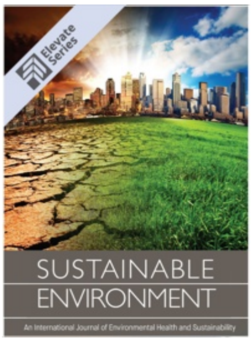

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Projected wind energy on forest land – A land use transition trajectory to reach 100% renewable energy goal in Sweden

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ABSTRACT

Transmission to renewable energy through wind energy challenges traditional land uses and existing landscape planning. Using Sweden as a case study, we quantified the spatial overlap between land cover and landownership with the projected onshore wind energy in five ecoregions, following the national strategy for wind energy production to meet 100% renewable energy production by 2040. Projected wind energy claims forests that are available for active forestry, woodlands not used by forestry and forests with high conservation value. Claims vary among ecoregions, emphasizing the need for regionalized context-specific planning to mitigate possible conflicts among different national and international environmental and sustainability goals.

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KEYWORDS
Renewable energy; forestry; high conservation value forest; forest owner; multiple use

1 Introduction

Onshore wind energy has expanded globally to meet the increasing demand for renewable energy (IRENA, 2023). As a result, landscapes are increasingly typified by the presence of turbines and surrounding infrastructure (Diógenes et al., 2020; Eichhorn et al., 2017). In landscapes with ongoing land use, wind energy establishments overlap single or multiple uses, values and interests at the sites, in their proximity, and at distance (Kiesecker et al., 2024; Rehbein et al., 2020). Intensive and overlapping land use characterizes the European continent, including traditional land use as well as land use for renewable energy (Hassan et al., 2024; Levers et al., 2018). Europe has a high capacity for wind energy, with four of the ten countries with the highest production globally being European, including Sweden (IRENA, 2023). As a late arriving type of land use in Sweden, wind energy adds to already existing cumulative anthropogenic pressure on ecological, economic and sociocultural landscape values and interests (Ramasar et al., 2022). As overlapping land-use interests are already pronounced in Swedish landscapes (Svensson et al., 2020), the expansion of wind energy risk to further intensify already existing land-use conflicts (Bjärstig et al., 2022) and may lead to situations with unsustainable consequences (Eichhorn et al., 2017; Rudolph et al., 2017). To facilitate sustainable wind energy expansion on a large scale, landscape planning must focus on minimizing negative effects and maximizing mitigation, integration and synergy opportunities (Svensson et al., 2023a). Therefore, when evaluating and understanding the multifaceted interactions between wind energy establishment and other interests and values, the choice of location is critical (Bjärstig et al., 2022; Harper et al., 2019). Since large-scale wind energy expansion is planned nationwide, Sweden makes an interesting case in a northern European context for evaluating the interactions between expanding large-scale wind energy and different land uses, landscape values and landowners.

In multiuse systems, spatially coexisting interests, values and goals can generate conflicting, neutral or synergy situations (Nilsson et al., 2016). Thus, priority and planning rely on informed decision making. Frequently, conflicts are apparent and arduous to avoid or mitigate, such as wind energy on land used by

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traditional seminomadic reindeer husbandry of indigenous Sami people in northern Sweden (Skarin et al., 2018). Globally, traditional and indigenous cultures occur in rural hinterland areas where they share resources and space with commercial resource utilization, including industrial forestry and renewable energy production and distribution (Fohringer et al., 2021; Da Silva & Galvão, 2022; Niebuhr et al. 2022). Thus, expanding wind energy risk is reaching tipping points that can result in irreversible loss of this important landscape and cultural value (Stoessel et al., 2022). For recreation, tourism and certain components of biodiversity (Svensson et al., 2020), negative consequences might be mitigated by adaptation and compensation measures in wind energy areas, allowing coexistence planning solutions (Kati et al., 2021; Tverijonaite & Sæþórsdóttir, 2020). However, for other values and land uses, co-occurrence with wind energy might provide opportunities for integration or even synergies (Bunzel and Bovet, 2019).

In Sweden, wind energy predominantly occurs in forest areas (Svensson et al., 2023). Similar situations can be found, for example, in Finland (Gaultier et al., 2023), Germany (Bunzel et al., 2019) and the US (Schlichting & Mercer, 2011). Forest landscapes harbor and provide manifold and diverse values and products, ranging from biodiversity conservation and carbon stock to recreational aspects and to the production of bioenergy and other wood products (Ameray et al., 2021; Anderegg et al., 2020; FAO, 2020; Gaultier et al., 2023; UNECE 2021). In this context, the boreal biome in northern Europe, and Sweden as a case, is of specific interest because of the high capital of these values as well as its presence of indigenous cultures.

In northern Europe, boreal forests cover vast rural areas with low human population density and extensive forest lands modified by large-scale, industrialized and systematic rotation forestry (Angelstam et al., 2020; FAO, 2020). Sweden is an important contributor to the European forest sector, with 20 million ha of in total 28 million ha forest land being considered as timber production land (SLU, 2024). As a consequence, biodiversity, traditional cultures and other critical forest ecosystem services and goods have long been marginalized (Felton et al., 2020; Sandström et al., 2016). Sweden covers an extended environmental gradient from nemoral to alpine ecoregions with characteristic assemblages of species, communities and ecosystems (Olson et al., 2001). Expanding renewable energy and industrial forestry practices must be balanced with environmental, biodiversity, ecological restoration and climate change mitigation goals. As Sweden currently cannot meet national and international environmental goals (e.g. Angelstam et al., 2020), such a balance has not been reached, asking for innovative prospects and strategies in sustainable landscape planning.

To realize the goal of 100% renewable energy production by 2040, the Swedish Energy Agency presented a national strategy for large-scale wind energy development to advance the sustainable expansion of onshore wind energy (ER, 2021). The strategy relies on a minimum of 80 TWh additional onshore production with region-specific energy production directives (Appendix Table A1). Based on previous research and regional expansion goals, formulated nationally, we use Sweden as a case for exploring opportunities and challenges in the wind energy-driven transformation of land use on forest land. To reflect the ongoing land use trajectory towards the 2040 goal, we developed a 2040 projection based on the status of onshore wind energy in 2022 and the expected future (2040) production capacity. To advance sustainable planning premises, we explored how wind energy affects different categories of forest and forest owners within and in proximity to wind energy sites in ecoregions and counties, the latter reflecting local situations. We expect that our findings will support forest and landscape planners and managers to make informed planning decisions that improve sustainable integration of the expanding wind energy land user in forests and forest landscapes already characterized by multiple uses and challenging conflicts.

2 Materials and methods

2.1 Study area and stratification

We followed the ecoregion division applied in the official statistics reporting of protected nature in Sweden (Statistics Sweden, 2024). These ecoregions are delineated by county borders, thus allowing to reflect county-specific planning on wind energy expansion (ER, 2021). Having a focus on forest lands and considering the low current presence of wind energy (Svensson et al., 2023a) and no project expansion (ER, 2021) in the alpine region, our study area covered four ecoregions in Sweden: north boreal, south

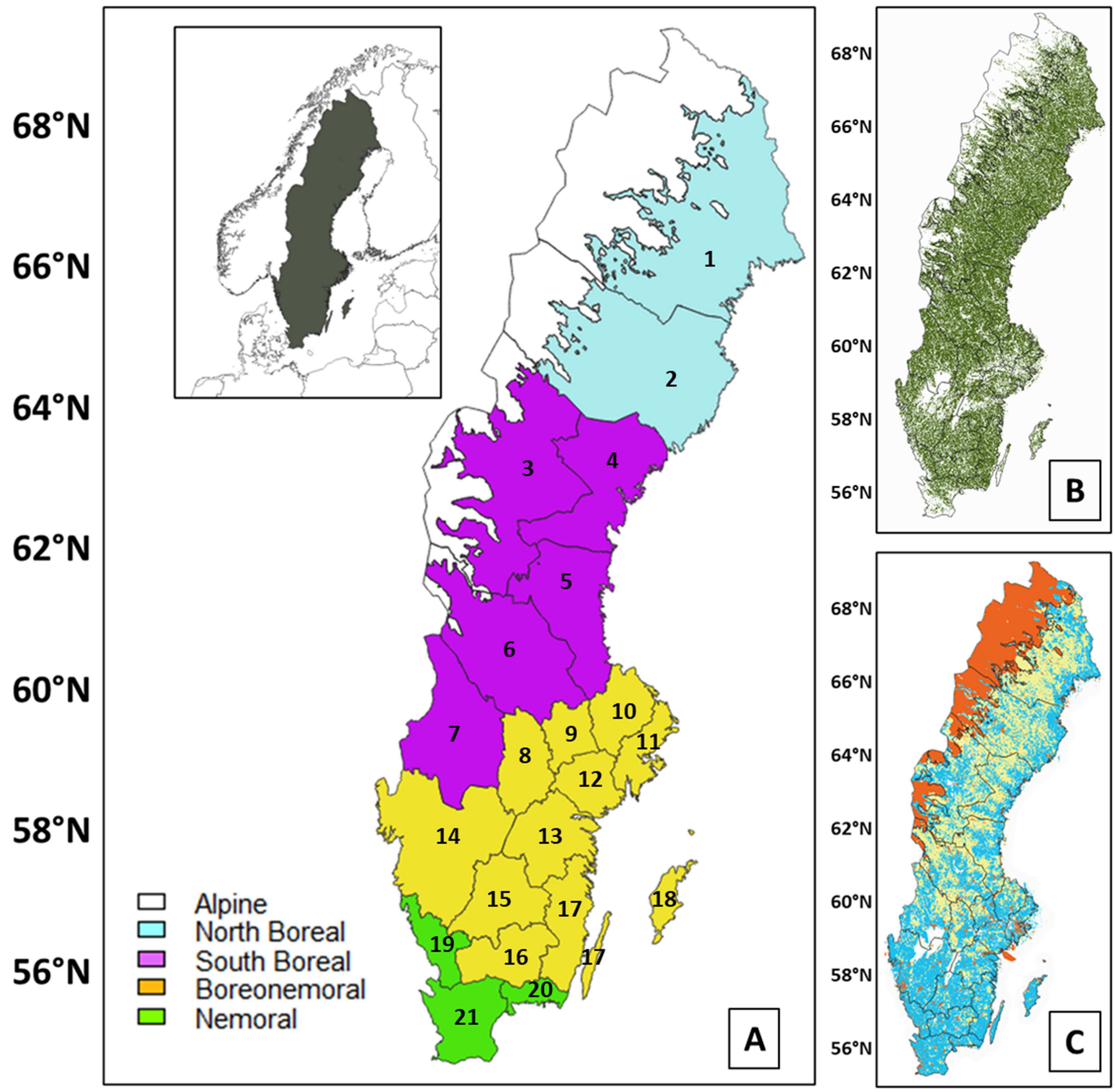

Figure 1. A: Distribution of ecoregions and counties in Sweden. Country delimitation is based on shapefiles provided by the European Union; https://ec.europa.eu, accessed 2021-09-22). B: Distribution of forest land within Sweden. C: Distribution of landowner categories (public (orange), forest companies (yellow) and non-industrial private forest owners (blue)) within Sweden. Counties: 1 – Norrbotten, 2 – Västerbotten, 3 – Jämtland, 4 – Västernorrland, 5 – Gävleborg, 6 – Dalarna, 7 – Värmland, 8 – Örebro, 9 – Västmanland, 10 – Uppsala, 11 – Stockholm, 12 – Sörmland, 13 – Östra Götaland, 14 – Västra Götaland, 15 – Jönköping, 16 – Kronoberg, 17 – Kalmar, 18 – Gotland, 19 – Halland, 20 – Blekinge, 21 – Skåne.

boreal, boreonemoral and nemoral (Figure 1A, Appendix Table A5). The total land area (exclusive inland water) below the mountain forest border is 32,723 kHa, with a forest cover of 24,366 kHa. The land and forest areas by ecoregions are 9009 kHa and 6852 kHa (north boreal), 11,534 kHa and 9647 kHa (south boreal), 10,240 kHa and 6909 kHa (boreonemoral) and 1941 kHa and 958 kHa (nemoral), respectively. For completeness, the alpine ecoregion covers 8242 kHa, of which 2542 kHa are forest lands (Appendices Table A2–A4).

Forests are the dominant land cover in Sweden (Figure 1B), except in the central and southern plains of the boreonemoral and nemoral ecoregions (Svensson et al., 2023a). Managed coniferous forests dominate in the northern and southern boreal ecoregions (75%, mainly *Pinus sylvestris* but also *Picea abies*), with forestry as a predominant land use (Neumann et al., 2022). The boreonemoral ecoregion denotes a distinct change in vegetation and land use with a mixture of coniferous and deciduous forests (e.g. *Ulmus glabra*, *Quercus robur*, *Acer platanoides* and *Fagus sylvatica)* and with both forestry and agriculture as important land uses (Neumann et al., 2022). Agricultural fields interspersed with patches of deciduous forests characterize the southernmost nemoral ecoregion, where agriculture is a major land use (Neumann et al., 2022). With about 90% of the human population located below 61°N and population concentrations along the east coast of the Gulf of Bothnia, the inland areas of northern Sweden are rural in character (<3.5 inhabitants per km^2 in the north and south boreal ecoregion, Statistics Sweden, 2023). A moderate population density defines the boreonemoral ecoregion (59.4 inhabitants per km^2), while the highest population densities (98.4 inhabitants per km^2) are present in the nemoral ecoregion (Statistics Sweden, 2023). Forest areas in northern Sweden are predominantly owned by private (44%) and forest companies (52%), while public ownership is strongly concentrated in mountainous areas (66%; Figure 1C).

2.2 Wind energy data, site, proximity and planning area

Our analyses covered three spatial scales: the wind energy site (i.e. the physical location of individual wind turbines), the proximity area surrounding these sites, and the planning area connected to each wind energy site, following Swedish Energy Agency standards; the site area was defined as 0.95 km^2 and the associated planning area was three times larger (ER, 2021). We calculated the proximity areas by subtracting the site area from the planning area, providing an estimate of the area affected in immediate proximity to the turbines. The area calculations were based on the spatial distribution of established and approved wind turbines using official data provided by the Swedish Energy Agency ($n = 6572$, https://www.energimyndigheten.se/fornybart/vindkraft/vindlov/vindbrukskollen/, accessed 27 January 2022). The baseline estimate for our 2040 projection of land cover, forest types and landowners is the distribution of present turbines following the same data.

We calculated the 2040 projection, which represents the claimed area for onshore wind energy to reach a 100% renewable energy goal by 2040, following the proposed energy production levels per county (ER, 2021, Appendix Table A1). The area estimates per turbine considered a 6-MW turbine with 3500 full load hours (ER, 2021), and at the time of data compilation, information on the production capacity of individual established and approved turbines (MWh) in the national database was incomplete. Consequently, we based our analyses on the area occupied by wind energy in 2022. This is to be understood as a conservative estimate, as some of the older turbines will be replaced by new turbines or removed. However, 28% ($n = 1887$) of all turbines were newly approved, and 61% ($n = 2857$) of the established turbines were built between 2012 and 2021. Furthermore, the estimate is also conservative with respect to the continued increase in expected energy demand beyond the estimates applied in the ER (2021; Garbis et al., 2024). A basic assumption in our study was that the distribution of present wind energy sites (distance between turbines but also spatial distribution across land cover and forest types) is representative of future sites; thus, we used the ratio between the present (status 27 January 2022) and future wind energy area to assess the site, proximity and planning areas in the 2040 projection (Table 1, Appendix Table A1).

2.3 Forest land and landowner categories

We defined three forest land categories by mapping and merging data from three different data sources using overlay analyses (i.e. considering the physical overlap of different layers and maps to classify a given pixel as a given forest type). First, we extracted land cover data from the National Land Cover Database (10×10 m; Swedish EPA, 2019a), identified the type of land cover, and extracted pixels mapped as forests. Second, we overlaid data on forest site productivity from the same database to identify high- and low-productivity forests (following the terminology of Hemäläinen et al., 2017, i.e. high productivity refers to forest sites with the capacity to support average annual growth of stem wood to a minimum of one m^3). Third, we overlaid high conservative value forests (vector data, forest values, status 2016, Swedish EPA, 2019b), including updates (Bubnicki et al., 2024), converted into a raster. Using a raster calculator, we merged the data and generated three spatially delineated forest land categories: 1) *forestry lands* (high-productivity forest lands without formal protection and without a high conservation value recognition), 2) *woodlands* (low-productivity forest lands that are not used for systematic rotation forestry and without a high conservation value recognition) and 3) *HCVF*, high conservation value forests (all known forests with high and low productivity, with documented high conservation values, including both formally

Table 1. The 2040-projection of wind energy site, proximity and planning area (in kHa) and share (%) of forest land available for study region, ecoregions, and counties in Sweden.

	Site area		Proximity area		Planning area	
Ecoregion/county	kHa	%	kHa	%	kHa	%
Study region	279.3	1.1	534.5	2.2	813.8	3.3
North boreal	61.0	0.9	117.5	1.7	178.5	2.6
South boreal	137.9	1.4	269.4	2.8	407.3	4.2
Boreonemoral	73.2	1.1	134.5	1.9	207.7	3.0
Nemoral	7.2	0.8	13.1	1.4	20.3	2.1
1 – Norrbotten	34.4	0.9	64.7	1.8	99.0	2.7
2 – Västerbotten	26.7	0.8	52.8	1.6	79.5	2.5
3 – Jämtland	28.6	1.1	56.7	2.1	85.3	3.2
4 – Västernorrland	29.8	1.6	58.4	3.1	88.2	4.7
5 – Gävleborg	30.2	1.9	59.1	3.8	89.3	5.7
6 – Dalarna	29.6	1.4	57.9	2.8	87.5	4.2
7 – Värmland	19.8	1.4	37.3	2.6	57.1	3.9
8 – Örebro	7.3	1.2	13.3	2.1	20.6	3.2
9 – Västmanland	6.7	1.9	11.5	3.3	18.2	5.3
10 – Uppsala	1.9	0.3	5.4	1.0	7.3	1.3
11 – Stockholm	5.7	1.4	9.1	2.2	14.8	3.5
12 – Södermanland	4.8	1.2	8.9	2.3	13.7	3.5
13 – Östergötland	3.1	0.4	5.9	0.8	9.0	1.3
14 – Västra Götaland	15.3	1.0	27.9	1.9	43.2	2.9
15 – Jönköping	11.3	1.5	21.0	2.7	32.3	4.2
16 – Kronoberg	7.9	1.2	14.9	2.3	22.9	3.5
17 – Kalmar	8.1	1.0	14.4	1.8	22.5	2.8
18 – Gotland	0.9	0.6	2.3	1.5	3.3	2.1
19 – Halland	5.2	1.6	9.0	2.8	14.2	4.3
20 – Blekinge	0.9	0.4	1.7	0.8	2.6	1.3
21 – Skåne	1.2	0.3	2.3	0.5	3.5	0.8

protected and not formally protected). We assumed that the spatial extent and content were correct and did not correct for any possible source of error (e.g. spatial inaccuracies) but removed missing land cover values (i.e. no data values) when quantifying the share of land covers. We did not preprocess the data other than those described above.

The establishment of wind energy affects different landowner categories differently (Svensson et al., 2023a), but so far, there is a lack of knowledge on its impact at various scales and types of forests. To fill this gap, we linked the 2040 projection to land cover, forest productivity and conservation but also to landownership, the latter mapped by the Swedish Environmental Protection Agency (Swedish EPA; Henriksson & Olsson, 2020). The data on landownership did not provide any personal information, nor did it involve human beings. We organized landownership into three major categories: 1) *public* (including the National Property Board, the Fortification Agency and other state agencies, including the Swedish EPA, regional and municipal authorities); 2) for*est companies* (Billerud-Korsnäs, Stora Enso, Holmen, SCA and Sveaskog state forest companies; other incorporates, the Swedish Church and forest commons, i.e. land owned in share by a community) and 3) *nonindustrial private forest owners* (NIPF) (ownership polygons up to 1000 ha owned by private persons and households). These three categories broadly represent the main distribution of ownership on land and inland water outside of urban and developed areas in Sweden.

2.4 Data analyses

Our work relies on descriptive statistics derived from the status of wind energy turbines in 2022 and projected expansion in 2024, as suggested by the national strategy for large-scale wind energy development in Sweden (ER, 2021). We quantified the spatial overlap of wind energy establishment at three spatial scales (i.e. site, proximity and planning area) with land cover, the three different categories of forest land and landownership across ecoregions and counties using zonal statistics (i.e. summarizing the values of a raster within the zones of another dataset). We used the software ArcMap (version 10.6), QGIS (version 3.20.3) and R (version 4.1.2) for our spatial analyses and data handling.

3 Results

3.1 Projected expansion of wind energy claims forest land

The projected onshore wind energy area is close to 1145 kHa (about 4% of the national terrestrial surface), with the boreonemoral and the south boreal ecoregions harboring the largest absolute areas (planning area excluding water, Appendix Table A2). In this area (excluding water), forest lands cover 71% of the total area in the north boreal, south boreal, boreonemoral and nemoral ecoregions 77%, 88%, 54% and 30%, respectively (planning area). However, differences among counties are apparent, particularly in the boreonemoral ecoregion. Compared to established wind energy in 2022, the projected onshore wind energy will claim almost twice the forest land area in 2040, corresponding to 3.3% of the forest land (planning area or the entire study region; Figure 2, Appendix Table A2). The greatest change will occur in the south boreal ecoregion, which covers 50% of the total wind energy planning area, whereas the nemoral ecoregion will experience a slight decrease (Figure 2). At the county level, the northernmost county in Sweden (Norrbotten) will provide the largest absolute area on all scales (site, proximity and planning area; Table 1).

The shares of forest land claimed compared to forest land available differ among ecoregions and counties. Here, the south boreal ecoregion provides the largest absolute and relative area for site, proximity and planning areas, covering a total of 1.4%, 2.8% and 4.2%, respectively, of the forest land area in the ecoregion (Table 1). Across counties, projected wind energy expansion claims, on average, a larger share of forest land in counties within the south boreal ecoregion compared with other ecoregions (Appendix Figure A1). Following the

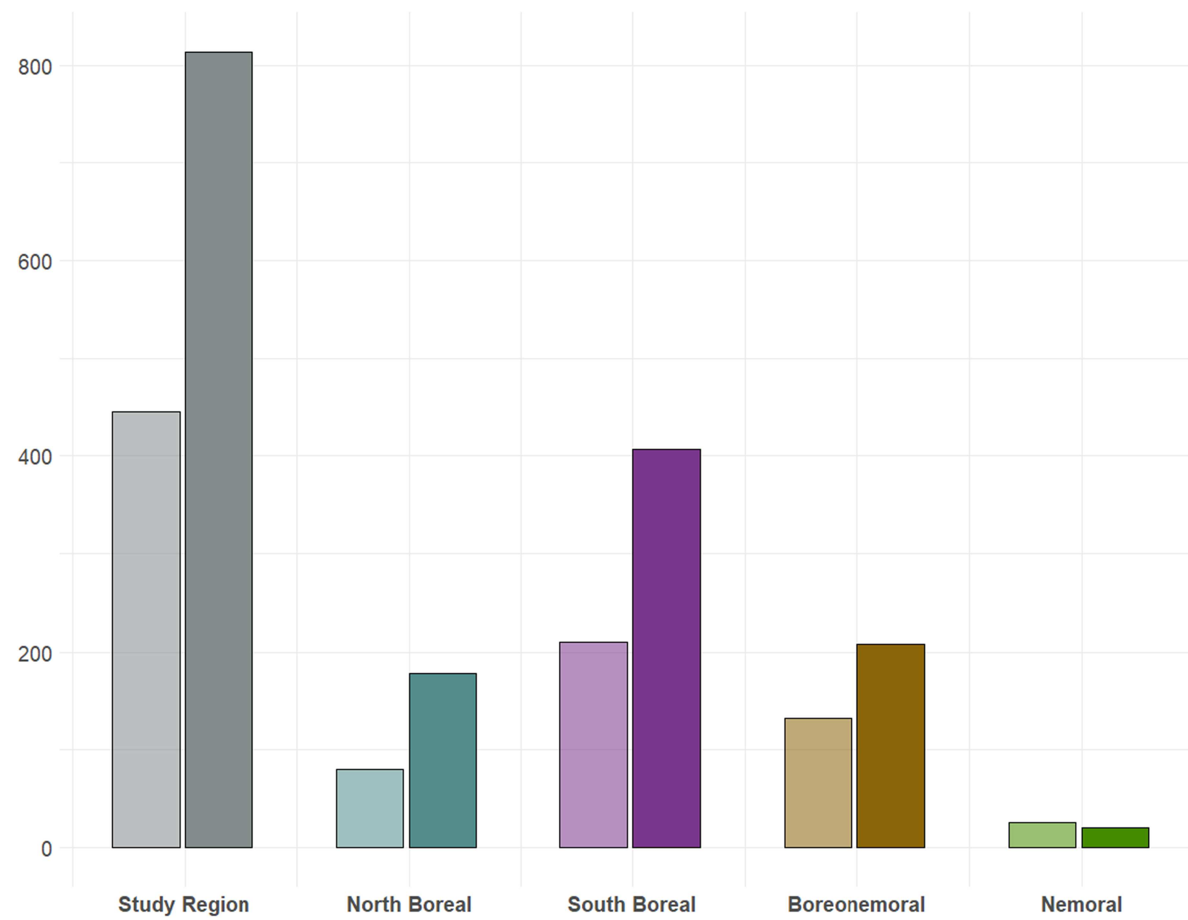

Figure 2. Wind energy planning area (kHa) on forest land in 2022 (left-sided, lighter-colored bars) and projection for 2040 (right-sided, darker-colored bars) for the entire study region (gray-colored) and separated for each ecoregion in Sweden (from north to south, North Boreal: blue-colored, South Boreal: purple-colored, Boreonemoral: brown-colored, Nemoral: green-colored).

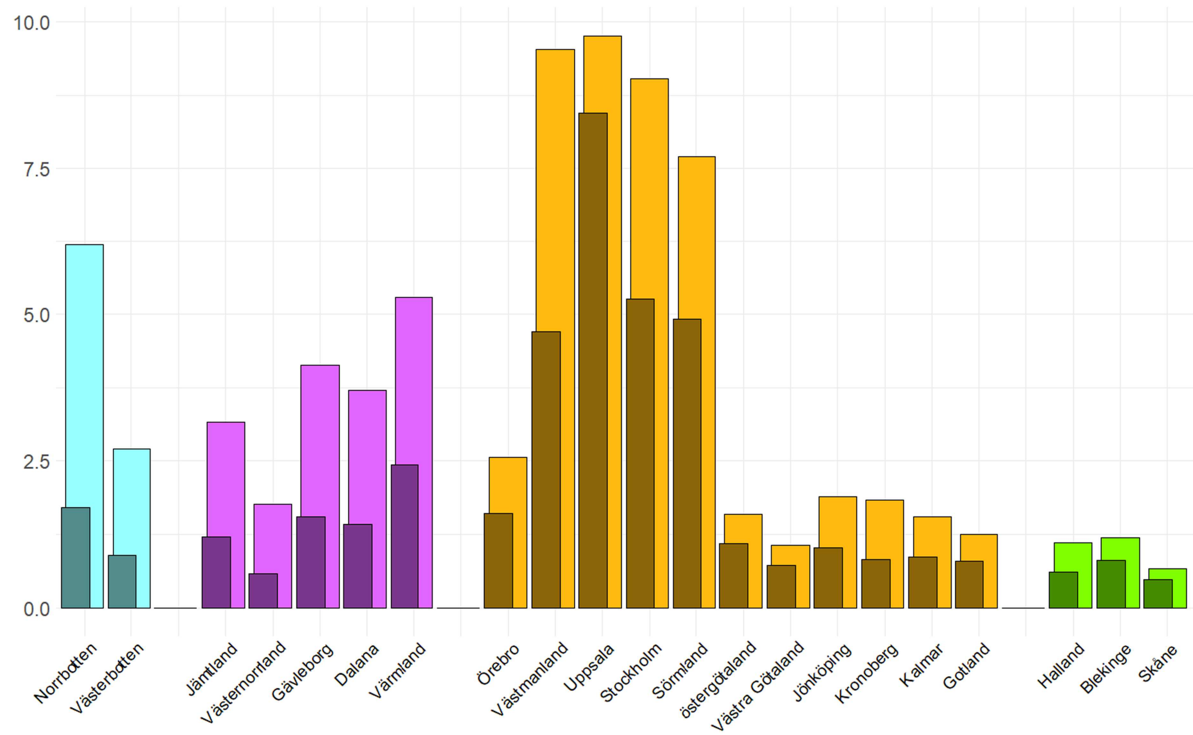

Figure 3. Percent change in forest land area between 2022 and the 2040-projection within the wind energy site (dark color) and proximity areas (light color), by county separated by ecoregion in Sweden (North Boreal: blue, South Boreal: purple, Boreonemoral: yellow, Nemoral: green). For data on area, see Appendix Table A2.

projected site and the proximity area, the demand for forest land increases in all ecoregions, yet considerable variation was detected among counties within the same ecoregion (Figure 3). For example, the northern counties in the boreonemoral region (Västmanland, Uppsala, Stockholm, Södermanland) show substantial changes with an increase in site area from close to 3 to more than 7 times and in proximity area from over 5 to over 8 times larger areas in 2040 compared with in 2022.

3.2 Projected wind energy expansion claims forestry land, woodland and high conservation value forests

Absolute area claims on forestry land are higher compared with woodland and HCVF since they are much more abundant, highest in the south boreal ecoregion and lowest in the nemoral region (Appendix Table A3). The relative share of the three forest land categories (i.e. weighted according to their abundance) varied considerably between ecoregions and counties (Figure 4). For the study region, we found that the projected wind energy expansion claims 3.5%, 2.9% and 2.1% of the forestry land, woodland and HCVF areas, respectively (Figure 4). For both forestry land and the HCVF area, we found the highest relative claims in the southern boreal biome (4.4% of forestry land and 3.2% of the HCVF area).

In each ecoregion, we found some counties that provide considerably higher shares of claimed forestry land compared to other counties in the same ecoregion, for example, 5.8% in Gävleborg (south boreal), 5.2% in Västmanland (boreonemoral) and 4.6% in Halland (nemoral). Similarly, claims on HCVF areas are considerably larger in some counties than others in the same ecoregion, except in the south boreal ecoregion, where all counties provide high shares, for example, 2.5% in Västerbotten (north boreal), 2.7% in Jönköping (boreonemoral) and 2.1% in Halland (nemoral). Similarly, there are substantial differences in woodlands, with Västmanland (boreonemoral), which has a particularly high land claim (12.7%).

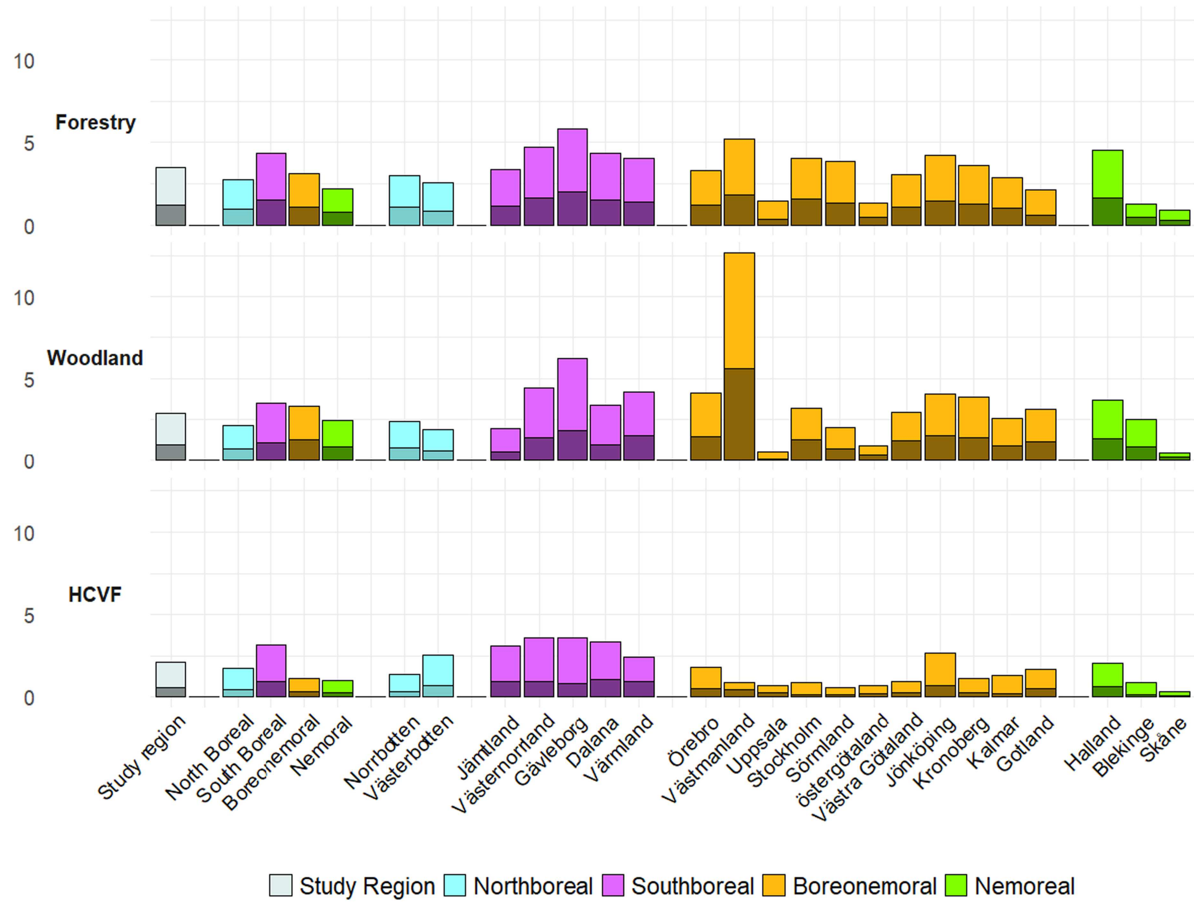

Figure 4. Percent of forestry, woodland and high conservation value forest (HCVF) area within site (lower bar, darker color) and proximity (upper bar, lighter color) areas by county separated by ecoregion in Sweden (North Boreal: blue, South Boreal: purple, Boreonemoral: yellow, Nemoral: green). The share is calculated as the percentage of total forestry, woodland and HCVF area by county. For data on area, see Appendix Table A3.

3.3 Projected wind energy expansion on forestry land affects landowners differently

Forest companies own most of the claimed forestry land for site areas in the north boreal (70%) and south boreal ecoregion (61%), while NIPF owns the most in the boreonemoral (71%) and nemoral ecoregion (90%, Appendix Table A4). In relation to the ownership distribution of forestry land in the study region, ecoregion and county scales, company-owned forestry land provides the greatest share within the wind energy sites in the study region and the north boreal, south boreal and boreonemoral ecoregions (Appendix Figure A2). Ownership shares follow an overarching pattern of decreasing share of company-owned forestry land and an increasing share of NIPF-land from north to south. Importantly, the landowner categories that own forestry land affected by future expansion differ between the wind energy sites themselves and the surrounding proximity area (Figure 5). In the proximity area, state-owned and NIPF-land often constitute a larger share (positive values of orange and blue bars) than within the sites, in contrast to site areas where the share of company-owned forestry land is largest (negative values of yellow staples).

4 Discussion

In countries with ambitious goals to expand renewable energy, as in many European countries, we can expect an increasing spatial overlap between onshore wind energy and other land uses and landscape values. In Sweden, wind energy is predominantly built on forest lands. Derived from the spatial interactions of projected onshore wind energy expansion across ecoregions and landowner categories, we show

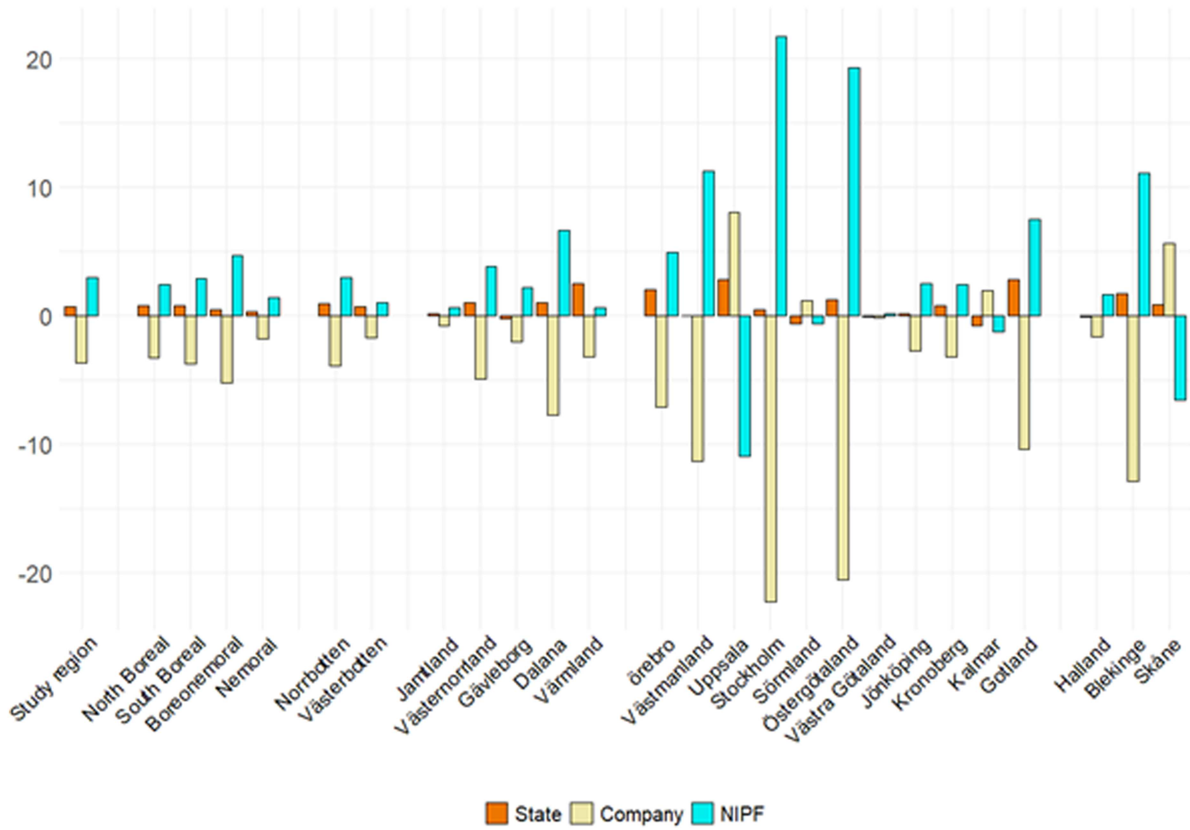

Figure 5. Proportional difference between landowner categories on forestry land in the wind energy site and proximity area in Sweden. Calculated by first quantifying the percentage of forest land site- and proximity area of total forest land area per county and landowner category, and second by subtracting the percentage of a given landowner category in the wind site from its share in the proximity area. Negative values indicate a higher share in the wind site compared to the proximity area, whereas positive values indicate a lower share. Data on forestry area (kHa; Appendix Table A4).

regional-specific overlap with forestry land, woodland and HCVF, with potential risks for conflicts. Within the context of Sweden as a forest-dominated country, our work highlights three main findings.

First, the proportional claim of forest land generally and forestry land (i.e. productive forest land available for forestry) specifically, the wind energy expansion claim is considerable but varies largely among ecoregions and counties within the same ecoregion. This suggests not only county-specific impacts of wind energy expansion on other interests and values of forest land (e.g. timber production, biofuel and other fossil-free products, reindeer husbandry, etc.) but also indicate where cold- and hotspots for integrating wind energy expansion sustainably in multiuse landscapes can be mapped, likely requiring county-specific planning solutions. This would require, for example, increased exchange across neighboring municipalities within a county on their comprehensive landscape planning and prioritization among different interests and values (Thellbro et al., 2022).

Second, on national scale, our projection suggests that the proportion of forestry land claimed by wind energy expansion corresponds to 3.5% of land available for forestry, 2.9% of available woodland and 2.1% of available HCVF. These claims are substantially higher in some counties, particularly within the south boreal ecoregion (Figure 4), emphasizing the need for county-specific forest landscape planning to meet the local landscape premises and, in extension, meet local sustainability, environmental and climate change mitigation and adaptation ambitions (EU, 2019, 2020, 2021).

Third, our results highlight a substantial expansion of wind energy for forest companies and NIPF-land, suggesting owner category-specific solutions for synergies or conflicts. Importantly, the planning area and the proximity area include different landowner category composition than the site area, with forest company land dominating the site area but not the proximity area. Since the impact of wind energy also is on distance, this discrepancy may risk local conflicts regarding negative impacts and compensation schemes for different landowner categories (SOU 2023:18).

4.1 Claim of forest and forestry land

Globally, forests are instrumental in environmental and climate change aspects to maintain the carbon stock and biodiversity, produce fossil-free products and provide other ecosystem services important for humanity (Anderegg et al., 2020; Muys et al., 2022). However, provision of different types of forest benefits is not always possible to integrate spatially with wind energy, which calls for trade-offs and decision making to prioritize a given set of benefits, which in turn demands well-developed landscape planning for informed decisions (Ameray et al., 2021; Thom & Seidl, 2016). In multiuse forest landscapes, wind energy is a late-arriving but major land-use actor that puts additional competitive pressure on landscapes. In Sweden, the establishment of current and future onshore wind energy claims forest land generally and forestry land specifically. Here, the change from the present to the projected establishment of wind energy points to a manifold increase in demand for forest land—up to more than 7 times based on site area, within the entire study region—with a regional hotspot in the boreonemoral ecoregion (e.g. Uppsala, 8 times higher). The projected transformation towards a green industry using renewable energy in northern Sweden may escalate and potentially modify future national and region-specific energy demands (Hedeler et al., 2023), which in turn most likely require a revision of wind energy expansion trajectories. Relying on descriptive statistics as a first steppingstone to project future wind energy expansion, we encourage future research to empirically test projected trajectories against current wind energy plans, as expansion continues to evaluate the implementation of suggested regional expansion goals (ER, 2021). If not planned accurately, we anticipate an increasing risk of competition and conflict between the many different existing forest and forest landscape land-use interests, values and long-term legacies such as indigenous Sami reindeer husbandry in northern Sweden. Importantly, the strong focus on clustering turbines at large sites to increase capacity production is a clear trend within wind energy expansion globally (e.g. farms with up to 600 turbines in the USA, >300 turbines in China and 140 turbines in Australia; Vella, 2017), including in Sweden (i.e. wind farm *Markbygden* with 1010 turbines planned, of which nearly 600 are already established (status 19 December 2025, www.pitea.se), north boreal ecoregion). Hence, this expansion strategy emphasizes the urgent need to differentiate suitable from unsuitable locations and balance between different local land use interests, including environmental and climate goals (e.g. Andersson, 2021; Kati et al., 2021).

The establishment of renewable energy, however, can be combined with other interests and land use goals (e.g. combining solar parks with goals in biodiversity and agriculture; Zaplata, 2023). In the context of wind energy, previous research emphasized that the location of wind energy sites in forests is positively correlated with the abundance of forest land and depends on legislation and regional planning (e.g. federal states in Germany; Bunzel et al., 2019). Similarly, we found that in ecoregions and counties with high forest abundance, projected wind energy expansion claims a relatively higher percentage of the forest land. Here, the location of wind energy sites on forestry land with less natural and biodiversity values is suitable, particularly if synergies with forestry, such as developed road infrastructure, can be secured (Bunzel et al., 2019). In the context of wind energy and in contrast to solar parks, however, many countries have difficulties to meet their wind development objectives without encountering conflicts with other land use interests (e.g. Croatia, Norway, Austria; Kiesecker et al., 2024; eastern China; Guan & Zepp, 2020). The informed choice of wind energy location requires overarching and comprehensive landscape planning at both the regional and local scales, considering multidimensional criteria to synchronize or prioritize different goals. Comprehensive spatial planning tools that consider social, cultural, environmental and market-related factors can support landscape planning in multiuse landscapes, including forests (Schlichting & Mercer, 2011).

In Sweden, large-scale rotation forestry practices have heavily modified the entire forest landscape below the mountain forest border, leaving no substantial extent of natural or even near-natural conditions (Bubnicki et al., 2024; Svensson et al., 2020), and negatively affected other land use interests and landscape values (e.g. biodiversity and/or reindeer husbandry; Felton et al., 2020; Sandström et al., 2016). Importantly, indigenous land use (i.e. Sami reindeer herding) is not spatially delimited to certain areas but co-occurs with other land use within the entire South and North Boreal ecoregions. The reindeer herding right is a civil right, protected as a property in Chapter 2, Section 15, of the constitutional

Instrument of Government, and in Article 1 of the First Protocol to the European Convention on Human Rights. The legal relationship between property owners and reindeer herders is regulated through the Forestry Act and the Reindeer Husbandry Act. There is growing concern that wind energy and its future expansion will critically influence the indigenous Sami culture generally and their exclusive seminomadic reindeer husbandry system specifically (Lawrence, 2014; Skarin et al., 2015; Jaakkola et al., 2018; Normann, 2020) in addition to other existing resource extraction methods, such as hydropower production and forestry (e.g. Sandström et al., 2016; Stoessel et al., 2022). Importantly, some reindeer herding districts might be affected by wind energy expansion more strongly than others (Lundmark, 2022), which calls for flexible planning and compensation systems. Here, our findings point to the greatest challenges for reindeer herding districts in the north boreal ecoregion, where we, by comparison, predict a lower relative expansion increase on forest land. Still, with the extensive cumulative pressure by multiple land uses (Sandström et al., 2016; Stoessel et al., 2022), future wind energy expansion may further modify available winter grazing grounds for reindeer (Skarin et al., 2018). Spatial interactions between land use interests such as indigenous cultures and wind energy establishment are not unique to Sweden but also occur in other boreal countries, resulting in different outcomes depending on socioecological settings (e.g. Canada, Mang-Benza & Baxter, 2021; Finland, Nysten-Haarala et al., 2021).

The importance of forest-produced services is likely context-specific. Thus, even in countries with intensive forestry, such as Sweden, forests provide many different ecosystem services relevant for large parts of society (e.g. recreation, game meat, mushrooms, berries; Bjärstig & Kvastegård, 2016; Neumann et al., 2022). The establishment of wind energy must consider conflict risks. For example, social opposition may be expressed in response to perceived negative environmental, visual and socioeconomic impacts due to reduced habitat quality and habitat loss for wildlife, reindeer herding, landscape values and local benefits. Risk may also be market- and policy-related, as well as related to site-specific factors, such as changes in tree composition and forest formation, which complicate wind flow estimations (Enevoldsen, 2016).

4.2 Projected wind energy and high conservation value forests

We found that the wind energy planning areas cover sizeable proportions of HCVF. Previous research has pinpointed Europe, particularly Western Europe, as a hotspot for overlapping established and planned wind energy development with key biodiversity and protected areas (Rehbein et al., 2020). Primary forests of high conservation value cover not more than 3% of the total forested area in Europe, generally located in less accessible hinterland areas (i.e. rugged terrain, less populated areas, along country borders; Sabatini et al., 2021). Although most of these primary forests occur in protected areas, less than half are strictly protected, highlighting the urgent need to preserve the remaining high conservation forests from further degradation (Muys et al., 2022; Sabatini et al., 2021). In Europe, competition for space is high, and the growing demand to find suitable places for the production of renewable energy that have low conflict potential (e.g. rural areas with low population density) but with good premises for wind (i.e. rugged and elevated areas) may risk affecting remote areas with high conservation value that have not been of interest so far. With Sweden contributing an important share of HCVF in Europe (Sabatini et al., 2021), but with forest protection way below national and international biodiversity and environmental agreements (Angelstam et al., 2020), we still lack comprehensive knowledge on the opportunities for synergies and risks for negative impacts of onshore wind energy on general biodiversity aspects (Niebuhr et al., 2022).

The literature assessing the impacts of onshore wind energy on birds and bats is extensive (e.g. Gasparatos et al., 2017; Gauld et al., 2022; Northrup & Wittemyer, 2013) but limited concerning other terrestrial animals, plants or biodiversity in general. Wind energy likely causes cumulative effects given its extensive connected infrastructure (i.e. roads, power lines; Niebuhr et al., 2022), particularly with turbines clustered in large wind energy parks (IRENA, 2023; Vella, 2017). Concerning overall environmental effects, however, wind energy establishments are considered to have a low negative environmental impact compared to other renewable energy sources (e.g. hydropower, Osman et al., 2022).

Claims in different types of forest land varied widely among and within ecoregions, indicating an imbalance in the provision of different forest services on the one hand (e.g. a relatively low share of HCVF relative to forest land in use for forestry) and on the distribution of wind energy establishment on the other hand. Interestingly, the proportion of forestry land nationally claimed by future wind energy is at comparable shares as the current protected forest areas (i.e. nationally 3.5% compared to 3.7%; Statistics Sweden, 2024; Svensson et al., 2023b). In countries with intensive forestry, such as many European countries (FAO, 2020), the balance between forestry and protection is questioned, and the debate is heated (Mack et al., 2022), which emphasizes the evident spatial competition of forest lands to achieve different goals (Muys et al., 2022; Zhang et al., 2022). This competitive pressure for space and provisioning becomes apparent not at least in the light of the European Forest Strategy for 2030, the European Biodiversity Strategy for 2030 and the Kunming–Montreal Global Biodiversity Framework, which all ratify a considerable increase in protected area and changes in forest policies and forestry practices (e.g. protecting, conserving and effectively restoring at least 30% of (degraded) terrestrial ecosystems and land; 2021, CBD, 2022, EU, 2020, 2021). In this context, wind energy expansion can become a serious competitor that requires a lot of forest land space.

4.3 Landownership at wind energy sites and in proximity

Our findings show that forest companies are the main landowners of land used as wind energy sites, but also that their ownership share decreases in proximity. The discrepancy between landowners on the site and those in proximity risk conflicts concerning, for example, financial benefits and compensation for negative impacts. For example, property prices or the quality of the scenic landscape view can be lowered near the wind energy site (Rudolph et al., 2017; Sunak & Madlener, 2016; Szumilas-Kowalczyk et al., 2020). In Sweden, applications for wind energy must be approved by the municipal government (the so-called municipal 'veto'), which means that the development of wind energy depends on local policy preferences. To increase incentives for municipalities to approve new wind energy and compensate municipalities that already have existing wind energy, the Swedish government is proposing support for municipalities corresponding to the property value change that wind energy causes. Additionally, local residents own a residential building within a radius of 10 times the total height of a wind turbine, and owners of neighboring properties are suggested to obtain compensation (SOU 2023:18)—but how this will play out in terms of local acceptance and/or mitigating conflicts is yet to be observed.

Social opposition has been identified as a major drawback for wind energy expansion globally (Herberg et al., 2023), making social acceptance a key feature for future establishment. Rural areas often target locations for wind energy, as these areas by definition are less populated and therefore likely to harbor fewer conflicts among different interests. However, a skewed distribution of financial benefits for wind energy establishments among landowners, local communities and residents can cause conflicts and jeopardize social legitimacy, highlighting the need to fairly distribute benefits locally and regionally. The physical location of wind energy sites is the most important factor for both wind energy acceptance and opposition (Bjärstig et al., 2022), making the spatial and socioeconomic context of sites a crucial feature for success and sustainability. This also highlights the role of local focus (cf. Thellbro et al., 2022) and a local-to-regional-to-national bottom-up wind energy strategy and planning process based on de facto socioecological landscape data and existing land-use values, interests and demands. For countries dominated by forests, this implies how wind energy expansion affects such values in forests and forest landscapes.

4.4 Study limitations

We based our analysis on the assumption that the distribution of present wind energy sites is representative of future sites, including the distance between individual turbines as well as their spatial distribution across different land cover and forest types, and in consideration to other land uses. As such, our approach does not consider potential changing trade-offs among the prioritization of different interests in planning processes or changing attitudes and decision-making among landowner categories. A comprehensive assessment considering the socioeconomic aspects of present and future wind energy establishment was beyond the scope of the present study. We encourage future studies to address this field of research, possibly combining quantitative and qualitative data.

5 Conclusions

The expected expansion of onshore wind energy will leave a marked footprint on forests and forest landscapes across Sweden. In addition to existing land use conflicts and general challenges to meet multiple demands and benefits of forests and forest landscapes, this requires well-informed landscape planning and decision making. We find evident differences not only between ecoregions but also among counties within an ecoregion. This calls for regional and local planning to achieve sustainable solutions. Our findings emphasize that the projected expansion of wind energy claims a considerable proportion of forest land generally and forestry land specifically (e.g. 3.5% of forestry land, 2.9% of woodland and 2.1% of HCVF below the forest mountain border), pointing at different trade-offs and priorities to facilitate synergies and reduce the risk of conflicts, with national and international environmental and sustainability goals forming the framework. We expect a possible coexistence between forestry and wind energy establishment. We found an imbalance between forest landowners at wind energy sites compared with those in proximity (i.e. about 4 times higher share of company-owned land in the wind site compared to 1 and 3 times higher share of state- and NIPF-owned land, respectively, in proximity). This emphasizes the need for new approaches in compensation models to increase local acceptance and socioeconomic sustainability.

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Public interest statement

In countries that have set ambitious goals for expanding renewable energy, such as many European countries, we can expect an increasing spatial overlap between onshore wind energy and other land uses and landscape values. In Sweden, for example, the proposed expansion of onshore wind energy is expected to have a significant impact on forest landscapes and is likely to affect different categories of landowners differently. To meet the general challenge of meeting the multiple demands and benefits of forests and forest landscapes, our findings emphasise the need for well-informed landscape planning and decision-making at different scales.

Author contributions

CRediT: **Wiebke Neumann:** Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing; **Therese Bjärstig:** Validation, Writing – original draft, Writing – review & editing; **Johan Svensson:** Conceptualization, Funding acquisition, Project administration, Validation, Writing – original draft, Writing – review & editing.

Disclosure statement

The authors do not declare any conflicts of interest.

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Data availability statement

Our analyses are based on official data published by the Swedish Energy Agency and the Swedish Environmental Protection Agency, including their published updates (Bubnicki et al., 2024; Henriksson & Olsson, 2020). Materials supporting our results and corresponding R codes are openly available in the Swedish National Data Service at https://doi.org/10.5878/08va-3474.

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Appendices

Projected wind energy on forest land – A land use transition trajectory to reach 100% renewable energy goal in Sweden.

Appendix Table A1. Suggested *establishment of onshore wind energy* per county by 2040 in Sweden, as established in the national strategy for sustainable wind energy development (ER 2021), including data on terrestrial surface, expected energy production capacity, number of turbines, site area and share of terrestrial surface (%), and planning area and share of terrestrial surface. Area in kHa.

Biome	County	Land area[a]	TWh production	Number of turbines[b]	Suggested site area	Share	Suggested planning area[c]	Share
North Boreal	Norrbotten	8700.5	10	476	45.0	0.5	135.0	1.6
	Västerbotten	4929.2	7.5	357	33.8	0.7	101.3	2.1
South Boreal	Jämtland	4364.7	7.5	357	33.8	0.8	101.3	2.3
	Västernorrland	1985.6	7.5	357	33.8	1.7	101.3	5.1
	Gävleborg	1658.0	7.5	357	33.8	2.0	101.3	6.1
	Dalarna	2518.1	7.5	357	33.8	1.3	101.3	4.0
	Värmland	1583.2	5	238	22.5	1.4	67.5	4.3
Boreo-nemoral	Örebro	775.3	2.5	119	11.3	1.5	33.8	4.4
	Västmanland	479.5	2	95	9.0	1.9	27.0	5.6
	Uppsala	778.4	2.5	119	11.3	1.5	33.8	4.3
	Stockholm	558.1	2	95	9.0	1.6	27.0	4.8
	Södermanland	552.1	2	95	9.0	1.6	27.0	4.9
	Östergötland	950.9	2.5	119	11.3	1.2	33.8	3.6
	Västra Götaland	2148.8	7.5	357	33.8	1.6	101.3	4.7
	Jönköping	957.8	3	143	13.5	1.4	40.5	4.2
	Kronoberg	772.3	2	95	9.0	1.2	27.0	3.5
	Kalmar	1014.9	3	143	13.5	1.3	40.5	4.0
	Gotland	300.3	1	48	4.5	1.5	13.5	4.5
Nemoral	Halland	487.0	2	95	9.0	1.8	27.0	5.5
	Bleking	254.6	0.5	24	2.3	0.9	6.8	2.7
	Skåne	1006.0	2.5	119	11.3	1.1	33.8	3.4
	Sweden	**36775.3**	**87.5**	**4165**	**394.3**	**1.1**	**1181.8**	**3.2**

[a]All land area, excluding 100 meters from lakes, water coures and sea water.
[b]Site area and number of turbines are based on 6 MW turbines with 3500 full load hours.
[c]The planning area is set as three times the site area.

Appendix Table A2. The area (kHa) *distribution of land cover types* on the wind energy site and planning area in Sweden, presented as the national total and national total below the mountain region (MR), i.e. the study region, per biogeographic region and per county. 0.0 shows less than 0.1 kHa.

	Site area							Planning area						
Strata	Forest-land	Open wetland	Farm-land	Other open land	Artificial surface	Inland water	Marine water	Forest-land	Open wetland	Farm-land	Other open land	Artificial surface	Inland water	Marine water
National total	281.0	25.1	51.7	25.9	9.4	5.0	44	817.8	80.3	161.4	69.0	29.1	20.6	18.0
National total below MR	279.3	24.2	51.7	20.9	9.3	4.5	4.4	813.8	78.7	161.4	62.3	28.9	19.8	18.0
Mountain region	**1.7**	**0.9**	**0.0**	**5.0**	**0.2**	**0.5**	**0.0**	**4.0**	**1.6**	**0.0**	**6.7**	**0.2**	**0.8**	**–**
Norrbotten	0.3	0.1	–	1.3	0.1	0.0	–	0.7	0.3	–	1.7	0.1	0.2	–
Västerbotten	0.9	0.6	–	2.5	0.0	0.4	–	1.7	0.9	–	3.0	0.0	0.6	–
Jämtland	0.5	0.2	0.0	1.2	0.1	0.0	–	1.6	0.4	0.0	1.9	0.1	0.1	–
Dalarna	–	–	–	–	–	–	–	–						
North boreal	**61.0**	**11.0**	**0.1**	**4.8**	**1.0**	**0.4**	**0.4**	**178.5**	**36.8**	**0.4**	**12.6**	**3.0**	**2.1**	**3.0**
Norrbotten	34.4	6.6	0.1	2.8	0.6	0.3	0.3	99.0	23.0	0.3	7.6	1.7	1.3	2.1
Västerbotten	26.7	4.3	0.0	2.0	0.5	0.2	0.2	79.5	13.8	0.1	5.0	1.3	0.8	0.8
South boreal	**137.9**	**10.1**	**1.0**	**4.4**	**2.5**	**1.7**	**0.1**	**407.3**	**33.1**	**4.1**	**12.1**	**7.6**	**7.9**	**1.0**
Jämtland	28.6	2.9	0.2	1.5	0.5	0.2	–	85.3	9.3	0.6	3.8	1.5	0.9	–
Västernorrland	29.8	2.3	0.0	0.9	0.4	0.2	0.1	88.2	6.8	0.2	2.5	1.4	1.6	0.8
Gävleborg	30.2	1.8	0.0	0.5	0.6	0.7	0.0	89.3	6.1	0.2	1.4	1.7	2.4	0.2
Dalarna	29.6	2.2	0.0	1.1	0.6	0.3	–	87.5	7.8	0.0	3.0	1.7	1.4	–
Värmland	19.8	0.9	0.7	0.4	0.4	0.3	–	57.1	3.0	3.1	1.3	1.3	1.7	–
Boreonemoral region	**73.2**	**2.8**	**38.4**	**10.2**	**4.9**	**2.2**	**3.5**	**207.7**	**7.9**	**120.5**	**32.7**	**15.2**	**9.0**	**12.7**
Örebro	7.3	0.3	2.1	0.7	0.4	0.5	–	20.6	0.9	7.3	2.1	1.0	2.1	–
Västmanland	6.7	0.6	1.3	0.2	0.2	0.0	–	18.2	1.2	5.9	1.0	0.7	0.1	–
Uppsala	1.9	0.1	5.1	1.1	1.0	0.5	1.7	7.3	0.2	15.1	3.3	2.7	1.8	3.6
Stockholm	5.7	0.3	1.2	0.9	0.3	0.1	0.5	14.8	0.5	4.3	2.7	0.8	0.3	3.5
Södermanland	4.8	0.1	3.5	0.4	0.2	0.0	0.0	13.7	0.2	10.3	1.4	0.8	0.2	0.3
Östergötland	3.1	0.0	7.2	0.4	0.3	0.2	0.0	9.0	0.1	21.1	1.8	1.1	0.7	0.1
Västra Götaland	15.3	0.6	13.5	2.7	1.1	0.4	0.2	43.2	1.5	41.4	8.7	3.8	1.7	1.0
Jönköping	11.3	0.4	0.4	0.7	0.4	0.3	–	32.3	1.2	2.1	2.5	1.2	1.2	–
Kronoberg	7.9	0.3	0.0	0.4	0.2	0.1	–	22.9	1.1	0.3	1.3	0.8	0.6	–
Kalmar	8.1	0.2	2.9	1.4	0.5	0.1	0.4	22.5	0.7	9.3	4.5	1.5	0.3	1.7
Gotland	0.9	0.0	1.2	1.4	0.4	0.0	0.6	3.3	0.1	3.5	3.4	0.8	0.1	2.3
Nemoral region	**7.2**	**0.3**	**12.3**	**1.4**	**0.9**	**0.2**	**0.4**	**20.3**	**0.9**	**36.4**	**4.9**	**3.1**	**0.8**	**1.3**
Halland	5.2	0.2	2.5	0.5	0.4	0.1	0.1	14.2	0.7	8.3	1.7	1.3	0.6	0.3
Blekinge	0.9	0.0	1.0	0.2	0.1	0.0	0.1	2.6	0.1	2.7	0.6	0.3	0.0	0.6
Skåne	1.2	0.0	8.7	0.7	0.4	0.0	0.2	3.5	0.2	25.5	2.6	1.6	0.2	0.5

Appendix Table A3. *Wind energy site and planning area on forestry land, woodland area and high conservation value forest (HCVF)* area (in kHa) in Sweden, presented as national total and national total below the mountain region (MR), i.e. the study region, per biogeographic region (A–E) and per county (1–25). Dash (–) shows no presence, whereas 0 shows <0.5 kHa. 0.0 shows less than 0.1 kHa.

	Site area			Planning area		
Strata	Forestry	Woodland	HCVF	Forestry	Woodland	HCVF
National total	246.8	23.4	10.8	712.1	69.4	36.3
National total below MR	246.6	23.0	9.7	711.6	68.7	33.5
Mountain region	**0.2**	**0.4**	**1.1**	**0.5**	**0.7**	**2.8**
Norrbotten	–	0.1	0.1	0.1	0.2	0.5
Västerbotten	0.1	0.2	0.6	0.1	0.4	1.2
Jämtland	0.1	0.1	1.1	0.3	0.1	1.1
Dalarna	–	–	–	–	–	–
North boreal	**51.5**	**7.3**	**2.3**	**147.9**	**21.7**	**8.9**
Norrbotten	28.4	4.8	1.1	80.2	14.1	4.7
Västerbotten	23.1	2.4	1.1	67.6	7.6	4.2
South boreal	**122.4**	**9.6**	**5.9**	**357.1**	**31.2**	**19.1**
Jämtland	24.4	1.8	2.3	71.6	6.2	7.5
Västernorrland	27.0	2.3	0.5	79.1	7.2	1.9
Gävleborg	27.6	2.1	0.5	80.0	7.0	2.3
Dalarna	25.9	2.0	1.7	75.3	7.0	5.2
Värmland	17.5	1.4	0.8	51.1	3.8	2.2
Boreonemoral region	**66.1**	**5.6**	**1.4**	**188.2**	**14.5**	**5.0**
Örebro	6.5	0.5	0.3	18.2	1.5	0.9
Västmanland	5.5	1.1	0.1	15.5	2.4	0.3
Uppsala	1.7	–	0.1	6.8	0.2	0.3
Stockholm	5.1	0.5	0.1	13.1	1.1	0.6
Södermanland	4.6	0.2	–	13.1	0.5	0.1
Östergötland	2.9	0.1	0.1	8.4	0.4	0.2
Västra Götaland	13.9	1.2	0.2	39.4	3.0	0.8
Jönköping	10.3	0.8	0.2	29.5	2.2	0.6
Kronoberg	7.2	0.7	0.1	20.8	1.9	0.3
Kalmar	7.6	0.4	0.1	20.9	1.1	0.4
Gotland	0.7	0.1	0.1	2.6	0.3	0.4
Nemoral region	**6.6**	**0.5**	**0.2**	**18.5**	**1.3**	**0.6**
Halland	4.7	0.4	0.1	12.8	1.1	0.4
Blekinge	0.9	–	–	2.4	0.1	0.1
Skåne	1.1	–	–	3.3	0.1	0.1

Appendix Table A4. *Landowner area (kHa) distribution of the forestry area* for wind energy land demand on site and planning area in Sweden, presented as the national total and national total below the mountain region (MR), i.e. the study region, per biogeographic region and per county. 0.0 less than 0.1 kHa. '–' for zero kHa.

	Site area			Planning area		
Strata	State	Company	NIPF	State	Company	NIPF
National total	4.5	134.3	116.9	16.8	372.7	354.0
National total below MR	4.4	134.1	116.8	16.5	371.8	353.5
Mountain region	**0.1**	**0.2**	**0.1**	**0.3**	**0.9**	**0.5**
Norrbotten	0.0	0.0	–	0.0	0.2	0.0
Västerbotten	0.1	0.1	–	0.2	0.3	0.0
Jämtland	0.0	0.1	0.1	0.1	0.4	0.5
Dalarna	–	–	–	–	–	–
North boreal	**0.8**	**37.3**	**15.5**	**3.1**	**105.1**	**47.6**
Norrbotten	0.6	24.0	4.9	2.3	66.6	15.6
Västerbotten	0.2	13.3	10.6	0.8	38.5	32.0
South boreal	**2.3**	**77.6**	**47.7**	**8.7**	**218.3**	**146.8**
Jämtland	0.4	13.8	12.1	1.3	40.4	35.9
Västernorrland	0.6	20.0	10.6	2.3	56.4	22.2
Gävleborg	0.2	17.8	10.1	0.5	50.9	30.7
Dalarna	0.6	22.3	4.5	2.3	61.0	16.7
Värmland	0.5	3.7	14.1	2.3	9.6	41.3
Boreonemoral region	**1.1**	**18.7**	**47.6**	**3.9**	**47.0**	**142.3**
Örebro	0.1	2.8	3.9	0.5	7.1	11.5
Västmanland	–	3.7	1.9	0.0	9.3	6.4
Uppsala	0.1	0.1	1.6	0.7	0.7	5.7
Stockholm	0.2	3.9	1.1	0.5	8.4	4.7
Södermanland	0.1	0.8	3.8	0.1	2.3	10.8
Östergötland	0.0	1.3	1.7	0.1	2.6	6.0

(*Continued*)

Appendix Table A4. (*Continued*)

Strata	Site area State	Site area Company	Site area NIPF	Planning area State	Planning area Company	Planning area NIPF
Västra Götaland	0.3	1.5	12.3	0.9	4.2	35.1
Jönköping	0.0	1.4	9.1	0.1	3.4	26.6
Kronoberg	0.0	1.9	5.3	0.2	5.1	15.8
Kalmar	0.3	1.1	6.3	0.7	3.3	17.4
Gotland	0.0	0.2	0.6	0.1	0.6	2.3
Nemoral region	**0.2**	**0.5**	**6.0**	**0.8**	**1.4**	**16.8**
Halland	0.2	0.3	4.2	0.6	0.8	11.7
Blekinge	0.0	0.2	0.7	0.1	0.3	2.1
Skåne	0.0	0.0	1.1	0.1	0.3	3.0

Appendix Table A5. Percent[a] distribution *of land cover types* and *landownership* within the ecoregions. Dash (–) shows no presence.

Ecoregion	Land cover: Forest-land	Open wetland	Farm-land	Other open land	Artificial surface	Inland water	Marine water	Landownership: State	Company	Private
Mountain	28.5	13.1	–	50.7	0.2	7.5	–	81.1	10.0	8.9
North boreal	61.3	13.3	0.9	3.7	1.3	6.2	13.2	7.1	52.7	40.2
South boreal	69.5	6.3	2.3	3.0	1.9	9.3	7.6	4.1	48.6	47.3
Boreonemoral	44.0	2.2	10.0	6.2	2.8	8.3	26.5	7.5	19.5	73.0
Nemoral	30.9	1.6	18.6	7.8	3.6	2.3	35.1	7.3	8.0	84.7

[a]Calculation of landownership exclusive water.

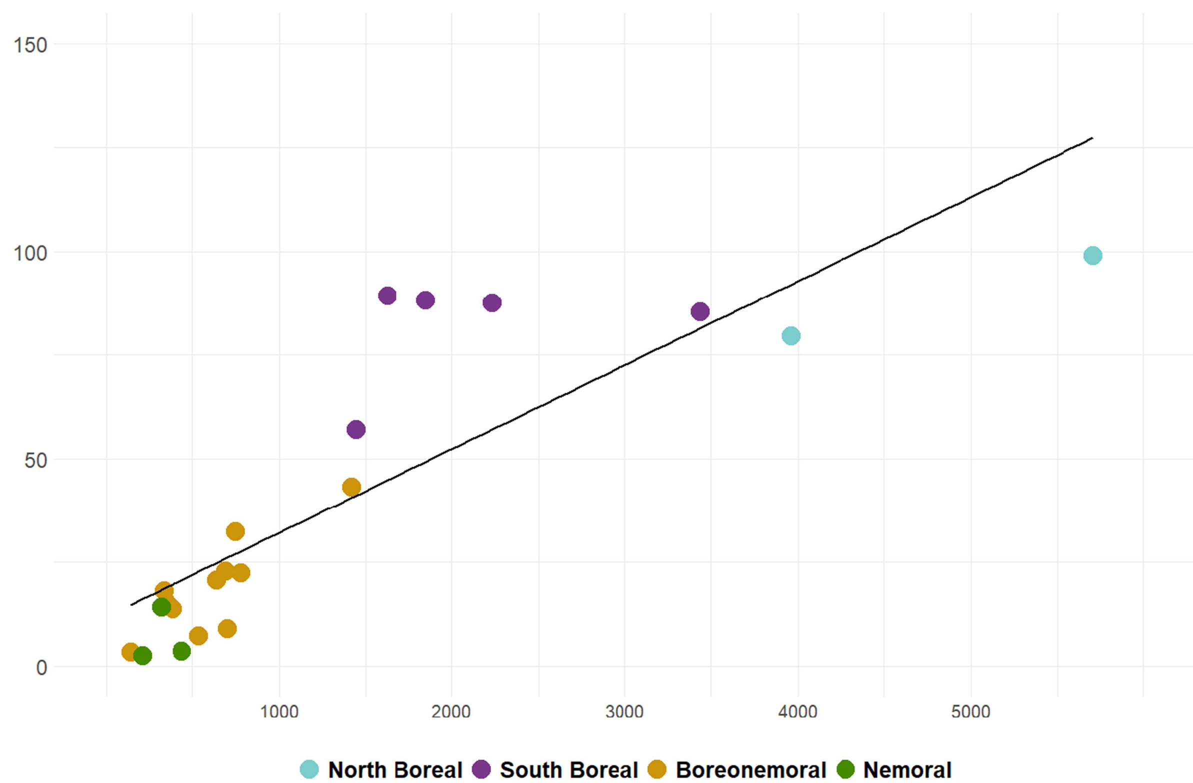

Figure A1. Relationship of area forest land (kHa) claimed by projected wind energy establishment and area of available forest land in each ecoregion and county in Sweden. The black line is a linear trendline.

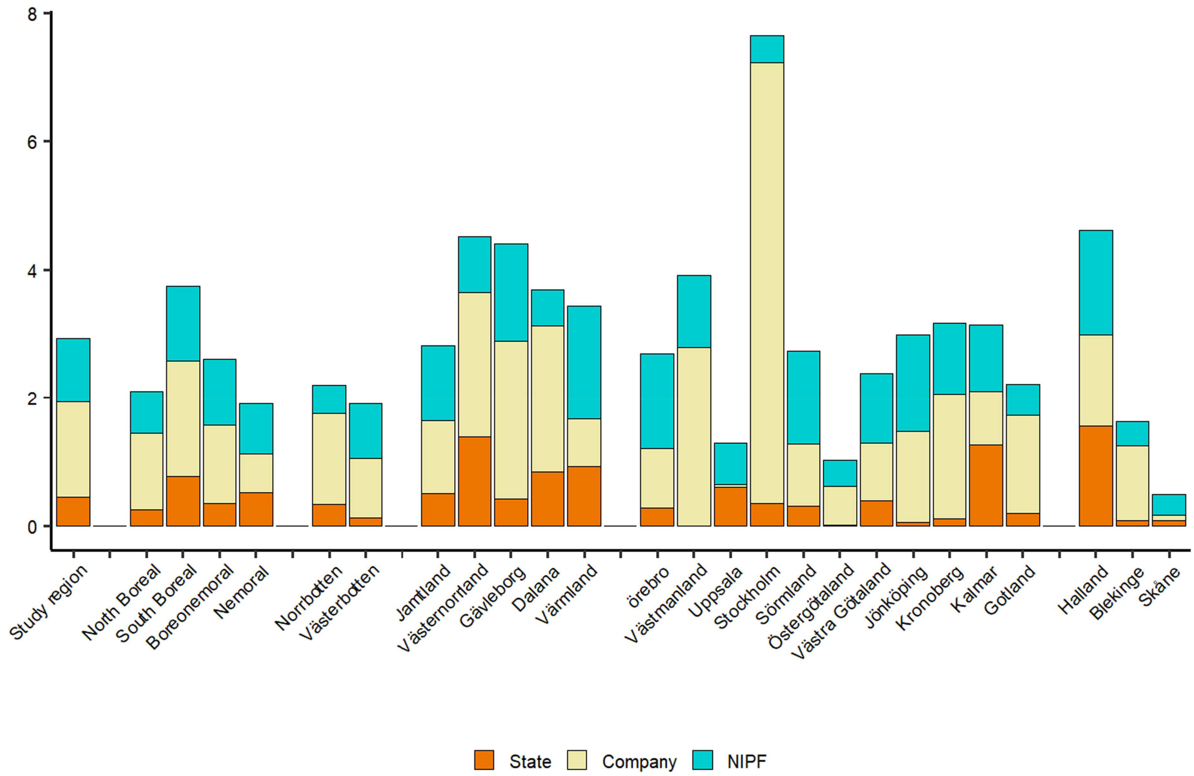

Figure A2. Landowner distribution on wind energy land demand of forestry area given as the share (%) of wind site area of public (orange), forest company (yellow) and NIPF-ownership (blue) in Sweden. The share is calculated as the percentage of total forestry area per landowner category on a given scale. Data are presented for the study region, per ecoregion and per county. Data on the forestry area (kHa) distributed across landowner categories in the wind site and planning area are presented in Appendix Table A4.