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A socio-technical framework for examining the consequences of deforestation: A case study of wind project development in Northern Europe

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ABSTRACT

Wind projects are frequently developed in forested areas, and especially in Northern Europe, due to less restrictions and social opposition, favorable renewable energy policies and, of course, the heavily forested areas in this region of the world. Wind project development in forested areas has an unpreventable impact on nature, namely deforestation. The felling of trees is carried out to free space for the wind turbine installation and potentially also to increase the performance of the wind turbine and lower the levelized cost of energy. This study examines the impact of such a felling strategy, including the environmental and social consequences of deforestation. Based on a case study carried out in Sweden, this research study develops the first socio-technical framework for examining the consequences of deforestation. The deliverables of this research include recommendations for wind industry and forest industry stakeholders on how to apply deforestation in future development of wind projects in forested areas in Northern Europe. In addition, the framework is expected to encourage academia to further develop and analyze the socio-technical parameters associated with wind project development in forested areas.

1. Introduction

Onshore wind power has been recognized as a key technology in the transition towards a world powered by renewables (Jacobson et al., 2017) and thus constitutes an important part of the various strategies employed in the battle against global climate change (Valentine, 2015; Rogelj et al., 2016). The political focus on and support for onshore wind power have resulted in an increase in the global installed onshore wind capacity with wind farms spread all over the globe. The wind power development in Northern Europe has been supported by feed-in tariffs, support schemes, and a strong, growing wind industry (Enevoldsen, 2016a), and as Fig. 1 clearly indicates, the UK, Sweden, Denmark, Finland, and Norway have seen a rapid growth in the development of wind power with a mix of on – and offshore installations in UK and Denmark, and almost entirely onshore installations in Sweden and Norway.

The rapid increase in onshore wind farm installations has led to a decrease in the number of suitable sites, increased social opposition (Enevoldsen and Sovacool, 2016; Ek and Persson, 2014), and increased land costs (Enevoldsen, 2016a). In response to these factors and because wind turbines have either been moved offshore (as in UK and Denmark) and/or increased remarkably in size (Enevoldsen and Valentine, 2016), and from the latter it has become possible to deploy wind turbines in forested areas. The Northern European countries are heavily forested, and these forests are often located in rural areas (Enevoldsen and Valentine, 2016). This means that land acquisition may be cheaper and that the noise and flicker impact on humans is virtually non-existing, reducing the barriers to new wind project development (Enevoldsen, 2016a). The percentage of each country's total land area covered by forest is shown in Table 1 below.

Table 1 indicates that these countries are heavily dominated by Norwegian spruce (Picea abies) and Scots pine (Pinus sylvestris). Both are categorized as coniferous evergreens, meaning that they do not shed their leaves in winter, why a uniform roughness conversion approach can be applied.

Despite the increased size of wind turbines, the forests are still causing changes in the wind flows, which makes it challenging to estimate the wind conditions above the forest canopy. The increasing turbulence intensity and changes in the logarithmic wind profile have been studied intensively for decades, but only recently with a special focus on the trees' impact on a wind turbine's performance (Bergström et al., 2013). A range of methods varying from determining the roughness length of trees based on observed tree heights (Enevoldsen, 2016a) to determining the leaf area density from airborne laser scans (Dellwik et al., 2016) has been developed to estimate the wind flows in and above the forest canopy in all lower boundary layer heights.

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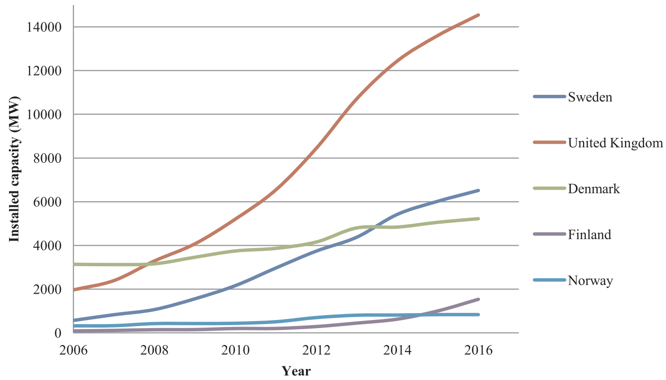

Fig. 1. Development in installed wind power capacity in Northern Europe (MW) (Global Wind Energy Council, 2016).

Table 1
Forest coverage for the Northern European countries (Enevoldsen, 2016a) (Finnish Forest Association, 2016).

Country	Forested land area (%)	Coverage of dominant tree types (%)
Denmark	13.5%	Abies alba and Picea abies 40.4% Various deciduous tree types 39.5%
Norway	38%	Picea abies 47% Pinus sylvestris 33%
Sweden	66%	Picea abies 42% Pinus sylvestris 39%
Finland	75%	Picea abies 50% Pinus sylvestris 46%
UK	12%	Picea sitchensis 29% Pinus sylvestris 17% Various deciduous tree types 40.2%

Researchers agree that the impact of forest edges is the most severe in terms of changes in turbulence intensity and wind shear (Arnqvist, 2013; Dellwik et al., 2014). Furthermore, there is broad consensus between academia and the wind industry that the drag and roughness from the forests are slowing down the wind speed (Enevoldsen, 2016a). Due to the two factors mentioned above, wind project developers often seek to cut down enough forest to avoid any severe impact on the mean wind speed, while ensuring that no forest edge effects occur near the wind turbines. The intention is to increase the annual energy production and simultaneously ensure a longer lifetime of the wind turbines, which conclusively impacts the return on investment and thus the levelized cost of wind energy.

However, deforestation has also been identified as one of the primary reasons for social opposition to wind projects in forested areas (Enevoldsen and Sovacool, 2016). The arguments are either based on locals' perceptions of forests as areas for hiking, picnics, or joyful memories with kids and/or the irony of felling trees to install a technology to limit the emission of greenhouse gases and curb global climate change. The second argument is noteworthy, as the estimated CO_2 loss of felling one km^2 of Norwegian spruce and Scots pine is 248,276 t. A wind farm of 20 wind turbines with rotor diameters of 100 m usually has 0.22 km^2 (Enevoldsen and Valentine, 2016) of space between each turbine, which, compared to deforestation, would equal an estimated CO_2 loss of 54,708 t for a mix of Norwegian spruce and Scots pine.[1] In addition, the felling of trees comes with a cost but also a potential income from timber or bio pallets, which can be included in the return on investment and the levelized cost of energy.

This research first suggests a literature-based, socio-technical framework for examining the impact of deforestation on a wind project. Subsequently, experiments were carried out for each of the parameters introduced in the framework in an effort to a) disclose whether deforestation is a necessary method for continuing the development of installed onshore wind power, b) potentially determine how much deforestation is needed, and c) potentially lend credence to the socio-technical framework as a sound method for investigating wind projects in forested areas.

2. Research materials and methods

The socio-technical framework is based on findings from an extensive literature review, which was carried out using a detailed search strategy that took into account the fact that the required interdisciplinarity of the study would demand a large number of articles. In Google Scholar and ScienceDirect, the following search words: "Wind power" and "forest" were applied in combination with "Northern Europe", "resource assessment", "social acceptance", "deforestation", "turbine performance", "Denmark", "Sweden", "Norway", "Finland", "United Kingdom", or "UK". The result was more than 1000 peer-reviewed papers. Next, a screening process was conducted to filter the number of papers, while applying the snowball technique to reveal any other relevant studies. The final number of peer-reviewed articles applied to analyze the framework tallied at 29, with an overweight of articles related to estimations of wind conditions. The number of articles for each parameter in the socio-technical framework is depicted in Fig. 2 below.

A country-specific search was applied, as the consequences of deforestation may vary depending on the global location. However, papers targeting other countries or non-defined locations were included in the study, if similarities and findings related to the Northern European countries were revealed.

2.1. The beta version of the socio-technical framework

The socio-technical framework presents the expected impact of deforestation in relation to development of wind projects. It is based on previous studies targeting the included parameters of the socio-technical framework. The framework is introduced in Table 2 below, including the references applied for the construction of each expected consequence.

The four parameters introduced in the framework have been chosen as they all impact the possibilities of future growth and development of the installed capacity of wind power in Northern Europe.

Table 3, which introduces the methods applied to test the socio-technical framework, clearly indicates the need for an interdisciplinary research strategy. The research strategy is inspired by Sovacool (2014) who suggested that engineering needs social science, something which is expected to have been left out in many of the previously developed projects in Northern Europe. The interdisciplinary framework suggested in this study combines perspectives across different scientific paradigms. This mixed methods design allows to triangulate findings, thereby strengthening the framework, and serves as a broad tool applicable for several stakeholders in the wind industry.

The literature applied in the construction of the socio-technical framework will be used in the analyses and discussions related to the tests carried out to examine in depth each framework parameter.

2.2. Wind resources

In order to examine the expected consequences of deforestation's impact on wind resources, a test has been carried out. The test simulates the changes in wind conditions according to whether the clear felling area surrounding a wind turbine is approx. 0, 1, 5, 12, or 23 ha. The test was carried out at a real operating site in the central, heavily forested part of Sweden. The elevation and tree heights are presented in Figs. 3 and 4 below, which uses the output from a national airborne laser scan presented in a grid with a spatial resolution of 20 × 20 m.

[1] Estimated using http://informatics.sepa.org.uk/CarbonCalculator/.