Renewable and Sustainable Energy Reviews 60 (2016) 1251–1262

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Onshore wind energy in Northern European forests: Reviewing the risks

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ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
5 February 2016
Accepted 29 February 2016
Available online 15 March 2016

Keywords:
Wind energy
Forest
Northern Europe
Risk management

ABSTRACT

Based on an extensive synthesis of more than 100 peer-reviewed studies, this study explores the risks associated with onshore wind energy in forested areas in Northern Europe. The analyses are performed using a risk management model to conduct a comprehensive literature review on onshore wind energy in such areas. Using an innovative division of a wind turbine's lifecycle and risk categories, this study provides a complete overview of the present academic literature on the risks associated with wind energy in forested areas. Consequently, this study contributes to the wind industry in terms of the risks to be considered for onshore wind projects in forested areas in Northern Europe and to inform the debate in the energy studies literature concerning the lacks and explanations regarding the risks currently covered by the academic literature. The comparative analysis performed in this research reveals trends in the literature and their implications for time and phases of research. The scholarship contribution to the research topic have been compared to geographic specificities and country profiles for each of targeted countries in Northern Europe, resulting in a complete overview and introduction of the risks associated with onshore wind energy in forested areas in Northern Europe.

Contents

1. Introduction . . . 1252
2. Research material and methods . . . 1252
   2.1. Risk framework . . . 1252
   2.2. Literature review . . . 1253
   2.3. Case selection . . . 1254
3. Construction risk parameters . . . 1254
   3.1. Site and resource assessment . . . 1255
      3.1.1. Changes in the layers surrounding the forest . . . 1255
      3.1.2. The impact of different forest formations . . . 1255
      3.1.3. The uncertainty of computer simulation programs . . . 1256
   3.2. Social opposition . . . 1256
      3.2.1. Social acceptance in Denmark . . . 1256
      3.2.2. Social acceptance in Sweden . . . 1256
      3.2.3. Social acceptance in Norway . . . 1256
      3.2.4. Social acceptance in the UK . . . 1256
   3.3. Project delays . . . 1257
   3.4. Cost overrun . . . 1257
   3.5. Land use . . . 1257
4. Operation risks . . . 1257
   4.1. Performance . . . 1257
   4.2. Environmental degradation . . . 1258
      4.2.1. Impact on humans . . . 1258

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http://dx.doi.org/10.1016/j.rser.2016.02.027
1364-0321/

4.2.2. Avian and chiropteran mortality . . . 1258
4.3. Return on investment . . . 1258
5. Decommissioning risks . . . 1258
5.1. Repowering . . . 1258
5.2. Recycling and waste . . . 1259
6. Discussion and comparative analysis . . . 1259
6.1. Comparative analysis of literature . . . 1259
6.2. Temporal phases and trends . . . 1259
6.3. Future research . . . 1260
7. Conclusion . . . 1260
References . . . 1261

1. Introduction

Human kind has been harvesting the wind to create energy for multiple purposes since roughly 3000 BC [1,2], the production of electricity being the latest trend. The deployment of wind turbines has increased dramatically in recent decades in Northern Europe [3–5], as green energy policies have created a market for renewable energy [6,7], mainly due to the fact that global warming and climate change have been accepted as posing a severe threat to the inhabitants on earth [8]. More than two decades ago, Grubb and Meyer [9] estimated the global potential for installed wind capacity to be 53,000 TW h/annually when considering the environmental and land use constraints. Since that study, however, the potential wind capacity is expected to have increased, as the general wind turbines have increased in size [10]. The increased wind turbine hub height [4,11] has rendered it possible to position wind turbines in forested areas. Moreover, wind project developers in Northern Europe have been forced to locate wind farms in forested areas and offshore due to the lack of space [4,10] and rising land prices [12]. Yet, offshore wind projects often requires larger investments and comes with a greater risk of cost overrun both during the construction and in the operational phase of the wind turbine's life cycle [13,14]. Besides acquiring land at cheaper prices, wind turbines in forested areas are generally expected to be deployed far from residential areas, which reduce the negative aspects of wind turbines such as visual impacts and noise emissions, and a study conducted a decade ago by the National Renewable Energy Laboratory revealed the great potential of deploying wind turbines in forests [15]. This is considered a mentionable strength of wind turbines in forest. On the downside, wind turbines requires space both for the wind turbine itself but also for road connections, cables, equipment required for the installation, etc., which may have a negative impact on the local forest environment, due to the felling of trees and interference with the animal life. Therefore, it should be sought to limit the felling of trees. However, from an efficiency point of view, it comes as no surprise that the presence of trees creates a demand for a higher hub height, which adds costs in the production of the wind turbines, due to the need for higher towers. However, even when taking this need into consideration, wind turbines deployed in forested areas risks a lower life time and less energy production, due to the increased turbulence intensity and wind shear [10].

In the initial search for literature it was found that a range of academic papers have been studying risks for onshore wind projects in general. However, few studies, if any, have adequately explored the risks related to wind farm development in European forests. The analysis of the performed literature review in this study reveal lacks of peer reviewed literature for several risk parameters.

In response to this apparent lack of research, this paper will review and explore the complete array of risks associated with developing wind farms in forests in the United Kingdom (UK), Denmark, Sweden, and Norway. The reasons for targeting exactly these countries are explained in details in 2.3, the main aspect is of course the fact that each country has enormous areas covered by forest where wind turbines can be deployed to harvest the strong winds in this region of the World [16]. By investigating the research topic using a holistic risk framework, this study aims at revealing the risks and introduce how the literature's contribution on risks have changed over time in relation to the developed wind capacity in the targeted countries. Clarification of the risks associated with wind energy production in forested areas is required to support the continued development of wind energy in Northern Europe, which this research seeks to cover by introducing the technical risks during the wind turbine's life cycle. However, a continuation of the positive trends of wind energy in Northern Europe is only possible with sociopolitical acceptance of wind turbines in forests, why the results explored in this research also are expected to affect the energy policy in the targeted countries. The cost of protecting the earth from climate change has been studied extensively and will be investigated in this research, with a specific focus on revealing the risks of local negative impact on wind projects. Summing up, this research will present the most comprehensive risk overview ever published for wind turbines in Northern European forests through the following contributions:

- An overview on existing literature targeting risks for wind turbines in forested areas in Northern Europe
- An introduction to risks, which stakeholders in the wind industry in Northern Europe needs to consider
- An overview on whether and potentially how the existing literature covers these risks sufficiently
- An overview of the development of academic contributions as a function of the installed capacity in the targeted countries
- An overview on the risks, which future studies needs to target.

2. Research material and methods

This section of the study presents the methods and materials used to analyze the risks associated with wind turbines in forested areas in Northern Europe.

2.1. Risk framework

This study proposes a risk framework consisting of 10 risk parameters divided into three phases of the wind project lifecycle (excluding the actual manufacturing of the wind turbine). The risk framework model were constructed based on the initial literature review and the feedback from employees from a wind turbine manufacturer, universities, wind project developers, anti-wind organizations, and politicians all part of the wind industry in the targeted countries. The 10 risk parameters have formed the basis of the research methods applied in this study and are expected to cover all of the risks that an onshore wind project in Northern European forested areas can face.

The remaining part of the research paper is structured according to the three phases of the wind project lifecycle, where the literature covering each risk parameter is presented and analyzed. (Fig. 1).

2.2. Literature review

This study applies a similar literature search strategy as Sovacool and Brossmann [23], as an initial broad search for literature has been conducted following specific search words, hereafter another search round were established including the word "Forest", which filtered away a large portion of irrelevant papers from the original search. This approach were similar to the search method applied by Sovacool and Brossmann [23], yet, it differs in the sense that Sovacool and Brossmann [23] also took popular articles into consideration and were targeting papers on hydrogen economy. In this research, the comprehensive literature study has been carried out to discover the risks when deploying wind turbines in forested areas. A search through peer-reviewed journals using the online databases; ScienceDirect and Google Scholar revealed a large number of previous studies. The review were conducted using the following keywords in the original search: "Risk," "Wind Turbines," "Wind Power," "Siting," and "Wind Energy," in an "And" combination with "Forest," "Denmark," "Sweden," "Norway," "England," "Northern Ireland,""Northern Europe," "Nordic," "Europe," "Wales," "Scotland," or "United Kingdom," and the 10 risk parameters presented in Fig. 2. The search for literature ended in July, 2015, and a total of 242 academic papers were identified, after which a filtering process was conducted, excluding irrelevant papers with little or no focus on the topic, as described above. The final result was 102 papers covering the 10 risk categories, which formed the basis for the most comprehensive review of onshore wind energy in Northern European forested areas. The outcome of the 102 papers is

Construction risks	Explanation of assumed risks	Operating risks	Explanation of assumed risks	Decommissioning risks	Explanation of assumed risks
Site and resource assessment	• Improper assessments • Insufficient knowledge of roughness effects in forests • Outdated software and calculation methods	**Performance**	• Lower-than-estimated production • Errors • Increased maintenance needs	**Repowering**	• Greater need for redoing the construction work
Social opposition	Complaints leading to delays due to the: • Environmental impact • Physical impact on humans • Socioeconomic impact	**Environmental degradation**	• Impact on birds and bats • Noise and visual interference	**Recycling and waste**	• Dismantling requires transport and space • Inaccurate waste impact estimates
Delays	• Social opposition • Environmental studies	**Return on investment**	• Unpredictable wind conditions result in worse investments than expected		
Cost overrun	• Road construction in forests • Felling of trees • Cabling				
Land use	• Felling of trees • Protected areas • Impact on wildlife leading to social opposition				

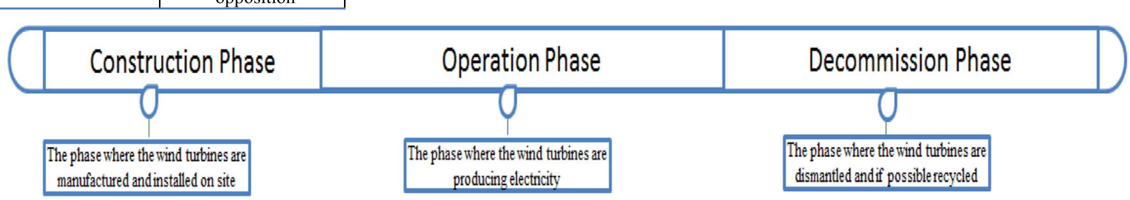

Fig. 1. Risk framework model.

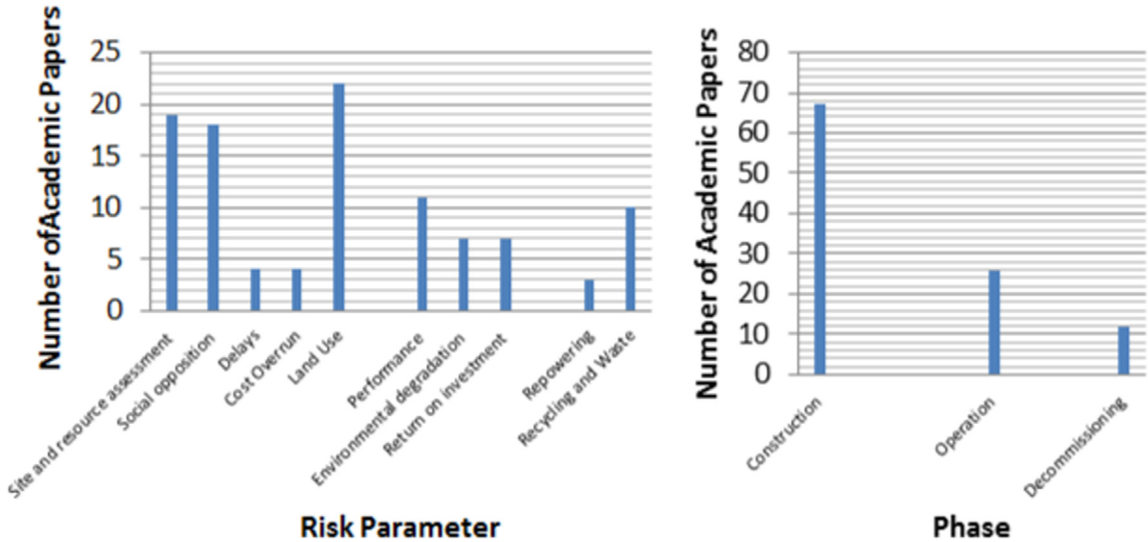

Fig. 2. Academic papers divided into risk parameters and lifecycle phases.

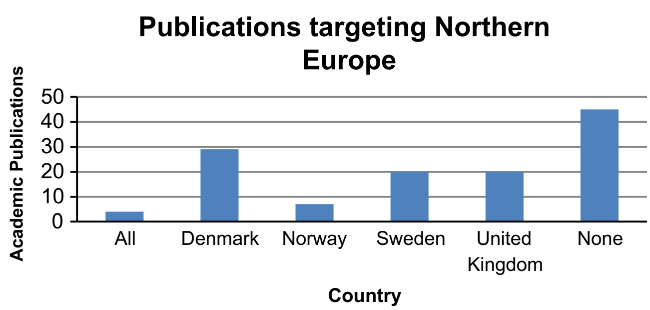

Fig. 3. Country division of published literature.

Fig. 4. The targeted countries (Denmark, Norway, Sweden, and the UK).

presented in Fig. 3, providing the reader with an overview of the coverage of the various risk categories associated with onshore wind turbines in forested areas in Northern Europe and each phase in the wind turbine lifecycle.

The most debated lifecycle phase and risk category regarding wind turbines in forested areas in Northern Europe was revealed as the *Construction Phase* and *Land Use*, yet some of the papers in the *Land Use* category could easily have been grouped together with *Social Opposition*. The fact that the construction phase is the most academically analyzed phase of a wind turbine lifecycle hardly comes as any surprise, since the remaining risks depend on the risk categories in this particular phase. Another detail of the result from the literature search, which might impact the overall results are the risk of including papers that only mentions "forests" without actually studying the impact of wind power in forests. Consequently, this would impact the research in a negative way, as the study then would be based on risks for onshore wind turbines not necessarily deployed in forested areas.

An analysis has been carried out revealing the number of publications targeting each of the countries in this study.

The results presented in Fig. 4 indicate a clear overweight in terms of the literature contribution from Denmark and *None. None* refers to general studies without a target country, such as "Europe," studies not focusing on any geographical risks, or studies referring to a country other than those referred to in this research. The studies not directly targeted on the implied countries have been included, as it is believed that some of the risk parameters can be applied across borders. *All* have been used for publications focusing on all of the countries in this study.

2.3. Case selection

Fig. 4 highlights the implied countries in this study. The argument for targeting these countries is being explained in the following.

The wind conditions in the targeted countries are considered some of the best for wind energy production [10,16], and the market acceptance level [17] favors the wind industry [18]. Denmark is covered by 13.5% forest [19], Sweden 66% [20], Norway 38% [21], and the UK 12% [22]. As presented in Table 1, the uniqueness parameters of the targeted countries are based on the domination of coniferous tree types, and additionally a similar wind regime with a prevailing wind direction from south-west. Such specifications could also have been discovered for other countries in the world, yet, these countries represent the mature and developing markets, see Fig. 6.

The intention of this study is to review the risks associated with wind turbines in forested areas through a comprehensive targeted literature study as summarized in a risk framework model for further application in the wind industry.

3. Construction risk parameters

As Fig. 2 above indicates, the five construction risk parameters relate to the risks that need to be considered in the period before the wind turbines are in operation. These parameters are vital for the later performance and return on the investment in the wind

Table 1
Northern European forest facts.

Country	Installed wind capacity (MW), late 2014	Percentage of country covered by forest (%)	The dominating tree types	References
Denmark	5376	13.5	Abies alba and Picea abies 40.4% Deciduous Trees 39.5%	[19]
Norway	819	38	Picea abies 47% Pinus sylvestris 33%	[20]
Sweden	5424	66	Picea abies 42% Pinus sylvestris 39%	[21]
UK	12,440	12	Picea sitchensis 29% Pinus sylvestris 17% Deciduous Trees 40.2%	[22]

turbine and even the political and public approval of the wind project.

3.1. Site and resource assessment

A common understanding of wind turbines in forests defines the gravest risk to be the uncertainties in site and resource assessments, as the impact of the trees remains an unpredictable factor. The main root error can be attributed to the unpredictable wind conditions [12,24,25]. The wind speed usually varies logarithmically, following

$$\frac{U(z1)}{U(z2)} = \left(\frac{z1}{z2}\right)^{\rho} \quad (1)$$

where $U(z1)$ and $U(z2)$ define the wind speeds at heights $z1$ and $z2$, and p is the power law exponent [2,4]. The wind speed in the forest is acting differently, however, as the wind profile mixes exponentially from inside the forest to logarithmically above the forest [12]. There are numerous issues when being unable to determine the wind speed, beyond undefined loads on the wind turbine, the energy output will vary a lot from what has been estimated. As a rule of thumb, the power in the wind is proportional to the third power of the wind speed [4], meaning that a wind turbine will produce 80% less energy at 6 m/s as compared to 8 m/s, and a miscalculation in the resource assessment can result in a misleading business case. This section therefore seeks to describe and divide the risks associated with the site and resource assessments in forested areas.

3.1.1. Changes in the layers surrounding the forest

The impact of forests on wind conditions can be understood by defining the changes of wind speed in the wind layers in, around, and above the forest, as illustrated in Fig. 5 below.

The size of the boundary layer varies between 100 m and 2 km. The lowest 10% is referred to as the "surface layer," where the air and wind flows are in direct contact with the ground. The topography of the surface impacts the beginning of the surface layer. With low vegetation and small obstacles, the surface layer starts at ground level ($z0$); above forests, however, the surface layer begins at a higher height, at a distance d, which is referred to in wind simulation terms as the displacement height [27]. Another layer within the surface layer is the roughness sublayer. In forested areas, this layer cannot be compared to a normal roughness layer above low vegetation due to the impact of the forest. This is where the wind profile shifts from exponentially within the forest to logarithmically above the forest, and this change in the wind profile causes turbulence and unpredictable wind flows. It is worth mentioning that the turbulence and changes in wind speed above the forest canopy vary on the impact from the atmospheric stratification [28].

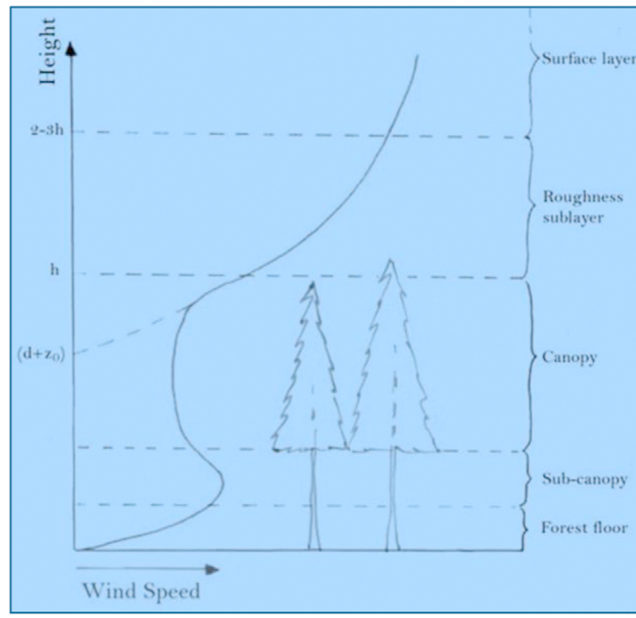

Fig. 5. The forest's impact on wind speed [26].

3.1.2. The impact of different forest formations

Bergström et al. [12] presented a study based on a range of measurements which revealed the impact of heterogeneous forests. The result was that the roughness impact from a heterogeneous forest with a lot of clearings will be higher than that from a homogenous, dense forest. It has also been proven that the forest formation has a varying impact on the wind conditions, depending on the point of measurement being at the edge or in the middle of the forest [25,29], and that clearings inside a forest have a major impact on the wind speed and turbulence intensity [12,30]. Different forest formations and tree types also have an impact on the roughness length. The academic literature seems to disagree on the roughness length for different tree types [31]. The amount of literature on this particular subject indicates the uncertainty of—yet need for—defining more precise roughness lengths for the tree types in Northern Europe. The importance of the roughness length can be defined by presenting the importance according to the velocity profile. As already mentioned, the velocity profile of the wind becomes logarithmic above the forest company, and following

$$V = \left(\frac{u}{k}\right) \times \ln\left(\frac{z-d}{z_0}\right) \quad (2)$$

where k determines the von Karman constant and u the friction velocity, z defines the height, d defines the zero-plane displacement height, and z_0 the roughness length, meaning that a change or incorrect estimation of these parameters can result in a different estimated wind speed and therefore a wrong estimated energy production.

3.1.3. The uncertainty of computer simulation programs

Raftery et al. [32] discussed five different models for wind shear over forests, concluding that none were adequate and that local measurements were needed for positioning wind turbines in forests. One of the reasons could be that the wind direction can change above the forest; a theoretical measurement gives a wind veer of 90° between the forest floor and boundary layer top and 60° between the ground and 250 m. According to Bergström [12], this is considered much higher than what is predicted by industry simulation programs. In addition to the study by Raftery et al. [32], Hui and Crockford [31] discovered that the settings applied in some of the widely used commercial software programs can vary considerably, thereby concluding that the software programs are capable of estimating the impact of the forest; it just comes down to too many options misleading the user.

3.2. Social opposition

Social opposition, even merely a lack of social acceptance, poses a great danger to the development of wind projects, often resulting from different incentives and pressures [33]. Devine-Wright [34] found that social opposition is a risk worthy to consider in the construction phase, as the social acceptance of the wind project constantly declines until the moment where the wind turbines actually come into operation. Hereafter, the social acceptance starts inclining [34]. A recent study by Enevoldsen and Sovacool [35] presented synthetic reasons for social opposition to wind farms, which have been summarized in Table 2 and analyzed subsequently to determine if the same reasons for opposition apply to forested areas in the targeted countries.

3.2.1. Social acceptance in Denmark

Surveys reveal that most Europeans support wind energy [36]. Previous studies have defined the social acceptance of wind turbines or lack thereof in each of the targeted countries. In Denmark, over 100,000 private citizens have personally invested in wind turbines [36], and this tradition concerning private ownership is expected to have contributed to the high level of social acceptance of wind power [45]. Moreover, there has been political support for wind turbines in Denmark since the oil crises in the 1970s, and the favorable feed-in tariffs in the 1990s encouraged a massive increase in wind turbine installations and the wind industry in general [45,46]. The recent trends in Denmark also focus on the development of new, large-scale wind farms [46,47], which may influence the public perceptions of wind energy.

Table 2
Synthetic reasons for social opposition to wind farms [32].

Dimension	Component(s)	References
Environmental impact	Flora and fauna	[36]
	Reduction of wildlife	[37–39]
	Felling of trees	[34]
Visual Impact	Size, color and shape of the wind turbine	[6,40]
	Number of wind turbines	[15,41]
	Noise and flicker effects	[4]
	Usage of landscape	[42]
	Involvement in location	[43]
Socioeconomic Impact	Tourism	[40,42]
	Property and land values	[40]
	Local benefits	[3]
	Lack of information	[40]
	Political and market acceptance	[17]
	Number of wind projects in the area	[42]

3.2.2. Social acceptance in Sweden

Khan [48] discovered that the development of Swedish wind projects is based just as much on the public acceptance of wind power in the local communities as the wind conditions. However, this can be closely related to the more recent political support for wind power in Sweden. Like Denmark, Sweden experienced oil crises in the 1970s; unlike Denmark, however, this resulted in investments in nuclear power, and the Swedish development of wind projects was very slow until the 2000s [49]. From 2005–2010, Swedish wind power production increased dramatically from 0.94 to 3.51 TW h [46]. This increase can partly be attributed to the government establishing national interest areas for wind power in 2004 and extending the renewable electricity certificate system from 2010 to 2035, which secured investments [50]. Moreover, the municipality with the highest installed wind capacity is Malmö [46], which is one of the most densely populated areas in Sweden and has a history of major nuclear power plant investments. Despite this increase in wind power in Sweden, researchers point out how the decentralized Swedish system often contributes to local opposition to wind projects [51]. In Sweden, the local community must approve wind projects [52,53], and, unlike Denmark, the municipality does not have to allocate areas for wind projects. A survey conducted in 2002 revealed that 28% of all Swedes have negative attitudes to wind power [54]. This number is expected to fall, as Ek et al. [46] found that municipalities with installed wind power were more likely to support wind power, and given the development of wind capacity in Sweden, a lower percentage of negative responses can be expected in the future. Those who oppose wind projects in Sweden are often older and have a high income [45,55]. People do not generally complain about the visual and noise impact of wind turbines (the NIMBY parameters [56])[46], and the opposition to turbines is strongest to those positioned in the landscape, as surveys have revealed the strongest opposition against wind turbines positioned on mountains and in forests [55], and the Swedes would even prefer higher energy costs to having wind turbines located in such areas [51].

3.2.3. Social acceptance in Norway

Completely opposite the Danish case, where there has been decades of political support for wind energy leading to a growing wind industry, Norway experienced neither political support nor rapid growth in the wind industry over the course of the 1990s and 2000s, which, combined with the large national oil industry, could be why studies have found that the public support and acceptance of wind power is too low to motivate the expansion of the wind industry in Norway [53].

3.2.4. Social acceptance in the UK

The UK has become one of the countries with the most installed wind turbines with respect to both onshore and offshore turbines. On the national level, large offshore wind farms have been recently established, avoiding many of the risks associated with the lack of social acceptance, which supports the inverse NIMBY public perceptions discovered by Warren et al. [57]. Warren and McFadyen [58] showed how the local public ownership of wind turbines reduces the risk of complaints and social opposition. With the increase in wind turbine size and increase in the number of wind turbines grouped together in a single project, however, an increase in rejected onshore wind projects has been experienced in the UK, which verifies the account of social opposition presented in Table 2. Enevoldsen and Sovacool [35] suggested that negative attitudes towards wind projects can be reduced by involving locals in the decision-making processes. This is especially important in Sweden due to the public inquiry round held in the end of the planning of Swedish wind projects, which allows local residents to block wind projects. Furthermore, Pettersson et al. [53] revealed that the Danish acceptance process for wind projects, which is somewhat comparable to the British process, yet, the environmental demands for British wind farms recently been criticized [59–60], relies on measurable parameters, such as noise emissions and flicker effect, whereas the legislation is more vague in Sweden and Norway [52,55]. Further along these lines, Pettersson et al. [53] found that the average development time for wind projects is higher in Sweden (ca. 5 years) than in the UK, Denmark and Norway (2–4 years). The average development time for European wind projects varies between 1.5 and 4.5 years [61].

Few studies does address the specific risks concerned to wind projects in forested areas in Northern Europe, whereas forest more has been treated as one of many parameters in such studies. Nevertheless, it becomes clear that social opposition threatens onshore wind energy in forested areas in Northern Europe, as all of the risk factors presented in Table 3 are present in the targeted countries and, besides the physical impact on humans, are likely to increase in forested areas. Therefore, future studies needs to target and address the risk of social opposition in forest only.

3.3. Project delays

As in all construction projects, delays are a risk worth mentioning. Wind projects in forested areas can be delayed by a range of events, some predictable and others less so. Table 3 categorizes the outcome of the literature review on the events causing delays in forest wind projects. More generalized reasons for delays, such as uncertain project management [62], have not been included in the table.

3.4. Cost overrun

Cost overrun presents an interesting risk parameter for the construction risks yet a rather novel risk parameter, as reflected in the low number of peer-reviewed studies published on this topic (see Fig. 3). Nevertheless, Sovacool et al. [66] investigated 35 wind farms to test the potential cost overrun aspects for wind power projects. The outcome was a mean cost escalation of 8%. Furthermore, the study revealed that a longer time period equals a cost overrun, which is entirely unrelated to the size of the project in question, yet no conclusions could be drawn on forest projects. However, it is possible to conclude that if the delays presented in Table 3 occur, they will most likely include cost overruns, despite the rapid innovations in the wind industry [67]. Even though wind power has been found to be one of the electricity infrastructures with the lowest cost overrun [68], the risks can be assumed to be greater for onshore wind projects in forested areas due to the fact that onshore projects in forested areas are often accompanied by higher development costs than other onshore projects in the construction phase, primarily due to the felling of trees, road construction, and greater distances for grid connection; nevertheless, no studies have targeted the cost overrun in forest wind projects.

3.5. Land use

The risk related to land use is associated with social opposition and social values in many of the existing studies. Having already described the risks associated with social opposition and land use, this section focuses on other parameters, all of which are related to the installation of wind turbines in forests [5]. The installation of wind turbines raises risks related to the local bio system [69]. For wind turbines in forested areas, this may include road construction and deforestation [69]. Such necessary activity might have bearing on the commercial viability of a project if too many trees are to be felled [70]. Based on the literature review, it is possible to conclude that the land use risks can be divided into four factors, as presented in Table 4.

Siyal et al. [72] suggested areas for new wind project development based on a map consisting of restricted areas combined with areas with great wind potential, meaning an approach that somehow follows the four factors mentioned above. As Santos-Alamillos et al. [71] explain, however, the land use constantly changes due to both nature and human interactions. By investigating the carbon emission savings from wind farms, the impact of the felling of trees can be determined as:

$$S = 24 \times 365 \times \frac{\text{pcap}}{100} \times \text{n} \times c \times E \tag{3}$$

S is the annual emission savings, pcap the capacity factor, n the number of wind turbines, c the turbine capacity, and E is the emission factors measured as CO_2 MW h^{-1}. For Scottish wind projects, Perks et al. [70] found that a clear-felling of a forest would require 12 years of wind turbine operation to repay the carbon payback. It can be concluded that specific risks do exist for onshore wind energy in the forested areas in Northern Europe.

4. Operation risks

The operation risks mainly relate to the performance of the wind turbines in forested areas. Furthermore, the intention was to investigate if environmental degradation risks were more severe for onshore wind projects in forests than for projects located outside of forests, but the literature provides no clear answer to this question.

4.1. Performance

The first risk parameter in the operation phase is a continuation of the first risk in the construction phase—the site and resource assessment—as conclusions regarding performance are closely related to the predicted performance [75]. As determined earlier in this research, trees pose obstacles that cause changes in the local

Table 3
Factors leading to delays.

Factors impacting delay	Reasons	Most likely to experience in	Reference
Policy	Vague definitions of “wind farms” condition what can be questioned during the development period	Sweden	[55,63]
	The public inquiry round in the end	Sweden	[46,52]
Site-specific	Due to the low temperatures in Northern European forests, icing can occur and extend the measurement period	Norway and Sweden	[24,64]
	Wildlife species living near the proposed wind farm can require additional environmental studies	UK, Denmark, Norway, and Sweden	[43]
Social	Opposition due to visual and noise impact	UK, Denmark, and Norway	[41,44,57,65]
	Opposition due to landscape interference	Sweden	[45, 46, 55]

Table 4
Risk factors associated to wind turbines in forested areas.

Factor	Risk	Reference
Market	Land use based on forestry	[71]
	Land use based on farming	[71]
Policy	Restrictive areas	[72,73]
	Changes in energy policy	[50]
	Approval of and enquiries regarding wind projects	[50,55]
Social	See Table 2	
Site-specific	Changes in tree types and forest formations make it difficult to estimate the wind flow	[12,24,25]
	Previous public usage of area	[74]

wind conditions [76]. This can be measured in terms of the turbulence intensity

$$Ti = u'/V \tag{4}$$

This indicates the changes in the wind speed, u' being the root mean square of the turbulent velocity fluctuations and V being the average wind speed. With high turbulence intensity, wind turbines risk fatigue loads and vibration errors beyond the capacity of the wind rotor and blades [74,77]. The literature presents numerous reasons for errors [78] and methods to detect and avoid these errors to optimize performance [76,79,80]. However, none of the studies specifically address the performance of wind turbines in Northern European forests.

4.2. Environmental degradation

Having already described the land use risks in the construction phase, this section focuses on the environmental risks from operating a wind turbine, which have been widely recognized in the literature in terms of the physical impact on humans and animals.

4.2.1. Impact on humans

The noise and shadow effect caused by wind turbines is one of the main reasons for complaints in the public enquiries [40]. The sound level of wind turbines is measured in dBA (decibel A), which measures the sound the ear is capable of hearing [10]. Basically, a wind turbine produces two types of noise:

- **Aerodynamic noise:** This is the type of noise created by the wing cutting through the air. People can only hear this noise when they are very close to the wind turbine.
- **Mechanical noise:** This is the type of noise created by the gears and other moving parts within the turbine. Soundproofing can reduce the mechanical noise.

Forested areas can be considered rural, which explains why there is a minimal physical impact on people.

4.2.2. Avian and chiropteran mortality

A range of studies have been conducted addressing the impact of onshore wind turbines on birds and bats [11,37,69,81]. Zhang [8] states that birds are one of the largest groups of animals experiencing fatal collisions with wind turbines, and a study estimated that wind turbines killed 234,000 birds annually [82]. While bats react to moving targets, the mortality of bats also increases around wind turbines [69]. Wind turbines have also been observed to have a negative influence on bird breeding and feeding behavior. However, even though attempts have been made [38], Wang et al. [83] state that the uncertainty regarding why and how birds are killed must be clarified in order to arrive at a proper conclusion concerning the impact of wind turbines on bird mortality; the same can be said for wind turbines in forested areas.

The felling of trees can be assumed to cause the death of birds and bats [84,85], yet it is unimaginable that wind turbines will cause the number of fatalities among birds caused by other energy resources [84] and other causes such as cars, cats and cables [39].

4.3. Return on investment

Besides an expectation of an investment in clean energy [86], wind turbines have become a topic for major investments and how to make the most of investments [87,88]. An excessive number of academic studies have been carried out on the return on investment and risk management of business cases of onshore wind projects [86,89]. The net present value of a wind turbine is a measure used by investors to rate their investment. The net present value can be calculated using

$$\text{NPV} = \sum_{N} CF_n \times (1+r)^{-n} \tag{5}$$

where n defines the numbers of years, CF_n defines the cash flow in the related year, and r is the discount rate [90]. When combining the net present value with the internal rate of return, the investor knows the risk allowed in the project. Yet even though the capital cost of a wind project can be estimated to be around 75% of the combined cost [91], many factors must be considered, including the electricity market [92], local financial support structures for renewable energy [93], the uncertainty of financial support structures [94], and of course most importantly the work conducted in the siting and resource assessment stage. None of the literature targeted in this study explicitly focuses on wind projects in forested areas, but it can be estimated that the increased risks in the construction phase possibly lead to a different investment scenario than the one for other onshore wind projects in Northern Europe.

5. Decommissioning risks

The decommissioning risks relate to the phase after the production lifetime of the wind turbine. Due to large multi-megawatt wind turbines being a novel technology with an average lifetime of 20–25 years, the industry has yet to experience large numbers of these turbines reaching this phase of the lifecycle; nevertheless, researchers have tried to estimate the opportunities and challenges that the industry will face.

5.1. Repowering

Del Río et al. [95] define repowering as the process by which existing wind turbines are replaced with new wind turbines with a higher energy output. Given that wind turbines have an average lifetime of 20–25 years and, as mentioned above, it is difficult to obtain land for wind turbines for numerous reasons, repowering can avoid some of the risks and investment costs that were previously encountered in the construction phase [95]; the land has already been acquired, the grid connection has already been established, and the public has grown accustomed to living with a wind farm. Most importantly, decades of wind data ought to reduce the risks regarding wind conditions dramatically. It is worth mentioning that new environmental studies must be carried out, and the political support for wind energy may have changed [95]. Denmark, a country that can be considered a repowering pioneer, had repowered approximately 66% of the old fleet of wind turbines by December 2005 [95], and the other global wind energy pioneers are currently doing the same [96,97]. While

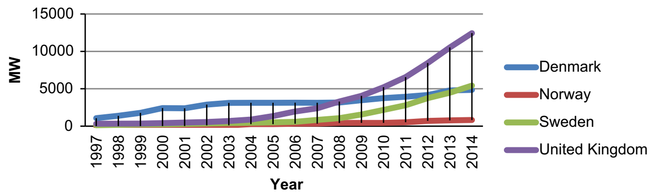

Fig. 6. Installed wind capacity in the targeted countries [108].

this risk parameter has not been covered by the literature, it can be expected to be a future topic, as repowering in forested areas can be expected to reduce the construction risks.

5.2. Recycling and waste

According to Zhang [8], a wind turbine produces enough clean energy within a few months to cover the energy used to manufacture and transport it. Furthermore, a range of lifecycle analyses of wind turbines focusing on the environmental externalities in terms of emissions in the manufacturing phase [98–103] have produced different outcomes. However, few, if any, studies have adequately investigated the environmental externalities caused by wind turbines in the decommissioning phase; this despite the increasing need for the wind industry to consider solutions for the bulky waste resulting from decommissioned wind turbines. For example, Andersen et al. [104] predicted that as of 2040, 380,000 t of fiber composites from wind turbines will have to be disposed annually, and the wind turbine blades in particular appear to pose a problem for recycling [105,106]. Based on these studies, it was found that 37% of the rotor and blades, 90% of the tower and 87% of the nacelle can be recycled due to the high percentage of the wind turbines consisting of metals.

The literature review in this study has not revealed whether there are special circumstances for onshore wind turbines in forested areas in Northern Europe; nevertheless, by applying the findings from the two risk categories *Cost Overrun* and *Land Use*, we know that the waste must be transported over longer distances than the general onshore wind project.

6. Discussion and comparative analysis

This section discusses the results from the literature search in order to determine if certain patterns can be discovered in the development of installed wind capacity compared to the publications of academic literature and the development of various risk parameters. The investigation has addressed whether there is a correlation between the installed wind capacity in the targeted countries and the development of publications of risk parameters. Fig. 6 presents the development in installed wind capacity in the targeted countries and Fig. 7 the development of the literature targeting each of the countries under investigation here.

6.1. Comparative analysis of literature

A clear correlation is revealed between the development of installed wind capacity and publications on the risks for onshore wind power in each of the countries in question. Denmark has a lengthy history with wind power [107] and has been the leading country for case studies in the period 1994–2010, while a dramatic increase in the installed wind capacity in the UK during the period 2007–2015 has led to an increase in British publications; the same goes for Sweden in the period 2009–2015 and more recently for Norway.

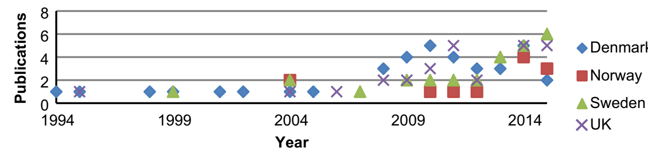

Fig. 7. The development of publications for each of the countries.

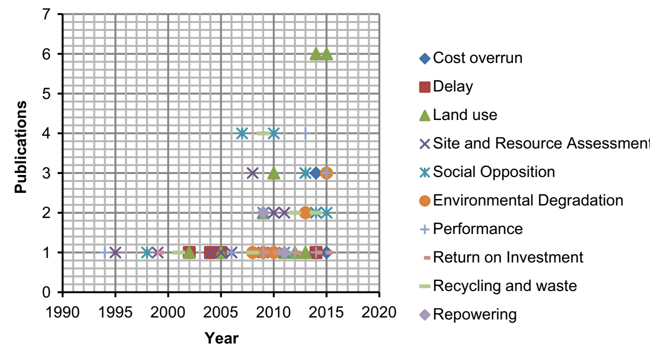

Fig. 8. The development of published literature.

Fig. 6 presents the development of installed wind capacity in each of the targeted countries, whereas Fig. 7 presents the development of publications related to each of the countries.

When analyzing the literature coverage as in the Methods section of this study, a natural source of error is that some topics produced more “search hits” than others; however, this only reveals which parameters have been considered to be the most “risky” by the academic literature, for which reason Fig. 8 reveals the development of studies addressing each risk parameter.

6.2. Temporal phases and trends

Besides indicating a clear increase in the academic study of the topics relating to the risks involved in onshore wind projects, it is also possible to conclude that the number of studies focusing on Land Use, Social Opposition, Environmental Degradation and Performance is increasing. It can be discussed whether the keywords apply to studies within these risk parameters.

When investigating the occurrence of risk parameters it becomes clear that in first phase from the mid to late 1990s, it is most about site and resource assessment. This can be explained due to the nascent stage of wind energy in Denmark, why it was critical to investigate how to develop the most efficient wind projects. The academic contribution of social opposition can be related to explosive growth in wind turbine size from 1995–1999, where the height of the largest wind turbines were doubled.

The second phase, from 2000–2010, presents a rapid growth in academic contributions, which of course can be related to wind energy installations in Sweden and in particular in the UK. Site and resource assessment is still an important topic around 2005, possible due to the boom in installed wind energy in the UK. New risk parameters are presented in this phase, as land use, environmental degradation, delay and repowering becomes an important topic. The first three risk parameters are most likely to contribute to the growing amount of studies on social opposition.

The final phase presented in this study, from 2010–2015, presents an explosion in studies related to land use, social opposition, cost overrun and environmental degradation. Statistics regarding developed wind farms in the targeted countries reveals larger wind farms with larger wind turbines. Combined with less publications and installed wind capacity related to Denmark, a country where the public are supportive of wind energy, the increase in size of wind farms could be the reason for the increasing concentration on land use and related topics, as wind farms suddenly removes nature instead of becoming a part of the landscape.

6.3. Future research

Having presented the most comprehensive literature study conducted on onshore wind energy in forested areas in Northern Europe, it can be concluded which of the 10 risk parameters that have been covered sufficiently and which have not. The division is merely based on the author's analysis of this paper and search results and categorized using “X” for parameters that have been covered, “–” for parameters with some coverage of wind turbine risks associated with Northern European forests and “O” for parameters which are only covering onshore wind projects in general.

Only two of the 10 risk parameters have been covered, and even for these two, more specific studies must be carried out. For the remaining risk parameters, further studies must be conducted on the risks for onshore wind power in forests. It is suggested for future practical studies to investigate the lacking constructing risks as soon as possible, as these factors impacts the later risks in the operation and decommission phase of a wind project. Studies can be carried out using data from operating wind turbines, where essential project management parameters such as time planning and construction budget will reveal two of the lacking factors in the construction phase, and add information to the return on investment. The forest agencies of the targeted countries does all have public available databases, from where it is possible to draw conclusions on the amount of forests that has been felled for each wind project, which could reveal the potential risk of land use. For a deeper investigation of the environmental impact, detailed studies on impact on animal and plant life would have to be conducted, maybe even for the entire period of a wind turbine. This challenge is generic for the risks in the operation and decommission phase, as most of the risk factors require experience, measurements and thereby knowledge from the entire wind turbine life cycle, which usually would last up to 20–25 years.

One can argue that for future reviews on broad topics like this one, the keywords applied in the literature search should be even more detailed and targeted than what has been applied in this study, in order to have a scope even further in on wind projects in forests. However, the excessive number of studies discovered on each of the risk parameters indicates that these are risks to be considered for onshore wind projects. It is also a fact that wind project development in forested areas in Northern Europe is a novel innovation and it is therefore to be expected that there is less academic coverage of the risks in the operation and decommissioning phases.

7. Conclusion

This study has explored the risks associated with onshore wind energy in forested areas in Northern Europe by applying the most comprehensive literature study on wind energy's risks in forested areas. The approach for the literature study and the overall research have been designed by a strategic risk framework consisting of 10 different risk parameters divided into 3 phases of a wind project life cycle. The outcome of the study is an overview of the risks for each of the targeted countries, which have been analyzed regarding its relation to the latest trends in academic literature. This revealed clear patterns and it can be concluded that trends in the literature implies that the community and wind industry shifts in what regard as important.

This study contributes to the wind industry by informing about the risks one has to consider before developing wind projects in forested areas. Furthermore, Fig. 9 presents that the wind industry still has a lot of risk parameters to consider and explore. Wind energy investors and politicians will learn what risks to be aware of, and further studies based on this research could categorize the importance of each of the ten risk parameters, in order to strategically analyze wind projects in forests. Wind manufacturers and developers will have to pay extra attention to the risks in the operation – and the decommissioning phase, as these have not been covered by recent literature and can be considered novel risks for peer reviewed literature.

This research presents a novel approach to comparative analyses of the relationship between the development of a technology and the development of scholarship. Besides presenting the areas where literature is lacking, scholars in wind energy studies are expected to be able to further develop the strategic risk framework for other geographical areas, for instance to gain knowledge of new markets. Furthermore, it has been learned that risk is complex and multidimensional, why the approach in this research is

Construction risks	Covered by the literature	Operation risks	Covered by the literature	Decommissioning risks	Covered by the literature
Site and resource assessment	X	Performance	O	Repowering	O
Social opposition	–	Environmental degradation	–	Recycling and Waste	O
Delays	–	Return on investment	O		
Cost overrun	O				
Land use	X				

Fig. 9. Evaluation of the academic contribution.

expected to be applicable for any energy technology. It can be concluded that the current academic contributions regarding the risks associated with onshore wind energy in forested areas in Northern Europe are insufficient, which might define the root cause of wind energy in forested areas; no one has yet completely revealed the risks and uncertainties facing the onshore wind industry in Northern Europe. Perhaps we better understand risk when we encounter such, yet, the contribution in this research aims at avoiding or at least minimizing the risks that can be experienced for wind projects in forests.

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