Stratum	Contiguous mountains	Coastal and archipelago areas protected from exploitation	Watercourses protected from hydro-electrical installations	Cultural environment	Recreation	Itinerant recreation and tourism
Mountains and foothills	-	-	-	-	4.4	1.9
Far north interior forestlands	-	-	26.5	0.1	<0.0	-
North interior forestlands	-	-	13.6	1.6	2.6	-
North coasts	-	-	13.7	0.2	8.5	2.6
South interior forestlands	-		-	1.1	9.2	7.6
South interior plains	-		-	8.5	13.5	10.1
Far south interior forestlands	-	-	21.1	1.2	3.5	1.1
Far south coasts	-	5.1	7.3	3.2	6.8	79.0

Footnote: Polygons that cross sub regions were separated per sub region for area calculations. The area cover of national interest (NI) categories are the net area, i.e. without overlapping area within the different NIs included in the category. Dash (–) indicates no occurrence. The single NI and the NI-categorization are presented in appendix 2. * Data for Norrbotten county, concerning Torneälven, Kalixälven and Piteälven river watersheds are missing in the public available data on protected watercourses, which implies an underestimate of area and share for the far north interior forestland strata.

Table A9.3. Total area (km^2) and area proportion (%) of the single national interests (NI) in the nature conservation values NI-category, per sub region and nationally.

Stratum	Nature conservation		Natura 2000 Species and Habitats Directive		Natura 2000 Birds Directive	
	km^2	%	km^2	%	km^2	%
Mountains and foothills	51,949	56.8	41,902	45.8	21,136	23.1
Far north interior forestland	7,378	9.3	2,504	3.2	485	0.6
North interior forestlands	5,656	7.0	1,871	2.3	699	0.9
North coasts	6,703	13.6	1,364	2.8	621	1.3
South interior forestlands	3,249	8.4	1,163	3.0	624	1.6
South interior plains	11,214	19.6	3,219	5.6	2,372	4.1
Far south interior forestland	10,640	16.7	3,678	5.8	1,479	2.3
Far south coasts	5,414	23.9	2,101	9.3	1,322	5.8
Nation	102,202	21.2	57,802	12.0	28,740	6.0

Footnote: Polygons that cross sub regions were separated per sub region for area calculations. The area cover of natural interest (NI) categories are the net area, i.e. without overlapping area within the different NIs included in the category. Dash (–) indicates no occurrence. The single NI and the NI-categorization are presented in appendix 2.

Table A9.4. Overlap (in %) between national interest (NI) wind power and the single NI in the nature conservation values NI-category.

Stratum	Nature conservation	Natura 2000 Species and Habitats Directive	Natura 2000 Birds Directive
Mountains and foothills	71.5	<0.0	<0.0
Far north interior forestlands	10.4	<0.0	<0.0
North interior forestlands	2	<0.0	<0.0
North coasts	5.6	<0.0	<0.0
South interior forestlands	4.0	<0.0	<0.0
South interior plains	26.6	<0.0	<0.0
Far south interior forestlands	5.6	<0.0	<0.0
Far south coasts	26.5	2.7	<0.0

Footnote: Polygons that cross sub regions were separated per sub region for area calculations. The area cover of national interest (NI) categories are the net area, i.e. without overlapping area within the different NIs included in the category. Dash (–) indicates no occurrence.

APPENDIX 10. ARTIFICIAL SURFACE

Table A10.1. Area (in km^2) of artificial surface, divided into sub-categories and presented per sub region and in total for 1 km and 10 km distance from wind power site boundaries.

	Buildings and urban areas (km^2)		Roads and railways (km^2)		Other built infrastructure (km^2)	
	1 km	10 km	1 km	10 km	1 km	10 km
1 Mountains and foothills	0.0	1.9	0.0	14.3	1.2	21.4
2 Far north interior forestland	0.0	3.2	12.8	149.9	1.1	8.6
3 North interior forestlands	0.2	12.2	35.7	436.8	1.3	11.7
4 North coasts	0.3	26.5	13.8	286.5	0.8	28.9
5 South interior forestlands	0.3	33.9	19.5	346.0	1.1	32.5
6 Far south interior forestland	5.8	127.2	41.8	657.3	5.3	113.9
7 South interior plains	3.7	132.6	54.1	1,043.6	5.0	109.6
8 Far south coasts	10.1	161.0	50.7	557.4	13.8	120.0
Total	20.4	498.5	229.3	3,491.8	29.6	446.6

Footnote: Artificial surface was calculated by pixels (10x10m) from the National land cover map (Swedish Environmental Protection Agency 2019); ‘Buildings and urban areas’ include pixels that indicate constructions (i.e. roofs and walls), ‘Roads and railways’ include pixels classified as roads and railways, ‘Other built infrastructure’ include pixels classified as artificial open and vegetation-free surface that are not building, road nor railway.