Wind energy and Biodiversity in Finland: Habitat tax for solving the green-green dilemma

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Tiivistelmä – Referat – Abstract

Ilmastonmuutos ja biodiversiteettikato ovat tällä hetkellä suurimpia ihmiskuntaan vaikuttuvia ympäristöuhkia. Yksi tapa lievittää ilmastonmuutosta on rakentaa enemmän tuulivoimaa. Suomessa rakenteilla tai suunnittelussa olevat tuulivoimalat tulevat melkein kymmenkertaistamaan Suomessa sijaitsevan tuulivoimakapasiteetin. Samalla kun lisää tuulivoimaa rakennetaan, myös tuulivoimaloista aiheutuvat negatiiviset vaikutukset biodiversiteettiin lisääntyvät. Tuulivoimalat aiheuttavat muun muassa habitaattikatoa, kuolleisuutta linnuissa, habitaattien pirstaloitumista sekä välttelevää käyttäytymistä villieläimissä. Tätä konfliktia kahden halutun ympäristötavoitteen välillä voidaan kutsua vihreä-vihreä dilemmaksi (engl. green-green dilemma).

Tämä tutkielma tarkastelee Suomessa sijaitsevien tuulivoimaloiden vaikutuksia habitaatteihin, sekä habitaattien syrjäyttämisestä maksettavan veron suuruutta vihreä-vihreä dilemman ratkaisemiseksi. Tutkielmassa hyödynnetään paikkatietoaineistoja Suomessa sijaitsevista tuotannossa ja tulossa olevista tuulivoimaloista, sekä habitaattiaineistoja jotta saamme selville mitä habitaatteja tuulivoimalat syrjäyttävät. Tämän lisäksi tuotannossa oleville tuulivoimaloille tehtiin kustannus-hyöty analyysi mahdollisen habitaattiveron suuruuden selvittämiseksi, joka tekisi 10 tai 25 prosenttia vähiten tuottavista tuulivoimaloista habitaattivaikutukseen nähden kannattamattomia. Tutkielmassa laskettiin kaksi erilaista veroa, joista toinen perustuu syrjäytyneen habitaatin määrään ja toinen syrjäytyneen habitaatin laatuun. Habitaattien laadun määrittämiseksi käytettiin apuna EU habitaattien punaista kirjaa, jonka perusteella habitaateille tehtiin priorisointijärjestelmä. Järjestelmän perusteella kullekin tuulivoimalalle annettiin tietty määrä habitaattipisteitä, perustuen kunkin voimalan takia syrjäytyneisiin habitaatteihin.

Tutkielman tuloksien mukaan Suomessa sijaitsevat tuulivoimalat syrjäyttävät pääasiassa metsähabitaatteja. Toisiksi yleisin syrjäytyneet habitaatit olivat merihabitaatit, sekä kolmanneksi yleisimpiä olivat suohabitaatit. Suurin osa syrjäytyneistä habitaateista eivät olleet uhanalaisimpia priorisointijärjestelmän mukaan, mutta tuulivoimaloiden syrjäyttämiin habitaatteihin tulisi kiinnittää huomiota, sillä tuulivoimalat syrjäyttivät jonkin verran uhanalaisina pidettyjä habitaatteja. Lisäksi priorisointijärjestelmä on puutteellinen, joten emme voi tehdä liian tarkkoja johtopäätöksiä tuulivoimaloiden syrjäyttämien habitaattien tilasta.

Tässä tutkielmassa tarkastellut kaksi erilaista veroa tekivät molemmat pääosin samoista tuulipuistoista kannattamattomia, joten tiettyjen tuulipuistojen tuotot olivat alhaisia verrattuna niiden habitaattivaikutukseen. Habitaattiveron määrä, joka teki 10 % tuulipuistoista kannattamattomia, oli 1,6 miljoonaa euroa syrjäytyneeltä hehtaarilta, kun korkeampi veroaste, joka teki 25 % tuulivoimaloista kannattamattomiksi oli 2,5 miljoonaa euroa hehtaarilta. Habitaatin laatuun perustuva vero oli 510 000 € habitaattipistettä kohden alemman veroasteen osalta ja 750 000 € habitaattipistettä kohden korkeammalla verolla. Laatuun perustuva habitaattivero Suomen tuulivoimaloissa olisi tämän opinnäytetyön laskelmien mukaan keskimäärin 1,75 miljoonaa euroa hehtaarilta alemmalla veroasteella ja 2,3 miljoonaa euroa hehtaarilta korkeammalla veroasteella.

Habitaattivero voi olla yksi ratkaisu vihreä-vihreä dilemman ratkaisemiseen. Tässä tutkielmassa esitetyt verot ovat huomattavasti korkeammat kuin Suomessa arvioidut elinympäristön ennallistamiskustannukset, jotka ovat noin 8000–15000 euroa hehtaarilta elinympäristöstä riippuen. Habitaattiveron on kuitenkin oltava riittävän korkea, jotta se vaikuttaisi tuulipuistojen kehittäjien taloudelliseen päätöksentekoon. Jos kyseinen habitaattivero otettaisiin käyttöön, olisi parasta miettiä tarkemmin mitä verolla halutaan saavuttaa, joka vaikuttaa myös veron suuruuteen. Jotta vero olisi kattavampi kaikenlainen habitaatteja syrjäyttävä toiminta tulisi sisällyttää veroon, sen sijaan että vero koskisi ainoastaan tuulivoimaloita.

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Tiivistelmä – Referat – Abstract
Climate change and biodiversity loss are among the two most serious environmental issues humanity is currently facing. One way of mitigating climate change is to build more wind energy. In Finland, upcoming wind farms are going to increase the national wind energy capacity by almost tenfold. As more wind farms are built, helping in climate change mitigation, the negative biodiversity impacts caused by wind turbines are also increasing. Negative biodiversity effects caused by wind energy include habitat loss, avian mortalities, habitat fragmentation and avoidance behaviour in wildlife. This conflict where two desirable environmental goals have negative counter-effect on each other can be called green-green dilemma.

This thesis looks at the biodiversity impacts on habitats caused by wind farms in Finland, and what would be the scale of a habitat tax paid for displacing natural habitat, that would help solve the green-green dilemma. This thesis utilizes geographical information system data of upcoming and in production wind farms and habitats to figure out which habitats are displaced by wind farms in Finland. Also, a wind farm level cost-benefit analysis was done for wind farms in production determine a scale of taxes, which would make 10 % or 25 % of wind farms with lowest net present value compared to habitat impact non-profitable. Two kinds of taxes were considered. Tax based on the quantity of habitat displaced, and a tax based on the quality of habitat displaced. For the determination of the quality of habitat, European red list of habitats was utilized in creation of a prioritization system for different habitats based on their endangerment category. With the prioritization system, each wind farm was given habitat points based on the habitats it was displacing.

According to the results of the thesis, wind farms in Finland are mostly displacing woodland habitats. The second most common habitat displaced was marine habitats and the third most common were mires, bogs and fens. According to the prioritization system created for this thesis, most habitats displaced by wind farms are not considered threatened. Still, there should be some consideration about the habitats displaced by wind farms, as minority of habitats were considered threatened according to the prioritization system. Also, we cannot draw too many conclusions about the status of the habitats displaced as the prioritization system has flaws.

The two different taxes looked in this thesis both ended up making mostly the same wind farms non-profitable, meaning there were outlier wind farms with low benefits with relatively high habitat impacts. Quantity of habitats-based tax which made 10 % of the wind farms non-profitable was 1.6 million euros per hectare of displaced habitat, and the higher tax rate making 25 % of the wind farms non-profitable was 2.5 million euros per hectare. The habitat quality-based tax was 510,000 € per habitat point for lower rate, and 750,000 € per habitat point for the higher rate. On average, quality tax in Finnish wind farms would be 1.75 million euros with the lower rate per hectare of habitat displaced, and 2.3 million euros per hectare with the higher rate according to the calculations in this thesis.

Habitat tax can be one solution for solving the green-green dilemma. Taxes presented in this thesis are considerable higher than habitat restoration costs estimated for Finland, which are approximately between 8000 € and 15000 € per hectare, depending on the habitat restored. Still, a habitat tax needs to be high enough to have an impact on the economic decision making of wind farm developers. If a tax habitat tax would be implemented, it would be best to think about the desired effect of the tax, which will affect the scale of the tax. Also, all kinds of activities displacing natural habitat should be included in the tax, not just displacement caused by wind farms for the tax to be more comprehensive.

Avainsanat – Nyckelord – Keywords
Wind energy, Biodiversity, habitats, tax, green-green dilemma, GIS, EUNIS, Red list of habitats, Wind farms

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Abbreviations

CO	Collapsed
CO_2	Carbon dioxide
CR	Critical
DD	Data deficient
EN	Endangered
EU	European union
EUNIS	European nature information system
EURIBOR	Euro Interbank offered rate
GIS	Geographic information system
GWh	Gigawatt hours
Ha	Hectare
IPCC	Intergovernmental panel on climate change
IUCN	International union for conservation of nature
kWh	Kilowatt hours
LC	Least concerned
LIBOR	London interbank offered rate
Meur	Million euros
MW	Megawatt
MWh	Megawatt hours
NDC	Nationally determined contribution
NE	Not evaluated
NPV	Net present value
NT	Near threatened
OLS	Original least squares
VU	Vulnerable
WACC	Weighted cost of capital
WEP	Wind energy production
WPD	Wind power density

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1 Introduction

Climate change and the loss of biodiversity are among the biggest environmental issues the humanity is facing currently. In a famous article, Rockström et al. (2009) identify nine planetary boundaries and proposed a quantification for seven of them. The paper estimated that out of the seven quantified boundaries, three were already transgressed, both climate change and the rate of biodiversity loss among them. According to the paper, there is great uncertainty about how long these boundaries can be transgressed, before they cause unacceptable environmental change.

One potential solution for climate change mitigation is wind energy. Wind energy is usually seen as a crucial part of the fossil energy free “green economy” of the future (Gasparatos et. al. 2017), but wind energy has its own negative impacts on biodiversity. As more wind turbines are being built, which help in climate change mitigation, the negative biodiversity impacts caused by wind turbines are also increasing. When these two things, climate change mitigation and biodiversity conservation are in conflict, the situation can be called green-green dilemma, as two desirable environmental goals may have negative counter-effects on each other (Straka, Fritze & Voigt, 2020).

In Finland there are a few limitations set for wind farms that are put in place to protect nature. Building of wind farms is restricted in nationally valuable landscapes and cultural environments. Also, wind farms are prohibited in nature conservation areas, wilderness areas protected by law and in important bird and biodiversity areas. Also, larger wind projects must do an environmental impact assessment. Still, wind farms could be built for example on Natura 2000 areas, and regionally valuable landscapes (Ministry of the Environment, 2016), thus valuable natural areas could the threatened by wind farms.

There are also many other factors that wind farm developers must consider when building wind farms. For example, wind conditions, municipal zoning, distance to settlements, roads and electricity grids, subsoil of the site, attitudes of different stakeholders have to be considered (Finnish wind power association, n.df.; Finnish wind power association, 2021). Wind projects in Finland also need a permission from the Finnish defense forces make sure wind farms do not affect national safety, as wind turbines intervene with army radar systems (Brenner et. al., 2008). This is considered one of the main reasons why wind farm development in eastern-Finland has been so minor compared to other parts of Finland, as Finnish defense forces have rejected multiple wind farms projects in recent years (Lempinen, 2019; Schönberg, 2022).

Many other limitations on the wind farm locations raise questions about the weight biodiversity is given in the decisions to build wind farms. Even though some critical areas for biodiversity are restricted from wind farms, other vulnerable habitats could be still displaced by current and future wind farms, since they might have otherwise favorable conditions. It would be important to figure out if upcoming and in production wind farms have already displaced habitats that are vulnerable, and if we could develop tools for combating negative biodiversity effects caused by wind farms.

Solutions for this issue have been already thought about. For example, in Norway concerns for environmental deterioration is one of the main forces driving wind energy policy (Vasstrøm & Lysgård, 2021). These concerns had already been noticed in 2014, as Norway appointed a green tax commission to consider the use of nature use fee (named as ecosystem service tax in official reports) reflecting the cost of loss for all interventions in nature (Norwegian ministry of Finance, 2015). No such tax has been implemented in Norway, but the tax proposed by the commission would have also addressed the biodiversity impacts caused by wind energy.

In Finland, the topic about the tradeoffs of wind energy is just starting to come to the public. Virtanen et. al. (2022) Looked at the how several factors of sustainability (social, economic, and environmental) can be balanced for offshore wind energy in Finland. The study identified conflicts between the factors and looked at suitable areas for offshore wind farm development. Also, a recent opinion piece in the popular Finnish new magazine Helsingin Sanomat by Toivanen and Remes (2022) called for placement of wind turbines into areas with lesser impact on natural habitats.

As we get more information about the biodiversity impacts of our societies, the negative impacts of wind power are also being noted. To get the most benefits with the least negative impacts from wind energy, and to solve the green-green dilemma, society should start thinking about how the current and upcoming wind turbines are placed in different habitats. One economic tool for solving this problem could be a habitat tax, in which tax is paid based on the habitat displaced, following the same idea as the Norwegian ecosystem service tax. As the accurate monetary determination of the negative impacts for Pigouvian tax can be difficult, we should at least have an idea of the scale of the tax that would make wind farms with low profits and relatively high habitat impact non-profitable.

1.1 Research questions

The goal of this thesis is to find out, in what kind of habitats the current and upcoming Finnish wind farms located are displacing. This way we can figure out if wind energy inside Finland is severely threatening habitat biodiversity. This thesis also looks at the possible habitat tax for wind farms. This thesis aims to answer the following research questions:

1) Which habitats are displaced by wind farms in Finland?
2) What would be the scale of the habitat tax, that would reduce the biodiversity impact of wind farms?

The research is done by using GIS (Geographical information system) data of Finnish wind farms, wind resources and European level data of habitats. For the scale of the tax, a wind farm level cost-benefit analysis is done to figure out the tax that would make least profitable wind farms with highest habitat impact non-profitable. In this thesis a wind farm means a cluster of wind turbines in a certain location by a certain wind farm developer which are part of the same wind farm project.

2 Background: Climate change, biodiversity, and wind turbines

2.1 Related literature

The biodiversity impacts caused by onshore wind farms are widely identified by scientific literature. Things such as the direct habitat impact area and of which it consists of is identified quite well. Also, the impacts and the causes on wildlife are quite well known in scientific literature. It is also known how these impacts compared with other energy sources. The topic is being discussed in more detail later in this thesis.

Multiple studies concerning the biodiversity impacts of wind energy using geospatial information have been done. Many of these studies utilize multi-decision criteria analyses, which try to find optimal wind farm locations while consider for example social, economic and environmental factors (Haaren & Fthenakis, 2011; Peri & Tal, 2020; Xu et. al, 2020; Kati et. al. 2021; Tercan, 2021; Virtanen et al., 2022). This kind of spatial planning is one way of finding solutions for the green-green dilemma, as economically suitable locations for wind farms are identified, and biodiversity is also considered. Different studies had different approaches on how suitable sites were identified from the biodiversity perspective. For example, Kati et. al. (2021) used the Landscape fragmentation indicator, Tercan (2021) used distance to conservation sites and important bird zones, while Virtanen et. al. (2022) accounted for habitat types, protected areas, bird routes and fish reproduction sites.

This thesis follows conventional methods for economic analysis, mostly following Blanco (2009), Rinne et. al. (2018) and Gul et. al. (2019). According to the knowledge of the author of this thesis, no similar kind of studies were found that utilized habitat data to the same extent to determine which habitats were displaced by wind farms. Most studies used biodiversity indicators to eliminate areas not suitable for wind farms, while this thesis looks on a national scale to see which habitats are being displaced by wind farms. Also, this study uses prioritization system modified from Kotiaho et. Al. (2015), which does not seem to be used by others in the context of wind farms. Also, determining the scale of a possible habitat tax has not been done this way according to the knowledge of the author.

2.2 Climate change

The leading international authority on climate change, the Intergovernmental panel on climate change (IPCC) defines climate change as a "...change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer..." (IPCC, 2018). This change in the state of the climate can be caused by natural internal processes, or by external forcings which include solar cycles, volcanic eruptions and changes in atmosphere or in land-use.

IPCC report from 2021 on the physical science basis of climate change states that it is unambiguous that human influence has caused warming of the atmosphere, ocean, and land. The current warming in the globe is mostly because of greenhouse gas emissions (such as carbon dioxide methane and nitrous oxide). The observed increases in the greenhouse gas concentrations in the atmosphere after the year 1750 are mostly caused by human activity, after the start of the industrial revolution. (IPCC, 2021). Ice core samples show that carbon dioxide (CO_2) concentrations over the last 650,000 years used to be around 180 to 300 ppm (parts per million) (IPCC, 2007). In 2019, the annual average of carbon dioxide in the atmosphere reached 410 ppm, which far exceeds the natural concentrations in the atmosphere. This is the highest concentration of CO_2 in the atmosphere in at least 2 million years (IPCC, 2021).

There are many kinds of human activities that emit greenhouse gases. If emissions were to be divided by economic sectors (Transportation, energy and heat production, Agriculture, forestry and land-use, industry, building and other), the biggest emitter globally is heat and energy production, which emits around 25% of greenhouse gases according to the 2010 data (IPCC, 2014). Energy and heat production are also the biggest emitting sectors in Finland. With a slightly different sector classification, the energy sector produced 72 % of the total greenhouse gas emissions in Finland (Statistics Finland, 2020).

Wind energy as a tool for climate change mitigation

Wind power is one of the many ways humans can mitigate climate change. As the energy sector is the biggest emitter of greenhouse gases in the world, the transformation of the energy system is crucial for climate change mitigation. The decarbonization of electricity generation is also one of the most cost-effective ways in stabilizing carbon dioxide levels, in which wind energy production can play a part (IPCC, 2014). For example, Net zero by 2050 Roadmap by IEA (2021) estimates that by 2050, almost 70 % of the total electricity production globally is generated from either wind or solar.

Wind power has many benefits compared to many other ways of energy production. Wind turbines do not emit any air particles or carbon dioxide during energy production. Because of low production costs, wind energy can also replace conventional energy sources in electricity markers such as coal or gas, which will result in a reduction of air pollution and greenhouse gas emissions (Saidur et. al. 2011; Kåberger, 2018). Emissions from wind energy production take place during the construction, maintenance and decommissioning phases. Despite these emissions, wind turbines emit much less emissions during their lifetime compared to fossil fuel-based energy production. One Life cycle analysis study from 2009 estimated that during its lifetime, a single 3 MW wind turbine can save over 120,000 tons of carbon compared when compared to fossil fuel energy production (Crawford, 2009). To put this in a context, the average carbon footprint of a Finn was around 10,1–12,6 tons of CO_2 per year (Nissinen & Savolainen, 2019).

Many countries have chosen wind energy for the task of decarbonization, as there have been many pledges of expanding wind energy capacity (UNEP, 2019; UNEP; 2020). Current climate action plans, or nationally determined contributions (NDCs) would lead to a global annual increase of 3.6 % in wind power deployment between 2015–2030 (Barthelmie & Pryor, 2021). In 2019, the installed total capacity of wind power was 622,704 megawatts in the entire world, which accounts to around 25 % of the total renewable energy capacity (Irena, 2020). Wind power capacity is also increasing at a fast pace, as the total worldwide wind energy capacity has doubled since the year 2013 (Irena, 2020). The pace of new installations is also increasing, as in 2020, around 90 gigawatts were installed worldwide, which is around 53 % increase in new installations compared to the previous year of 2019 (Global wind energy council, 2021).

Wind power is also increasing in Finland. In 2020, Finland had a wind power capacity of 2,585 MW, which accounted for around 10 % of the total energy production in Finland. There was also a 13 % increase in capacity and 29 % increase in energy production compared to the year 2019 (Finnish Energy, 2021). Wind power in Finland is also going to increase rapidly in the future. According to the Finnish wind power association, there were 249 announced wind power projects at different phases of planning at the beginning of the year 2021. These projects account for around 21,300 MW of new wind energy capacity, which is almost ten times the current wind energy capacity in Finland (Finnish wind power association, 2021b). This rapid increase in wind energy will also increase negative effects on biodiversity.

2.3 Biodiversity

Biodiversity can be simply described as a variety of life on all levels of biological organization (Gaston & Spicer, 2004). There are many different definitions for biodiversity, but possibly the most important and more formal definition of biodiversity appears in a convention on biological diversity, which defines biodiversity as: "... the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems." (United Nations, 1995). The European Union has a biodiversity strategy for 2030, which aims to protect nature and reverse ecosystem degradation, with the main objectives being putting biodiversity of Europe on the path to recovery by 2030, and to build resilience against future threats (EU, n.d.).

The United nations definition of biodiversity includes different biological entities that exist at multiple levels interlinked to each other. Heywood & Watson (1995) split biodiversity into three distinct groups, which each include different components of biodiversity. These groups are genetic diversity, organismal diversity, and ecological diversity. Genetic diversity includes different genetic components that structure the organisms, such as genes, chromosomes, and nucleotides. It also encompasses the variation in genetic code of individuals within a certain population, and between different populations (Gaston & Spicer, 2004). Another part of biodiversity is organismal diversity. It includes different taxonomic hierarchy levels of biodiversity, such as individuals, populations, species, families, and kingdoms (Gaston & Spicer, 2004).

The last and the most relevant group of biodiversity for this thesis is ecological diversity. It includes the scales of ecological differences, from a smaller scale such as populations and habitats, to a large scale, such as ecosystems and biomes (Gaston & Spicer, 2004). These hierarchies can be considered as ecological systems, in which genes and species exist. Ecological systems, such as habitats or ecosystems are more like conceptual entities, which present various parts of the natural continuum, that integrate into each other in complex manners. Ecological systems also do not exist by themselves but are created into existence by the species and non-living factors that affect them (Heywood & Watson, 1995) Two ecological system terms present in this thesis are ecosystems and habitats. Even though the terms are sometimes used interchangeably, they have slightly different emphasis. The term habitat has slightly more species emphasis compared to the term ecosystem (Kontula & Raunio, 2018), which has more of an emphasis on processes, such as the flow of energy and nutrients. (Heywood & Watson, 1995).

2.4 Negative biodiversity impacts of wind farms

Direct habitat loss caused by wind farms

Habitat loss is the biggest threat to biodiversity, as it makes different species and populations suffer when their habitats are lost or degraded (Hanski, 2011). Habitat loss can affect biodiversity in many ways and on many levels. Habitat loss negatively affects species richness, population abundance and distribution, genetic diversity, population growth, predatory-, breeding- and foraging success rates among other things (Fahrig, 2003). One of the main reasons for habitat loss and the negative biodiversity effects related to it are land use changes (Sala et. Al., 2000; Newbold et. al., 2015; Newbold et. Al., 2016). Unfortunately, the negative impacts caused by land use changes on biodiversity are expected to increase even more during this century (Jetz, Wilcove & Dobson, 2007; Rondini & Visconti, 2015; Visconti et. Al. 2016; Powers & Jetz, 2019).

In the case of wind energy, the wind turbine, buildings, substations and roads need space, which will have a direct impact by replacing natural habitat and causing habitat loss, as vegetation cover must be cleared. A Canadian study estimated that one wind turbine with all its infrastructure replaces on average 1.23 hectares of habitat (Zimmerling et. al. 2013). Another study on the topic done in the United States by Denholm et. al. (2009) estimates, that wind turbines have permanent direct habitat impact area of 0.3 hectares/MW, which lasts at least the lifetime of the project. Permanent impact area includes turbine pads, roads, substations, buildings, infrastructure and areas that must be cleared around the turbine. According to Denholm et. Al. (2009), wind turbines will also temporarily disturb an area of 0.7 hectares/MW. This area will eventually return to its original state, but depending on the area it might take from a few years to decades (Arnett et. al. 2007). Temporarily disturbed areas include construction-access roads, storage and lay-down. Wind turbines, substation and infrastructure usually take up only 1–5 % of the total project area of the wind farm (McGowan & Connors, 2000), leaving the rest of the area for other uses such as recreation, forestry, or agriculture.

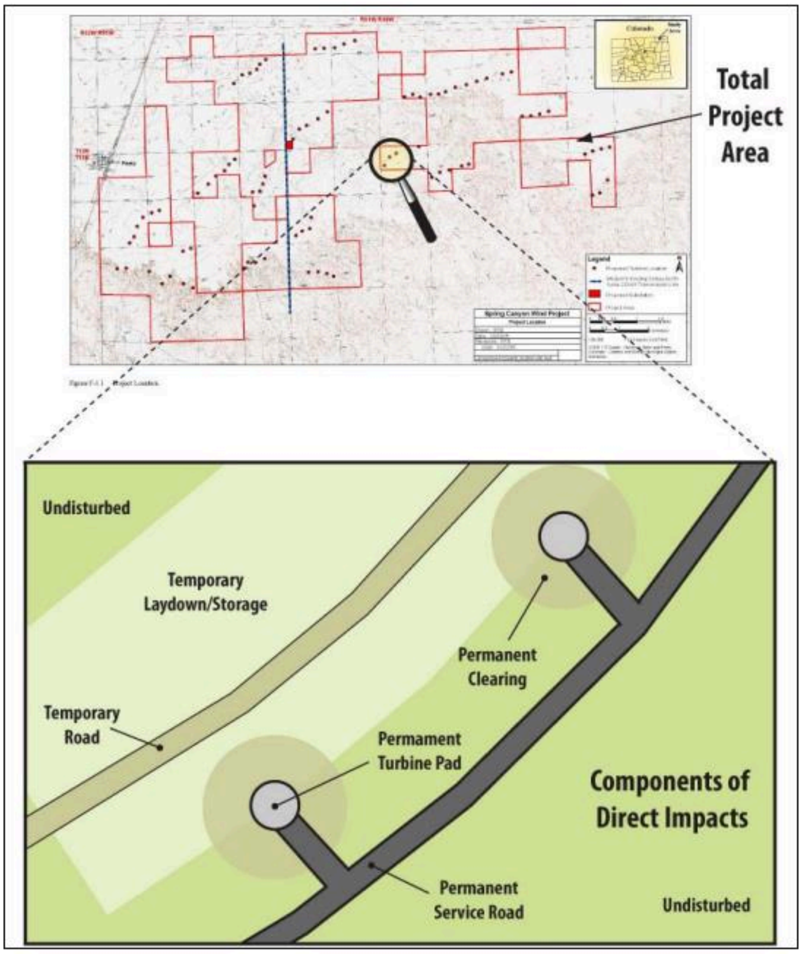

Figure 1. Wind farm land use: Total project area and direct impact area, including temporary and permanent land use. (Denholm et. al. 2009).

Habitat impact area

Wind turbines will also have biodiversity impacts that occur outside the direct impact area. Denholm et. al. (2009) suggests that a metric of “habitat impact area” could be used to measure the area suffering from fragmentation and decrease in habitat quality caused by wind turbines. Some estimates in the literature tell that direct clearings affect only 3–5 % of the habitat impact area, while the rest is affected by fragmentation, species avoidance and avian mortality (McDonald et. al. 2009). Still the size of these impacts can vary very much site to site, and turbines will affect distinct species in the area differently. Therefore, creating any accurate universal habitat impact area metric per wind turbine or by megawatt can be extremely difficult. Still, it is important to note that the negative biodiversity effects of wind turbines extend beyond direct habitat loss.

Habitat fragmentation

Replacing natural habitat with wind turbines can cause habitat fragmentation. Habitat fragmentation is considered to be one of the main threats to biodiversity along with habitat loss (Rogan & Lacher Jr., 2018), although the role of habitat fragmentation is still under some scientific debate (Flecther Jr. et. al. 2018). Habitat fragmentation occurs when habitats are divided into multiple smaller areas more isolated from each other. As habitats become smaller, they are less likely to be able to sustain the local population, which will eventually lead to a reduced total population size (Fahrig, 2003). Also, as habitats fragment, it increases the proportion of edges in relation to the habitat area. This is called the edge effect. The disruptions caused by the edge effect can extend as far as 340 meters into a forested area for certain species (Bohall Wood, Bosworth & Dettmers, 2006). The edge effect increases the chance of species leaving the habitat, which may increase mortality and decrease reproductive rates of a population (Fahrig, 2002).

Roads are one main reason for habitat fragmentation (Spellerberg, 1998; Saunders et. al. 2002; Coffin, 2007) and they also have a significant role in fragmentation caused by wind turbines. Around 79 % of the direct impact area of a wind turbines consist of roads (Denholm et. al. 2009). A Study by Diffendorfer et. al. (2019) also found that the construction of new road networks for wind turbines is a predictor of landscape fragmentation. Wind energy can also cause a lot of fragmentation compared to some other energy sources, as wind turbines are scattered geographically rather than concentrated in one location (McDonald et. al. 2009).

Avian and insect fatalities

Wind turbines also have other impacts on wildlife species. One ecological problem with wind turbines is that avian creatures such as birds and bats can collide with wind turbines rotor blades, which can cause fatalities. Sovacool (2009) estimates that single wind turbine kills around 0-40 avian creatures per year. For most wind farms, bat fatalities can outnumber bird fatalities (Schuster, Bulling & Köppel, 2015). Mortality with bird species depends on multiple species-, site- and wind farm-specific factors, such as species size, flight type, social behavior, flight paths, weather, food availability, turbine size and wind farm configuration (Marques et. al. 2014). For bats, similar factors seem to influence mortality, as food availability, seasons, migratory behavior, and weather among other factors were linked to increased wind turbine bat mortality (Schuster, Bulling & Köppel, 2015). In addition to bird and bat fatalities, wind turbines cause insect fatalities. A single turbine could kill around 40 million insects every year, but how insects interact with turbines and the effect of these fatalities on populations is still poorly understood (Voigt, 2021).

Displacement and avoidance behavior

Turbines can also cause displacement (reduced breeding density) and avoidance behaviors in wildlife. These can be caused in bird species by the visual, noise and vibrational impacts of the turbine, construction of the turbine and by the movements of cars and people related to the turbine maintenance (Drewitt & Langston, 2006). Avoidance behaviors can be either macro-avoidance (modification of flight route to avoid the wind farm) or micro-avoidance (avoidance of turbines within the wind farm). Because of the avoidance, resting and foraging grounds of birds can be made inaccessible, which can have significant impact for resting and breeding species. (Schuster, Bulling & Köppel, 2015). The range of displacement and avoidance can also vary by species and site-to-site. For example, Pink-footed geese in Denmark were found to have reduced densities only within 100-meters of the wind turbine (Larsen & Madsen, 2004), while diver birds in Denmark had a lower density up to 4 kilometers from the wind turbine (Petersen, Clausager & Christensen, 2005; Drewitt & Langston, 2006).

Biodiversity effects of wind energy compared to other (energy) sources

Wind energy has its own share of negative effects, but this is the case for every energy source. For wind energy, one of the biggest problems seems to be the area needed for energy production. Mcdonald et. al. (2009) estimated that wind energy needs around 72 hectares of area to produce one terawatt of power, while the same figure for natural gas was 18.6 hectares, for coal 9.7 hectares and for nuclear energy 2.4 hectares. Wind power was exceeded only by different biomass-based fuels, which needed 285–894 hectares to produce one terawatt of power depending on the fuel crop and the way of production. Life cycle study by Fthenakis and Kim (2009) got similar results, as wind energy was only exceeded in land use per Gigawatt hours by biomass, hydroelectric reservoirs and some cases of surface coal mining.

Even though wind energy needs a relatively large area, it still has some advantages compared to other energy sources related to the area disturbed. On average wind energy needs more area than oil or gas wells, but wind energy production is less variable site to site compared to oil or gas wells (Jones, Pejchar & Kiesecker, 2015) meaning the area disturbed related to the energy produced is easier to predict. Wind energy development can also be more selective in its placement on lower habitat impact areas, since wind energy resources are more widely available (Kiesecker et. Al. 2011). Also, different problems related to fuel cycles are not present in wind power, such as additional areas disturbed while searching for new fuel, or possible serious water- and land contaminations (Fthenakis & Kim, 2009).

Avian mortality is also one of the most discussed issues publicly related to wind turbines. Looking at the total anthropogenic avian death, wind turbines have a very minor role in the bigger picture. According to a report done in the US, wind turbine avian deaths were estimated to account for only 0.003 % of the total deaths caused by anthropogenic sources (Erickson, Johnson & Young, 2005). According to the report, wind turbines were estimated to kill 28.5 thousand avian each year in the US, while deaths related to power lines were 130 million, deaths caused by pesticides 67 million and death caused by domestic and feral cats were 100 million per year.

Compared to other energy sources, wind energy does not stand out in a negative way in avian mortality. According to Sovacool (2013) wind turbines kill 0.269 avian creatures per GWh (Gigawatt hour) due to collisions, while fossil fuels kill 5.18 avian per GWh. The fatalities caused by fossil fuels included deaths caused by mountain top coal mining, acid rain, mercury pollution and anticipated effects of climate change. Out of the fatalities caused by fossil fuels, climate change impacts (which were hardest to quantify according to the study) were estimated to kill 4.98 birds per GWh. Another energy source with higher avian mortality per GWh according to Sovacool (2013) was nuclear power, which had an avian mortality rate of 0.416 per GWh. These deaths were caused by uranium milling and mining, and collisions with nuclear power plants. There is also some evidence that wind energy even has a lower avian mortality rate than solar energy per GWh, which was estimated to have a mortality rate of 0.7–3.5 per GWh (Ho, 2016)

2.5 Tax as a policy instrument for habitat protection

Humans obtain benefits from habitats (or ecosystems) which can be framed as ecosystem services. These ecosystem services include provisioning services (e.g., raw materials, food and water), regulating services (e.g., pollination, climate regulation and water purification), cultural services (e.g., recreation, aesthetic values and mental health) and supporting services (e.g., soil control, nutrient cycling and photosynthesis). As habitats are lost, it can cause a loss of beneficial ecosystem services as well (Dobson et. al., 2006; Rodríguez-Echeverry et. al., 2018). The loss of these benefits will affect not just the wind farm developers, but a larger group of people in society. Thus, the Habitat loss caused by wind farms could be seen as a negative environmental externality as these losses of ecosystem services are not reflected in the market price of wind farms. As ecosystem services are not valued in the markets, they are often given too little weight in policy and other decisions (Costanza et. al., 1997).

Taxes are used widely in many different contexts to disincentivize behavior that causes negative externalities. One example of this could be a carbon tax, which aims to reduce carbon emissions, as the release of CO_2 is more expensive. Tax based on similar logic could be applied to habitat loss caused by wind turbines. As a habitat tax based on the quantity or/and the quality of habitat displaced could for example courage construction of wind turbines with less overall habitat impact, building wind farms offshore or to land that is already degraded and construction of more profitable wind farms, as the opposite behavior is discouraged.

One type of tax for negative externalities is Pigouvian tax. The tax suggests that the externality should be internalized with a tax in the price of the good (construction of the wind farm in this case). The tax should be equal to the cost of the negative externality (loss of habitat/ecosystem services) to society, in order to create an efficient solution. In practice a reasonable Pigouvian tax would be difficult to determine in the case of habitat loss caused by wind farms, as the valuation of all the different ecosystem services in all the different habitats is not an easy task to do. As a first step, it would be important to know what the scale of a habitat tax would need to be, in order to have some mitigatory effect on habitat loss by making wind turbines with least profit compared to the habitat impact non-profitable.

3 Data and methods

To find answers to the research questions, GIS-data was utilized. European ecosystems data (habitat data), Finnish wind atlas data (wind resource data) and wind farm data given by Finnish wind power association was combined in ArcGIS-program to figure out which habitats were displaced by wind farms, and also how much wind energy was produced by wind farms already in production. To assess the quality of the habitats, a ranking system was made for each habitat. Based on the ranking system, a “habitat score” was assigned for each wind farm. For wind turbines in production, a wind farm level cost-benefit analysis was done to figure out the scale of the habitat tax with sufficient effect. Two taxes were considered: A tax based on the area of habitat displaced (quantity tax) and a tax based on the habitat score (quality tax).

3.1 Income from wind energy production

Wind farm and wind resource data

The data for the wind turbines was provided by Finnish Wind Power Association. The data included the coordinates and other location information of the wind farms, information about the phase of the project, number of turbines and total megawatts of the wind farm among other things. More information about the turbines in production, such as hub height and rotor diameter at a precision of a meter were gathered from the Finnish Wind Power associations (2021a) interactive map.

There were some wind farms for which hub height or rotor diameter information was not available on the Wind Power associations website. For some of these cases the rotor diameters and hub heights were found from the website listed in the excel provided by Finnish wind power association. Linear model was used to fill missing data. The original least squares (OLS) regressions were done to produce figures for hub heights and rotor diameters. For the OLS, only the wind farms with data for both hub heights and rotor diameters were used as the data set. For independent variables, the year of completion of the wind farm and megawatts per wind turbine in the wind farm was used for both dependent variables of hub height and rotor diameter. For hub height, the R-squared was 0.88 with a p-value of <0.01. For rotor diameter, the R-squared was 0.94 with a p-value of <0.01. All the wind farm data was imported to ArcGIS program using the coordinates included in the data. Seven wind farms were left out of the analysis (Pori, Pori; Eckerö, Mellanön; Hollola, Tuohijärvi; Iisalmi, Katajamäki; Kristiinankaupunki, Surmankeidas; Sysmä, Rekolanvuori & Vöyri, Lasor), as they lacked coordinate data.

For wind resource data, the Finnish wind atlas data was used (Finnish meteorological institute, 2009). It was provided by Finnish meteorological institute in shape format to be used in ArcGIS. The bulk data included the arithmetic average monthly wind speed of 50-, 100- and 200-meter heights from the ground level. In the wind atlas the elevation of the ground was calculated from the average elevation in each grid square, so the elevations in the wind atlas do not correspond to the real elevations of the ground (Finnish meteorological institute, 2010). This means that hills and other higher points in which wind turbines could be located are not accounted for. The data was in 2500 x 2500-meter grid squares, which encompassed whole area of Finland. The data was also imported to ArcGIS program.

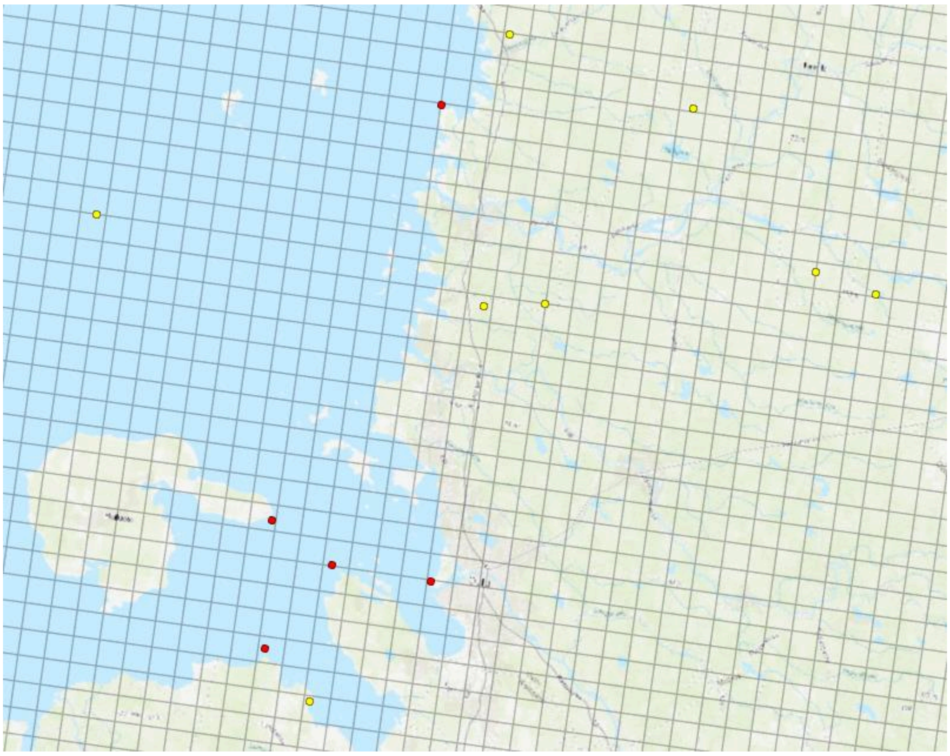

Figure 2. Finnish wind atlas data presented as 2500x2500 meter grid squares, with each grid square containing average wind speeds for different months and heights. Wind farms are presented as dots ArcGIS-program. Red dots present wind farms in production & yellow dots present upcoming wind farms.

The two different data sets (wind turbines and wind resource data) were converted into the same coordinate system (WSG 1984) using the project tool in ArcGIS. The wind resource data was linked to the wind turbine data using the spatial join tool. This way, each wind turbine point was assigned data about the wind resources in that certain location in each month at different heights. After this, the wind turbine data with the wind resources was exported into a spreadsheet.

The economic analysis of the wind farms was done only for the farms already in production, since important data such as hub height, rotor diameter and number of turbines was lacking for most wind power plants in other phases. The calculations for the profitability of the turbines are not completely precise as certain assumptions had to be made. The purpose of the economic analysis in this thesis is only to get the general magnitude of a habitat tax that would make the wind farms with the poorest wind resource utilization compared to the habitat impact non-profitable. An imaginary scenario was assumed, where all the turbines were built at the same time, using the same cost prices. The oldest turbines under analysis were built in 1993 and the newest in 2020. This assumption does not consider how prices have differed over time, as wind turbine costs have declined over the years (Elia, Taylor, Gallachóir & Rogan, 2020). This assumption means that wind turbine built in 1993 are more profitable in the analysis because lower investment costs were assumed.

The wind speeds usually increase as we go up in the atmosphere. To estimate more realistic wind energy production, different wind speeds were used for different wind farms with different heights. Since the heights of the wind speeds in Finnish wind atlas are taken from the ground level, wind turbine hub height was used to assign each turbine for a certain wind speed height category instead of wind turbine height from the sea level. As mentioned before, there were three different wind speed heights in the data: 50-, 100- and 200-meters. Turbines with a hub height between 0–74,99-meters were assigned to 50-meter category, hub heights between 75–149,99 were assigned to 100-meter category and turbines with a hub height over 150-meters were assigned to 200-meter category. For each wind farm, the wind speeds were taken from the height which it was assigned to. Because the data had information on only three different wind speeds, some turbines that are close to being in a higher category (for example turbine with a 149-meter height) might have significantly lower than actual energy yields, since they are lowered down to a 100-meter category, thus their wind speeds are taken from only 100-meter heights, not 149-meter heights. Same thing can happen vice versa if the turbine is at the lower end of the category.

Wind energy production

The wind energy available in a certain site at various wind speed is called wind power density (WPD). WPD was calculated using Rayleigh's function, which is a special case of Weibull's distribution function. Weibull's distribution is two parameter function used for fitting wind speed frequency distributions (Seguro & Lambert, 2000). The two parameters are scale parameter *c*, which equals the units in the wind speed (meters in second in this case). Scale parameter determines the spread of the distribution. The second parameter is dimensionless shape parameter *k*, which affects the slope of the line in the distribution.

Rayleigh's distribution function is a case of Weibull's function where the shape parameter *k* equals two. Rayleigh's function was used since acquiring the shape parameter for each wind farm would have been outside the scope of this thesis. The assumption for using the shape parameter *k* equals two for this case is quite reasonable, as the Weibull's shape parameter in Finland is mostly around two (Campisi-Pinto, Gianchandani & Ashkenazy, 2020).

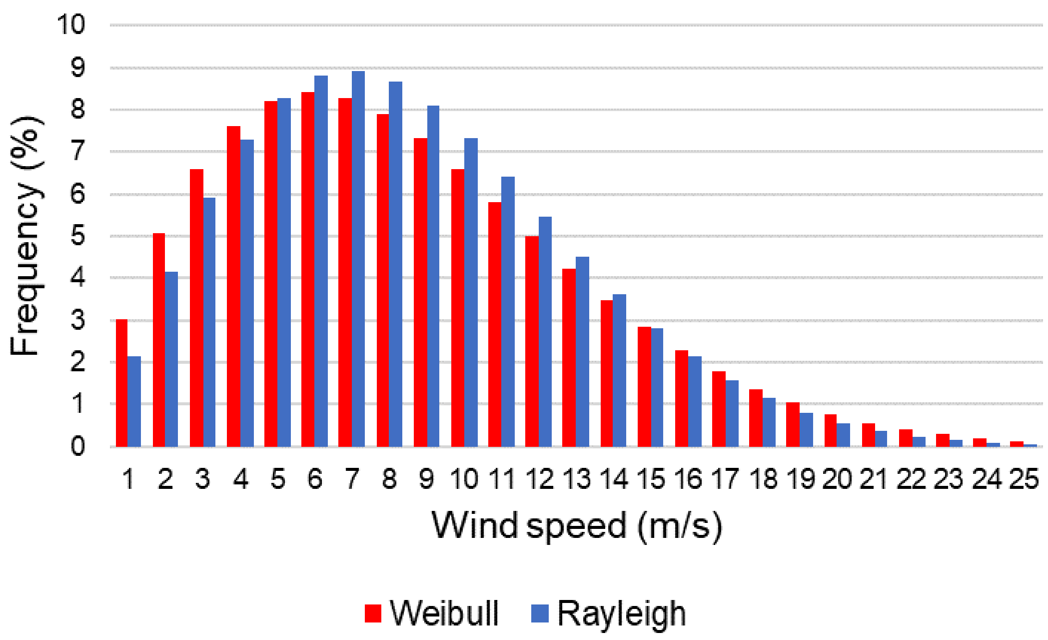

Figure 3. Example of Weibull's and Rayleigh's wind speed probability distributions of January for wind farm "Tornio, Röyttä II" at 100-meter height.

The monthly WPD for each wind turbine location was calculated using Rayleigh's function used by Gul, Tai, Huang, Nadeem & Yu (2019). WPD will tell how much energy in kilowatt hours (KWh) is available per m^2 of area for the wind turbine each hour. WPD for Rayleigh's function is the following:

$$WPD_{Ry} = \frac{6}{\pi}\left(\frac{1}{2}pV^3\right)$$

Where p is air density, for which standard air density of 1.225 kg/m^3 was used. V equals the monthly average wind speed in the location, depending on the wind speed height category the turbine was assigned to. Things such as freezing, cut-in or cut-out wind speeds and wind direction were not considered in wind energy production.

Wind power density only tells how much energy is available for the wind turbine. According to Betz law, wind turbines can only extract a maximum of 59.3% of the energy in the wind. This is also theoretical maximum, meaning that the wind turbine would have to be perfect in energy extraction. Modern wind turbines can extract 50 % or less of the energy from the wind (U.S department of energy, 2015). To take the efficacy of the wind turbines into account, a multiplier of 0.50 was used for all wind farms. The energy available was also multiplied with the rotor area of the turbine and divided by 1,000,000 to get the units in megawatt hours (MWh). To get the monthly energy production, the energy produced by the wind turbine was multiplied with the number of hours in each month. Leap years were not considered. Overall, the function to get the monthly wind energy production (WEP) in MWh is the following:

$$WEP_{Ry} = \frac{\frac{6}{\pi}\left(\frac{1}{2}pV^3\right) * A * e * t_n}{1000000}$$

Where: p = standard air density, 1.225 kg/m^3, V = Average monthly wind speed in wind speed height category, A = Rotor area swept, e = Wind turbine efficiency multiplier (0.5) and t_n equals time in hours in a month n.

After the monthly energy production for each wind turbine was calculated, it was multiplied with the electricity price to get the revenue from the electricity production. After the total revenue for one turbine was calculated, the revenue was multiplied with the number of turbines in the wind farm to get the total revenue of the whole wind farm. For the electricity price, a three-year monthly mean was used for each month. The historical market data for monthly electricity prices in Finland for 2018 to 2020 was taken from the Nordpool (2021). Wind energy tariffs that a wind farm might get for its production were not included in the profits.

Discount rate

A discount rate allows us to determine the present value of future costs and benefits. In this case, the discount rate is equal to the cost of capital, which is the the expected rate of return that market participants require in order to attract funds to a particular investment (Pratt & Grabowski, 2008). The discount rate and cost of capital both tell what the percentage of the return is, which equals expected income with present value. The cost of capital could be also said to be the opportunity cost for an investment.

The cost of capital is a forward-looking measure, which represents the expectations that an investor has. The expectations consist of two different things. The first is the risk-free rate (or the base rate), which tells us the rate of return that the investor expects to get when letting someone else use the money on a risk-free basis, also known as time value of money. The second is the risk premium related to the uncertainty of not knowing when and how much income will be received (Pratt & Grabowski, 2008). The risk includes the systematic and unsystematic risks, systematic risk being the risks associated with the overall market, and unsystematic risks being the risks related with the certain sector or a project (IEA, 2021a).

As the risk-free rate should be the same for every investment alternative, thus the risk premium is the primary cause for differences in observed capital costs (Steffen, 2020). Steffen (2020) identifies three different dimensions that affect the risk in renewable energy projects. The first dimension is the country where the project takes place, as political and economic factors inside the country can affect the risk related to the project. The second dimension is the technology used in the project. For example, the risk related to resource availability and operational failure (such as component failure) are lower in solar plants compared to wind farms. The third dimension is that the risks can vary over time. As technology matures, the risks related to it are usually decreased as the technology proves itself over time. Also, financial institutions become better at financing the project related to the technology, which also reduces the risk.

For investments that use multiple types of capital, such as equity and debt, the cost of capital can be measured using weighted cost of capital (WACC). In Finland debt come with tax-benefits, as interest payments are tax deductible (Staffen 2020). Basen on Estache and Steichen (2015), Staffen (2020) defines WACC after taxes as:

$$WACC_{after\,tax} = (1-\delta) \cdot C_e + \delta(1-t) \cdot C_d$$

Where t is the corporate tax rate, δ equals to the share of debt (in %) in total capital, C_e equals to cost of equity finance (in %) and C_d equals to the cost of debt finance.

In the study on cost of capital of renewable energy projects Steffen (2020) has estimated WACC after tax for onshore wind energy in Finland. Addition to the tax benefits, changing interest rates must be considered when comparing cost of capital over time. To deal with changing interest rates, Steffen used common benchmark interest rate of LIBOR (London interbank offered rate) as a markup. Steffen estimates that the WACC after tax for Finland is 6.1 % minus the LIBOR rate. The LIBOR rate Steffen was using have since been replaced in Europe, partly because of a rate fixing scandal. Instead of LIBOR, an average 12-month EURIBOR (The Euro interbank offered rate) of 2021 was used. The average 2022 EURIBOR rate was –0.491 % (Global Rates, 2021), thus the discount rate used was rounded to 5.6 %. This discount rate was used for all income and costs annually for all wind farms.

3.2 Costs of wind energy production

The cost parameters were chosen based on the economics of wind energy article by Blanco (2009). The costs in the economic analysis include investment cost, operating and maintenance costs, land purchase cost and property tax. In addition to these costs, decommissioning costs were also included in the analysis, which was not included in the article. Investment, decommissioning and land purchase costs happen only once, but other costs occur every year over the lifetime of the turbines.

Investment costs

For investment costs, the estimates from the Finnish wind power association were used. The Finnish wind power association roughly estimates that a megawatt of wind power costs 1.2–1.5 MEur (Million euros) (Finnish Wind power association, n.da.). For the this analysis 1,35 MEur per MW was used. For offshore turbines, the Finnish wind power association estimates that the investment costs are around 20–50 % higher. In the economic analysis, there were two offshore wind power sites. For those two sites, a multiplier of 1.35 was used when calculating the investment costs. The investment costs include the construction and materials of the wind turbines and other infrastructure such as roads and connection to the electricity grid, and financing costs related to them (Finnish Wind power association, n.da.). The total megawatts of each wind power project were multiplied with the investment costs per MW to get the total investment cost for each project. Investment costs occur at the start of the project; hence they were not discounted.

Operating and maintenance costs

Operating and maintenance costs occur every year during the whole lifetime of the project. These costs include maintenance, repairs, insurance, and administrative costs. According to the Finnish wind power association, yearly operating and maintenance costs are 2–3 % of the total investment costs. For the analysis, a rate of 2.5 % was used. Operating and maintenance costs were calculated for 25 years, which is about the average life span of a wind turbine widely considered in the literature. Costs were discounted with a rate of 5.6 % and summed together to get the net present value of the total operating and maintenance costs of each project.

Land purchase costs

Wind turbines need to be placed somewhere and need a certain amount of space, not only for the turbines but for other infrastructure as well. 34 hectares/MW estimated by Denholm, Hand, Jackson & Ong (2009) was used for the total project area needed for a wind farm. The estimate is based on an average project area established by the wind power developer in the United States. The total project area is much bigger than the previously discussed direct impact area, as it includes the spacing between the turbines and boundaries around the wind turbines.

Assumption was made that all the wind turbine developers bought the land needed for the wind turbines at the beginning of the project, instead of renting the land. Total land purchase costs were calculated by multiplying the megawatts of the project with the area needed (34 hectares per MW). For the land purchase price, a three-year average (2018 to 2020) of purchased land on a regional level was used (National land survey of Finland, 2021). In Finland, wind turbines are mostly located in areas that are used for forestry (Finnish tax administration, 2020; Finnish wind power association, n.db.). For every project, the prices for unbuilt properties consisting of forest land were used, even though there was no information about what kind of land was used for each project at this point. There are scale advantages when purchasing land (more land purchased, lower the price per hectare), so depending on the area needed for the project, the mean prices for 2–5, 5–10 or over 10 hectares were used.

Municipal property tax

Wind turbines are taxed according to Finnish property tax legislation. The tax is aimed at the constructions located on the land (KivL 2.2 §). For wind turbines, only the foundation, tower and engine room are under the property tax, as other parts of the turbine are machinery according to the law, and thus are not taxed by the property tax (Finnish tax administration, 2020). These parts that are included in the property tax account for around 30 % of the initial investment costs (Finnish wind power association, n.dc.). The Government decree of ministry of finance (Decree 1036/2018, 21.1 §) states that the taxable value of the real estate on the first year is 75 % of the initial investment cost. This also applies to wind turbines. After the first year, the taxable value of wind turbines decreases by 2.5 % every year (ArvL 21:1.6 §) until the taxable value reaches 40 % of the total investment (ArvL 30.4 §)**.** The minimum taxable value is usually reached after 24–25 years (Finnish wind power association, n.dd.).

According to Finnish tax administration (2020), the property tax rate itself depends on the total megawatts of the whole wind park, and on the municipality in which the turbines are located. If the size of the wind park is 10 or more megawatts, a higher power plant property tax rate is used. If the size of the wind park is less than 10 megawatts, a smaller general property tax rate is used. Each municipality can set their own tax rates, but the power plant property tax is capped at 3.1 %. For each wind park, the tax rates of 2021 were used based on the total MW size and municipality. The tax rates for each municipality were obtained from the website of Finnish tax administration (2021). Some small municipalities did not have a separate power plant property tax. In those cases, the property tax rate was used for wind farms over 10 MW.

The total tax of each wind farm for 25 years (the lifetime of a turbine) was calculated with the following formula:

$$\sum_{i=0}^{25} t_i = \frac{\left(\frac{r}{100}\right) * \left(C * p * v * e^i\right)}{(1+d)^i}$$

Where t_i is the total annual tax paid for year i, r is the tax rate for that specific wind farm, C is the investment cost of the turbine, d is the discount rate (rate of 5.6 % was used) and i is the year. p is the multiplier of the investment included in the property tax (0.3). v is the multiplier of the taxable value of the initial investment (0.75) and e is the multiplier of the decrease in the taxable value that happens each year (0.975). Even though municipal property tax is aimed only at the construction on the land, off-shore wind farms were assumed to pay the taxes the same way as onshore wind farms.

Decommission costs

Decommission costs occur at the end of the wind power project. In this case, after 25 years of operation the wind turbine is deconstructed. Finnish wind power association estimated decommissioning costs to be around 60,000 €–120,000 € per turbine in a wind power park with 10 turbines (Finnish wind power association, n.de.). The decommissioning costs include the preparation of the demolition, the demolition and transportation of the different turbine parts and the landscaping of the turbine location, and the revenue from the recycling of the parts is also subtracted from the total decommissioning cost of the turbine (Finnish wind power association, 2014). The figure of 120,000 € was used as a decommissioning cost of a single turbine, so the number of turbines was multiplied with decommissioning cost to get the total decommissioning costs for each wind farm. The decommissioning costs were set to happen after 25 years of operation and were discounted with the rate of 5.6 %. The figure that was given by Finnish wind power association concerned the costs of decommissioning 10 turbines, so the figure has likely price reductions related to economy of scale. This was not considered in the cost of 120,000 € that was used.

3.3 Habitat data & habitat impacts of wind farms

European nature information system habitat classification

As ecological systems do not really have clear or universally accepted boundaries, their classification usually depends on a certain criterion, and different classifications do not necessarily overlap. One of these classifications is the EUNIS (European nature information system) habitat classification. It is a unified habitat classification system for European countries, which encompasses terrestrial, freshwater, and marine habitats. In EUNIS, each habitat has their own name, code (A to J and X) and description (EEA, 2020). According to the EUNIS classification, habitat is defined as “a place where plants or animals normally live, characterized primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality etc.) and secondarily by the species of plants and animals that live there" (Davies, Moss & Hill, 2004). As the content for a certain ecological system can be defined, it will be easier to draw geographical boundaries for that ecological system (Heywood & Watson, 1995).

In EUNIS classification, the habitats have a classification hierarchy, in which level 1 is the highest and broadest level of classification. Each level has its own categories. For example, level 1 has 11 categories, such as coastal habitats (B), inland surface waters (C) mires, bog, and fens (D) and woodland, forest, and other wooded land (G). As we go lower on the level of classification, the habitats get more specific. For example, level 1 habitat "coastal habitats" has three categories included in it: coastal dunes and sandy shores (B1), coastal shingle (B2) and rock cliffs, ledges, and shores, including the supralittoral (B3). These three categories included in the coastal habitats (B) are considered level 2 habitats. Each level 2 habitat has its own categories. For example, coastal dunes and sandy shores (B1) includes nine different categories, such as Sand beach driftlines (B1.1), coastal dune scrub (B1.6) and machair (B1.9). These categories are considered level 3 habitats.

Table 1. Example of EUNIS habitat levels 1-3.

LEVEL 1	**LEVEL 2**	**LEVEL 3**
…	…	…
B – Coastal Habitats	B1 – Coastal Dunes and sandy shores	B1.1 - Sand beach drift lines
		B1.2 - Sand beaches above the driftlines
		...
		B1.9 - Machair
	B2 – Coastal Shingle	B2.1 - Shingle beach driftlines
		...
		B2.6 - Shingle and gravel beach woodland
	B3 – Rock cliffs, ledges & shores, including supralittoral	B3.1 - Supralittoral rock (lichen or splash zone)
		...
		B3.4 - Soft sea-cliffs, often vegetated
C – Inland surface waters	C1 – Surface standing waters	C1.1 - Permanent oligotrophic lakes, ponds, and pools
...	...	...

The red list classification of habitats

Red list classification can be a tool used to identify biodiversity components (ecosystems, species, or habitats) which are at risk of extinction, losing biodiversity, ecological functions, or ecosystem services. This information is critical for monitoring the status of biodiversity and informing decisions and priorities in land-use, protection management and economic activities (Keith et. Al., 2013). The most well-known red list classification, the international union for conservation of nature's (IUCN) red list of threatened species was established as early as 1964. As its name says, the red list was originally made for species, not for ecosystems or habitats. Much later, in 2016, IUCN published its guidelines for red list of ecosystems categories and criteria. Based on the IUCN framework and other publications, the European red list of habitats was also created (Janssen et. al., 2016).

As other red list classifications, The IUCN red list of ecosystem framework helps us with monitoring and management of ecosystems and allows us to identify ecosystems most at risk of losing biodiversity. The IUNC red list and the European red list of habitats are based on the same eight categories of endangerment. Six of these categories tell us more about the risk of ecosystem collapse. According to IUCN, ecosystem is considered collapsed when: "...it is virtually certain that it is defining biotic or abiotic features are lost from all occurrences, and the characteristic native biota are no longer sustained Ecosystem." The categories from highest- to lowest-degree of risk are: collapsed (CO), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT) and least concerned (LC). The other two remaining categories are data deficient (DD) and not evaluated (NE), which tells that the risk cannot be or has not been evaluated. Three categories, CR, EN and VU are considered as "threatened." (Bland, Keith, Miller, Murray & Rodríguez, 2017).

Each category is based on different criteria. In the European red list of habitats, there are five different criteria, some of which have their own sub-criteria. All of them assess the risk of habitat collapse and degree of endangerment. The five main criteria are reduction of quantity, restricted geographic distribution, reduction in abiotic quality, reduction in biotic quality and quantitative analysis of probability of collapse. In the European red list of habitats, all European habitats were assessed using all the criteria, and qualified for a certain level of threat based on the criteria met (Janssen et. al., 2016)

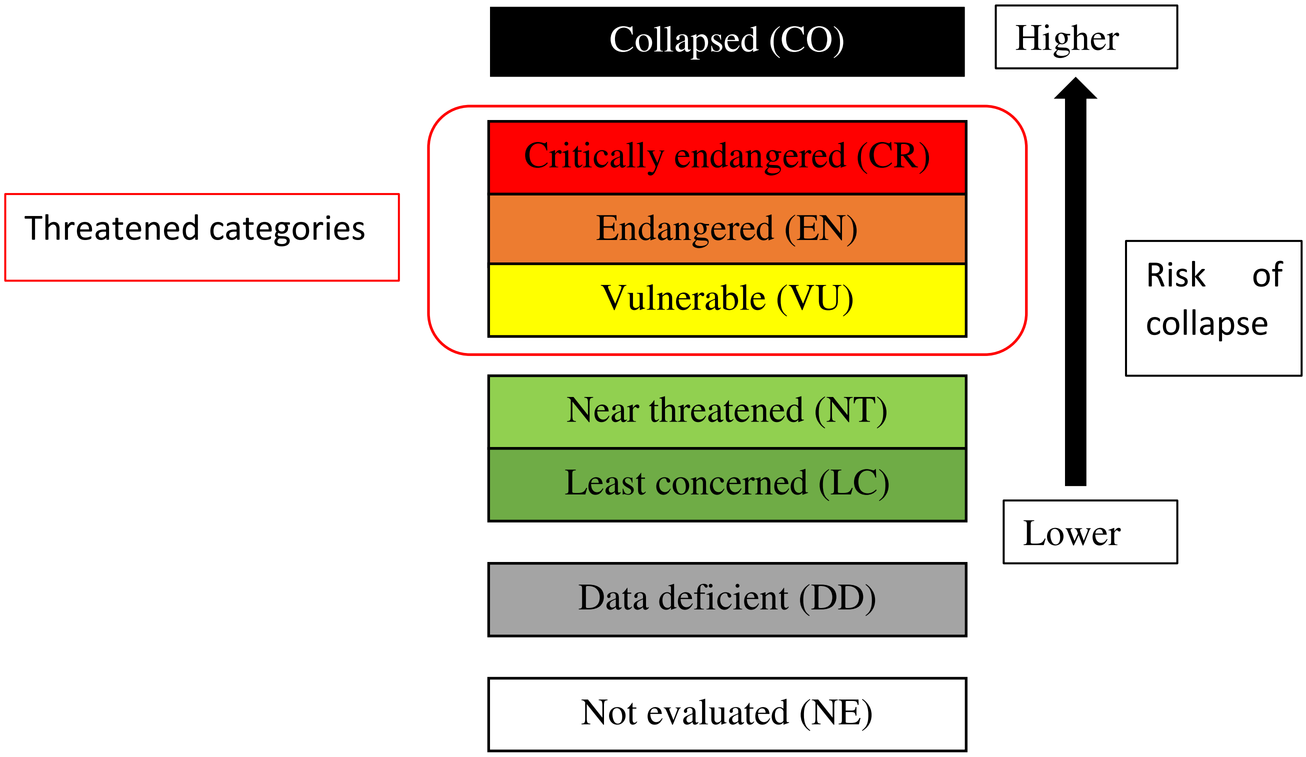

Figure 4. European red list of habitat endangerment categories (Modified from source: Jansen et. al., 2016)

EUNIS habitat classification was used as the basis for the habitats evaluated in the European red list of habitats. Red list classifications were done for level 3 habitats in the case of terrestrial and freshwater habitats, and for level 4 habitats in the case of marine habitats, as such was recommended in a feasibility study done by Rodwell et. al. (2013). Overall, 223 terrestrial and freshwater habitats (Janssen et. al., 2016) and 257 marine habitats (Gubbay et. al. 2016) were assessed for the European red list of habitats. As the result of the assessment, red list classifications for each habitat were produced for the EU28 (current EU countries and United Kingdom) and EU28+ (EU28 and adjacent regions) areas. Overall, 36.4 % of the terrestrial and freshwater habitats were considered "threatened" inside the EU28 area (Janssen et. al., 2016).

Habitat data

For habitat data, ecosystem types of Europe version 3.1 was used (EEA, 2019). The data presents the probabilities of EUNIS level 2 terrestrial and freshwater habitats. Version 3.1 of the data also included marine ecosystems using a new classification, which was not directly compatible with EUNIS or red list of habitat classifications, thus marine habitats were given a lesser focus in this thesis. The data was in raster form, with a spatial resolution of 100 x 100 meters (Weiss & Banko 2018). Habitat data was also imported into the ArcGIS-program with other GIS-data.

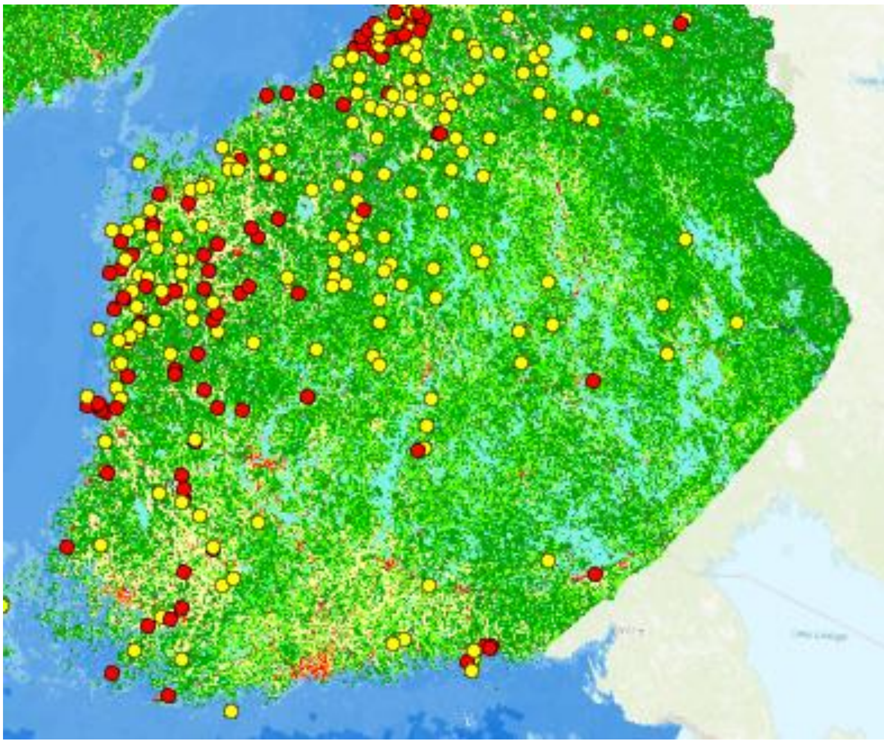

Figure 5. Southern Finland with habitat data & wind farms in ArcGIS-program. Red dots presenting wind farms in production & Yellow dots presenting upcoming wind farms.

Red list status of habitats and habitat score system

As mentioned in a previously, the European red list of habitats classifications corresponds to the level 3 EUNIS habitats for terrestrial and freshwater habitats. Therefore, we cannot tell how endangered level 2 habitats are using the European red list classification. To prioritize different habitats in the data with each other regarding their level of endangerment, a classification system was created for level 2 terrestrial and freshwater habitats. The complete classification system created can be found in the appendices section of this thesis.

First, some terrestrial and freshwater level 2 habitats were eliminated, as they do not occur in Finland. This was done by using the clip tool in ArcGIS on the ecosystem types of Europe data, which cuts away data points that are outside a certain selected (in this case the area included Finnish wind atlas data) area. For the remaining level 2 habitats, the information about the level 3 habitats included in them was collected. Also, the red list classification of these level 3 habitats was gathered. This was done partly with the help of an article by Chytrý et. Al. (2020), from which the code of corresponding red list habitat of the level 3 habitats was taken for most cases. Also, the red list of habitat fact sheets (EEA, n.d.) were used for linking level 3 EUNIS and a red list habitats.

Even though most level 2 habitats that are not located in Finland were eliminated, there were still level 3 habitats included in the level 2 habitats that do not exists in Finland. To make sure these level 3 habitats do not affect the prisonization of level 2 habitats, the geographic occurrence of each remaining level 3 habitat was checked using the terrestrial habitat fact sheets related to the red list of habitats (EEA, n.d.). If the geographic occurrence in Finland was marked as "present" or "uncertain," the level 3 habitat was kept in the data, otherwise it was removed.

For each remaining level 3 habitat, a habitat score was given using conservation status of the corresponding red list habitat. The conservation status for each red list habitat was taken from Jansen et. al. (2016) using the EU28 conservation status, and then given to the corresponding level 3 habitat. For two level 2 habitats "coastal lagoons" and "estuaries" conservation status was taken according to their Helcom (Baltic Marine Environment Protection Commission) classification status. The habitat prisonization scoring used by Kotiaho, Kuusela, Nieminen & Päivinen (2015) group was utilized. Habitats with the conservation status of critical (CR) were given a score of 5, endangered (EN) a score of 4, vulnerable (VU) a score of 3, near threatened (NT) a score of 1 and least concerned (LC) a score of 0. Habitats with no conservation status and with a status of data deficient (DD) were left out of the scoring process.

Habitat scores of level 2 habitats

The score for level 2 habitats was calculated by taking the average score of each level 3 habitat remaining in the level 2 habitats inside Finland. The score for each level 2 habitat was between zero to five, with zero being least threatened, and five being most threatened. As the conservation statuses are only assigned to level 3 habitats and not level 2 habitats, we cannot draw a conclusion that a level 2 habitat is considered endangered if its score is for example four. Also, there was no data about how much of each level 3 habitat is included in the level 2 habitat, so a weighted average could not be given based on the incidence of the level 3 habitats. The scoring used is a one way of prisonization between different level 2 habitats, as habitats with a higher habitat score are assumed to be more endangered.

Table 2. *Example of habitat score system for B1 and B2 level 2 habitats. Only level 2 and level 3 habitats that can occur in Finland are included.*

EUNIS Habitat level	EUNIS2007 code / Red list code	EUNIS2007 or Red list Habitat name	EU 28 Red list conservation status	**Score of level 2 habitat /** (Score of Level 3 habitat)
1	B / B	Coastal Habitats	-	-
2	B1 / B1	Coastal dunes and sandy shore	-	**2**
3	B1.1; B1.2 / B1.1a	Atlantic, Baltic, and Arctic sand beach	VU	(3)
3	B1.31; B1.311; B1.321 / B1.3a	Atlantic and Baltic shifting coastal dune	NT	(1)
3	B1.4 / B1.4a	Atlantic and Baltic coastal dune grassland (grey dune)	VU	(3)
3	B1.5; B1.51 / B1.5a	Atlantic and Baltic coastal Empetrum heath	VU	(3)
3	B1.6 / B1.6a	Atlantic and Baltic coastal dune scrub	LC	(0)
3	B1.7; B1.72 / B1.7a	Atlantic and Baltic broad-leaved coastal dune forest	LC	(0)
3	B1.7; B1.71 / B1.7c	Baltic coniferous coastal dune forest	VU	(3)
3	B1.8 / B1.8a	Atlantic and Baltic moist and wet dune slack	VU	(3)
2	B2 / B2	Coastal shingle	-	**0**
3	B2.1; B2.2; B2.3; B2.4 / B2.1a	Atlantic, Baltic, and Arctic coastal shingle beach	LC	(0)

The habitat scoring process had a few exceptions. For marine habitats (code A) and level 2 habitats coded I (regularly or recently cultivated agricultural, horticultural, and domestic habitats) and J (constructed, industrial and other artificial habitats) were given a score of 0. The marine data was not compatible with the red list habitat data, and level 2 habitats I and J were human built habitats, which did not have a red list habitat classification, excluding one level 3 habitat (arable land with unmixed crops grown by low-intensity agricultural methods).

The level 3 habitats in G4 (mixed deciduous and coniferous woodland) did not have conservation status, since they are a mix of different code G (woodland, forest, and other wooded land) level 3 habitats. For G4 habitats, some were removed, as they included a mix of woodland, forest and other habitats that could not be present in Finland. For the remaining G4 habitats (G4.1, G4.2 and G4.3), the average score of the possible level 3 code G habitats included in them was taken to get the score for each level 3 habitat in the level 2 habitat G4. For example, G4.2 (mixed taiga woodland with betula) includes G3.A, G3.B and G3.C mixed with G1.91. From these, only G3.A, G3.B and G1.9 exist in Finland, so the habitat score for level 3 habitat G4.2 was taken by counting the average scores of G3.A, G3.B and G1.9. For the level 2 habitat G4, the habitat score was counted by taking the average score of all the level 3 habitats (G4.1, G4.2 and G4.3) included in it.

Direct habitat impact area of wind farms

The direct habitat impact area was calculated for all upcoming and operational wind farms. For the direct habitat impact area that each wind farm has, 0.3 hectares per MW estimated by Denholm et. al. (2003) was used. 0.3 hectares was multiplied with the megawatts of each wind in the data to get the direct impact of the wind farm. There were some cases in upcoming projects cases where MW data was lacking. Data was filled with using the average turbine MW (5.5 MW) of upcoming wind farm projects. Two cases (Utajärvi, Pontemajärvi and Kajaani, Katajamäki) did not have the data on number of turbines or MW, so the information was retrieved from the environmental impact assessment documents of the projects.

The data on the size each wind farm's direct habitat impact area was imported to ArcGIS. The data was connected to each wind farm on the map using the join tool. For each wind farm, a circle area around the farm representing the direct habitat impact was drawn using the buffer tool. The buffer tool allows you to select the radius distance of each buffer. To get the correct radius size *X* in meter for each buffer circle, the outcome of the following formula was used as distance:

$$X = \frac{H_n \cdot 1000}{\pi}$$

Where H_n is the hectares of habitat displaced of wind farm *n*. Habitat displaced is multiplied with 1,000 to get the distance of the radius in meters. After this the buffer zones were joined with the ecosystem types of Europe data to get the information about which habitats are directly impacted by each wind farm. Because of the circular buffer, an assumption was made that the direct impact of every wind farm is circular. The actual habitat area displaced and disturbed is spread to a larger area, as seen in figure 6, thus the actual habitats displaced by wind farms might be different than the habitats displaced, according to this thesis. Still, most of the time wind farms are mostly surrounded by the same habitats they displaced using this method.

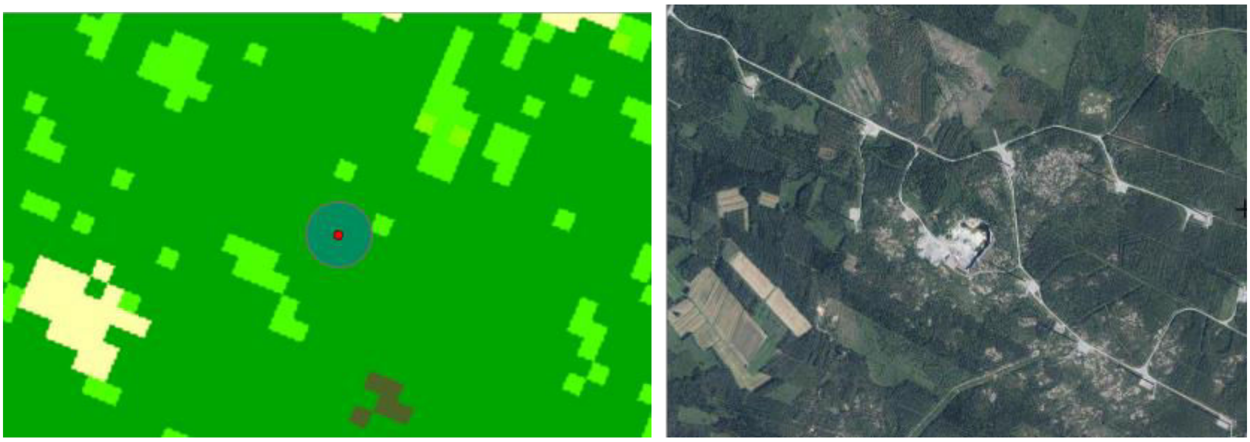

Figure 6. Estimated area displaced by a wind farm seen as a circular buffer zone vs. the actual area displaced by a wind farm taken from Karttapaikka-service of the national land survey of Finland.

Also, the issue of double counting could not be solved, meaning that few wind farms have direct habitat impacts which overlap on the same area. An approximate check on the ArcGIS map shows that double counted areas were not too plentiful, so double counting should not have a significant effect on the results of the thesis. Also, as the ecosystem data of Europe is not too precise, wind farms located on a small island or near the shore were displayed as being in a marine habitat, meaning that their habitat score was to be 0, even though the islands would have terrestrial habitats in them

Figure 7. Wind farms with overlapping buffer zones representing the direct habitat impact area

The data on direct habitat impacts of each wind farm was imported into spreadsheet, where it was processed into a more apprehensive form. Total habitat score was calculated for each habitat for each wind farm by multiplying the size of each habitat inside the buffer zone with the habitat score of the habitat. ArcGIS gave a size for each habitat inside the buffer zone. This size was not in a certain metric, but the sizes of the areas were still proportional to each other. The average score of a habitat of a wind farm was also calculated by dividing the total habitat score with the buffer size area of the habitat displaced. The average score could be between 0–5.

3.4 Habitat taxes

The effects of two different kinds of habitat taxes were considered for wind farms in production which were profitable. The first tax is based on the size of the habitat area displaced by the turbines aka the quantity tax. The net present value per hectare of habitat displaced was calculated and drawn into a chart describing the supply of wind energy. Tax based on the amount of habitat displaced takes only the quantity of habitat displaced into account. Two tax rates were considered, which would make 10 % and 25 % of the wind farms non-profitable. The taxes were taken from the net present value of per hectare displaced by the profitable wind farm.

The second type of habitat tax was based on the habitat score of the turbines aka the quality tax. Habitat score-based tax was only considered for wind farms with a habitat score larger than zero, with the wind farms with the total habitat score of zero being removed from the analysis. The net present value per habitat point was calculated for each wind farm in production. The tax based on habitat-score takes the quality of the habitat into account instead of just quantity of habitat displaced. Again, two tax rates were considered, rates which would make 10 % and 25 % of wind farms non-profitable based on the net present value per habitat point of profitable wind farms.

4 Results

4.1 Habitats displaced by wind farms

A total of 8912 hectares (ha) of habitat was displaced by wind farms. The most common level 1 habitat displaced by a wind farm was “woodland, forest and other wooded land” (code G) with 82.24

% of the total habitat displaced (around 7330 hectares). The second most common displaced habitats were marine habitats (A) with 10.57 % of total displaced habitat, which accounted for 942 hectares. The third most common level 1 habitat displaced was “mires, bogs and fens” (D) with 4.24 % of total displaced habitat (378 ha). No wind farms displaced habitats in “habitat complexes” (X) or “heathland, shrub and tundra” (F). For level 2 habitats the most common terrestrial or freshwater habitat displaced was Coniferous woodland (G3) with 63.79 % (5685 ha) of the total habitat displaced. The second most common was mixed deciduous and coniferous woodland (G4) with 10.66 % (950 ha). Both level 2 habitats had a score of two or less. More detailed graph of level 2 habitats can be found from the appendices section.

For mires, bog and fens, the most common level 2 habitat displaced was aapa, palsa and polygon mires (D3) with 3.75 % of total habitat dispalced. Finland only had aapa and palsa mires, with aapa mire being in the red list category of least concerned (LC) and palsa mires being in the status of critical (CR), hence the substantial portion of displaced habitat being aapa, palsa and polygon mires could be non-issue or severe problem for habitat conservation. Also 0.49 % (44 ha) of the total habitat displaced was raised and blanket bogs (D1). Raised bog is the only level 3 habitat in that category located in Finland, and it has a red list status of endangered (EN), meaning that wind turbines located in these areas have or will displace habitat classified as threatened with a high probability.

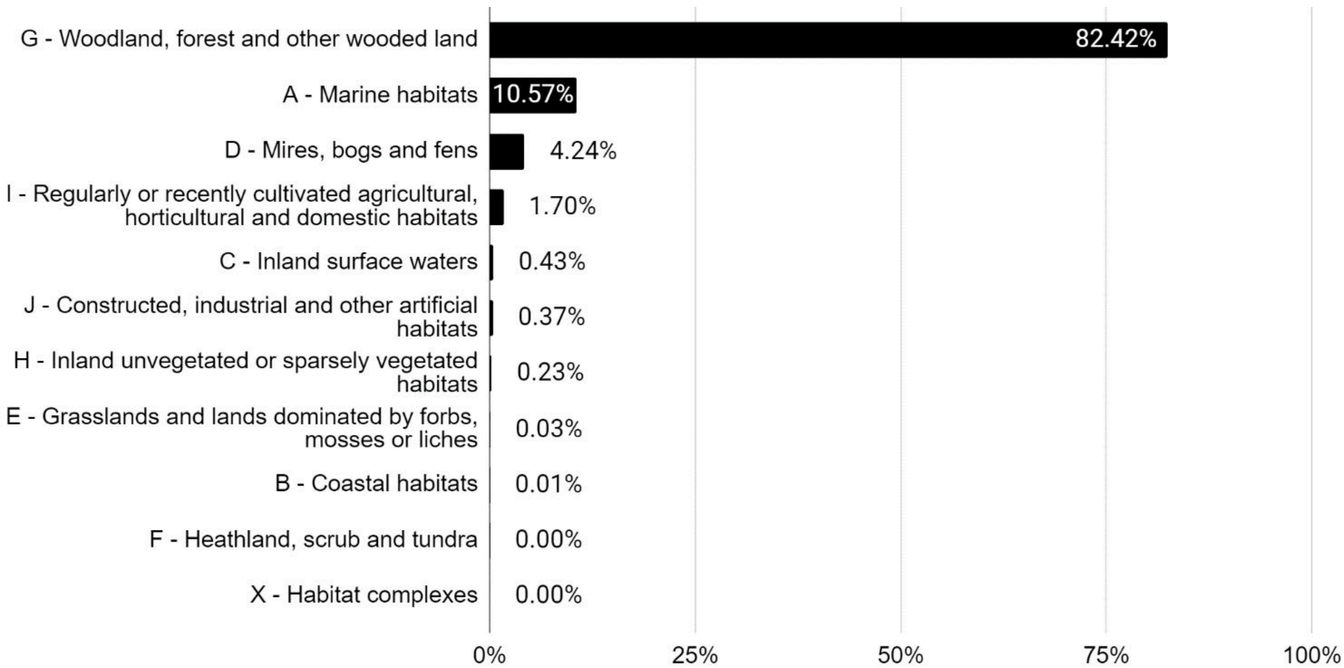

Figure 8. Percentages of level 1 habitats displaced by wind farms.

Most habitats which were displaced had a habitat score between 1 and 2. This is most likely because the most common displaced habitat was woodland, forest, and other wooded land (G), which had a habitat score between 1–2. The second most common habitat score of displaced habitats was 0. The habitats with a score of 0 included all marine habitats (A) as the most common zero-point habitat displaced, second most common being agricultural, horticultural, and domestic habitats (I), and constructed, industrial and other artificial habitats (J) being the least displaced all zero zero-point level 1 habitat. Also, other level 1 habitats such as coastal habitats (B) and heathlands, scrubs, and tundra (F) and sparsely vegetated habitats (H) had zero-point level 2 habitats included in them. None of the habitats displaced had a habitat score larger than 4. 0.5 % of the habitats displaced had a score between 3–4, with almost all the area with a score of 4 being raised bogs (0.49 % of the total habitat displaced), and the rest (0.01% of total habitat displaced) being seasonally wet and wet grasslands (E3). For the habitats with a score from 2 to 3, most were aapa, palsa and polygon mires (D3) with a small minority (0.02% of total habitat displaced) being mesic grassland (E2).

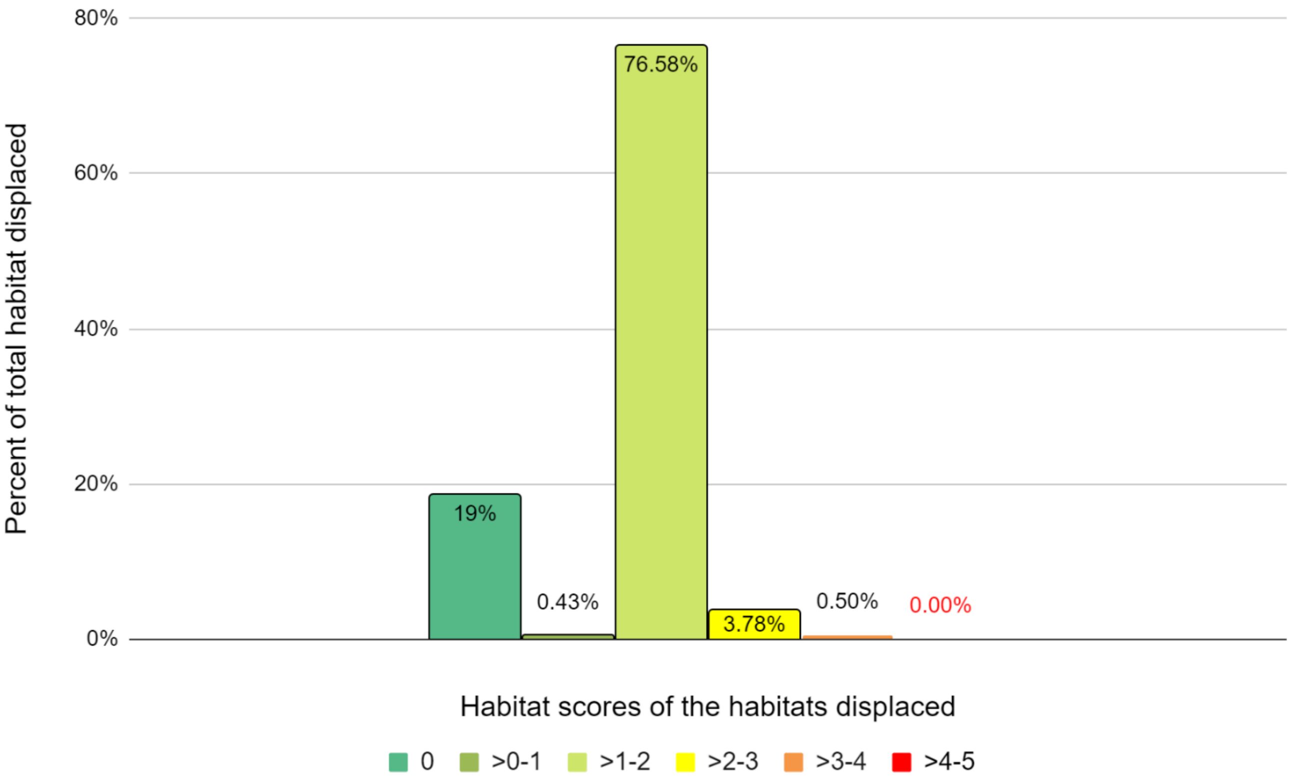

Figure 9. Percentages of habitats displaced by habitat score.

4.2 Details about the wind farms

Habitats displaced by 384 wind farms were looked at in the thesis. These wind farms displace approximately 8912 hectares of habitat, of which 903 hectares were displaced by offshore wind farms, and 8009 hectares by onshore wind farms. 140 wind farms were already in production, while 244 wind farms were upcoming in various phases of development. Most of the biggest wind farms had an average habitat score of approximately two or zero, as they are mostly located marine or woodland habitats. The average habitat score seems to increase as the size of the wind farm goes up but decreases as the habitat score reaches two. The wind farms with the highest average score seem to be quite small, meaning that the high habitat impact happens in a relatively small area.

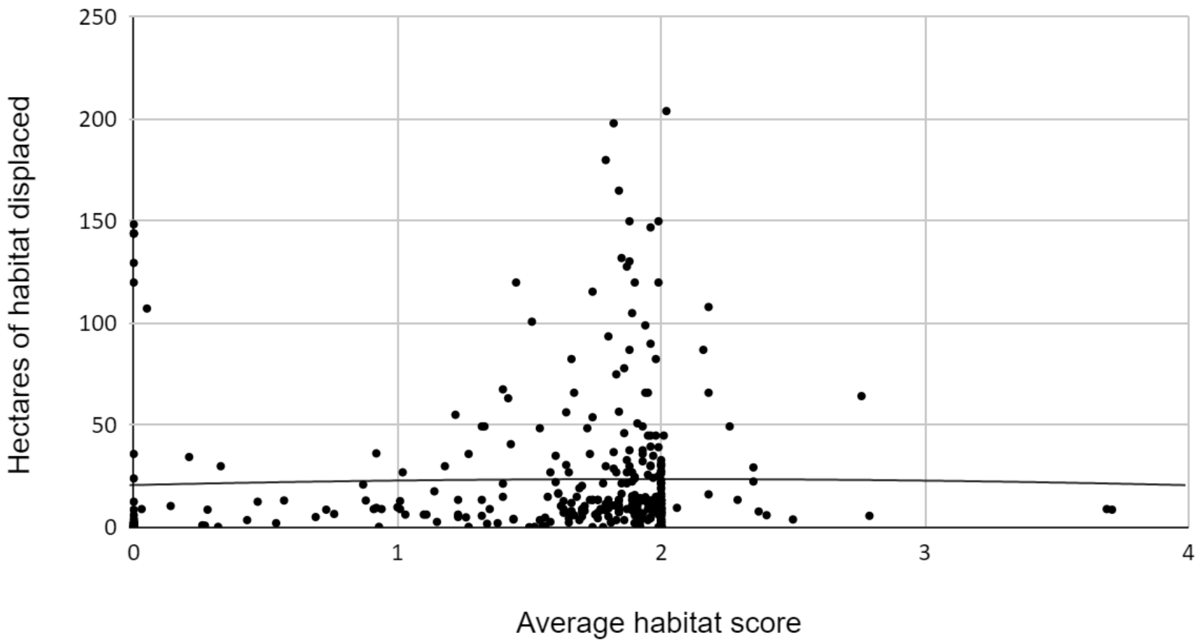

Figure 10. Hectares of habitat displaced & average habitat scores of wind farms.

The total habitat score calculated for each wind farm increases as the total area displaced increases. This is also very intuitive, as larger wind farms are expected to have larger biodiversity impact. Average habitat score of a wind farm was around 68. Out of 384 wind farms, 42 wind farms had a total habitat score of zero. 264 wind farms had a habitat score of less than 50, and 352 wind farms had a habitat score which was less than 200. Only 7 wind farms had a score higher than 500, from which Ii, Yli-Olhava had the highest habitat score, with a score of 801. Ii, Yli-Olhava also displaced most hectares of habitat. Some large wind farms were in areas which had mostly habitats with a score of zero, so their total habitat score was also exceptionally low. Many of these low habitat score wind farms with large area of habitat displaced were offshore wind farms located in marine habitats, which had a habitat score of zero.

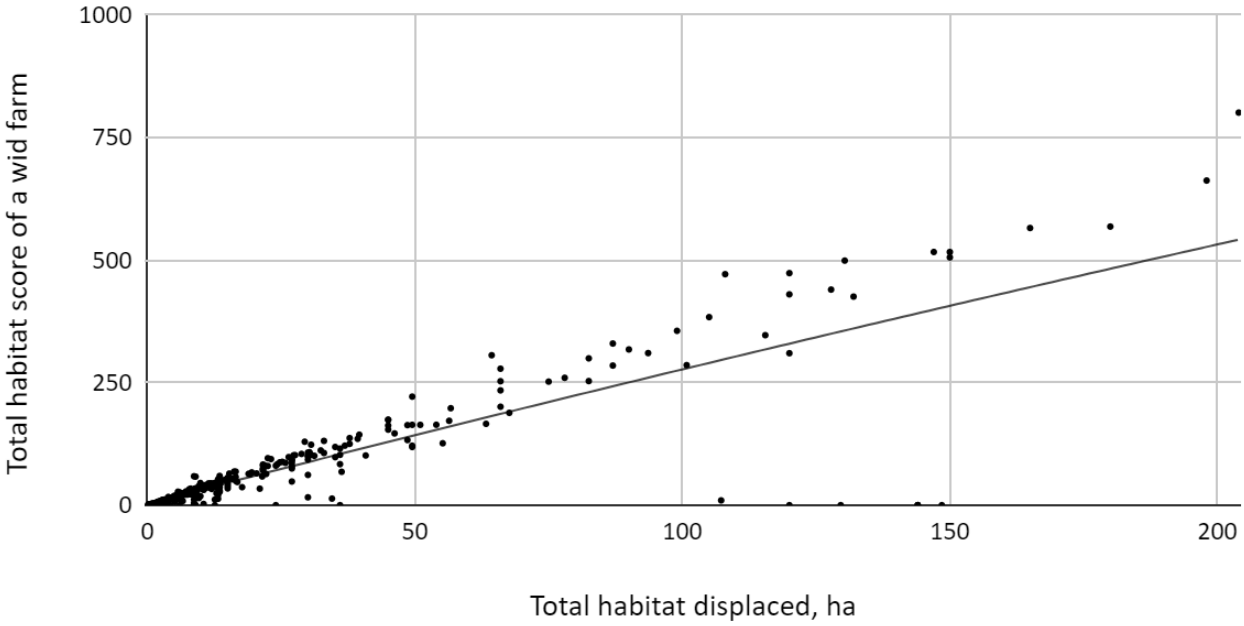

Figure 11. Total habitat scores & total habitat displaced in hectares of each wind farm with polynomial trend line. Each black dot presents a single wind farm.

In the case of geographical location, most habitat were displaced by wind farms in the northern Finland (Kainuu, Lapland and North Ostrobothnia), with North Ostrobothnia being the place of most habitat displacement. As the habitat displaced was dependent on the MW of the wind farms, also most wind farms by capacity are also located in the northern Finland. Also, 52.67 % of the total habitat score occurred in the wind farms located in northern Finland. The wind farms in Northern Finland had a slightly higher habitat score compared to the percentage of the area of habitat displaced. This tells us that wind even though most wind farms are in Northern Finland, the wind farms in other parts of Finland displace slightly more valuable habitats according to habitat point prioritization.

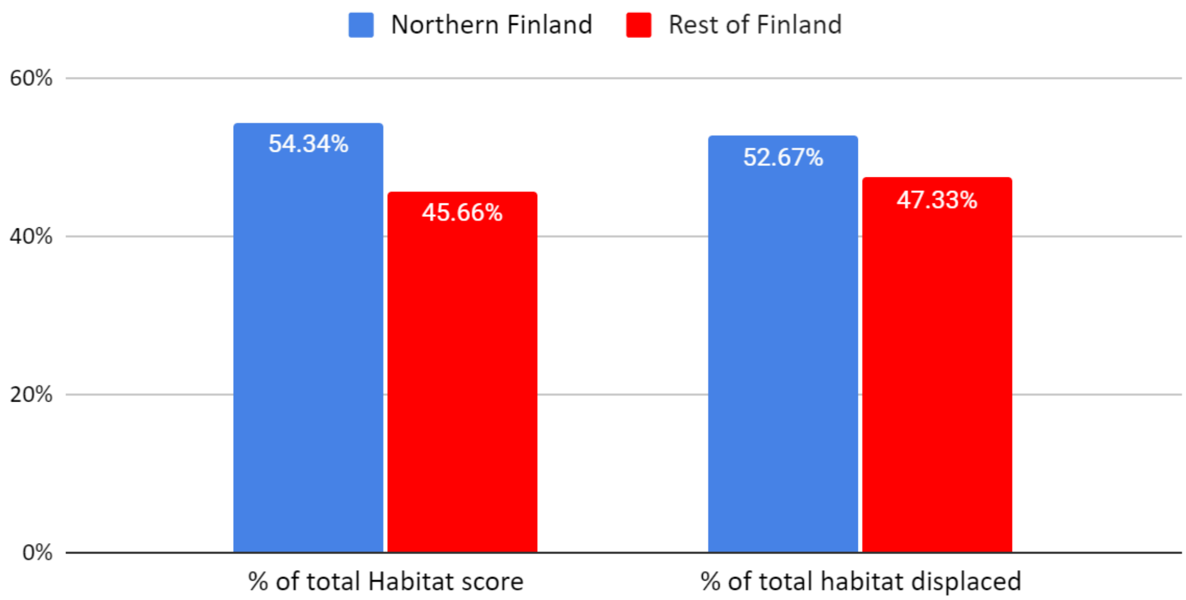

Figure 12. Percentages of hectares of habitat displaced & habitats scores. Northern Finland (Lapland, Kainuu & North Ostrobothnia) and Rest of Finland.

Most of the habitat was displaced by wind farms larger than 80 MW, as almost 75 % of the habitat was displaced by these larger wind farms. Smaller wind farms (under 80 MW) displaced around 25 % of the total habitat. This seems logical as larger wind farms are expected to displace more habitat overall. Interestingly, smaller wind farms had a larger habitat score compared to the percentage of habitat displaced. This tells us that according to the methods used, smaller wind farms are built on more endangered habitats on average.

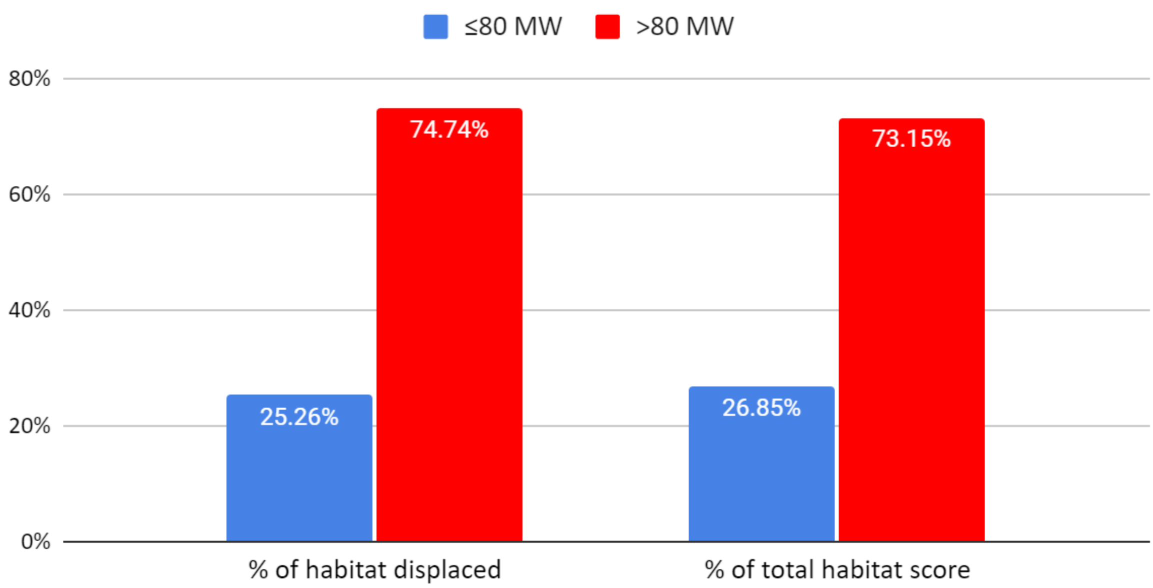

Figure 13. Percentages of hectares of habitat displaced & habitats scores. Small & large wind farms.

Most of the habitat is displaced by upcoming wind energy projects, and 91.2 % of the habitat displaced was by upcoming projects, as they have almost ten times more capacity compared to the capacity already in production. Wind farms currently in production were 8.8 % of the total habitat displaced. The wind farms in production displace around 781 hectares of habitat, and upcoming wind farms displace 8131 hectares of habitat. Upcoming wind farms had a slightly smaller habitat score per habitat displaced compared to wind farms in production. This tells us that future wind farms are on average in less valuable habitats according to the habitat point prioritization.

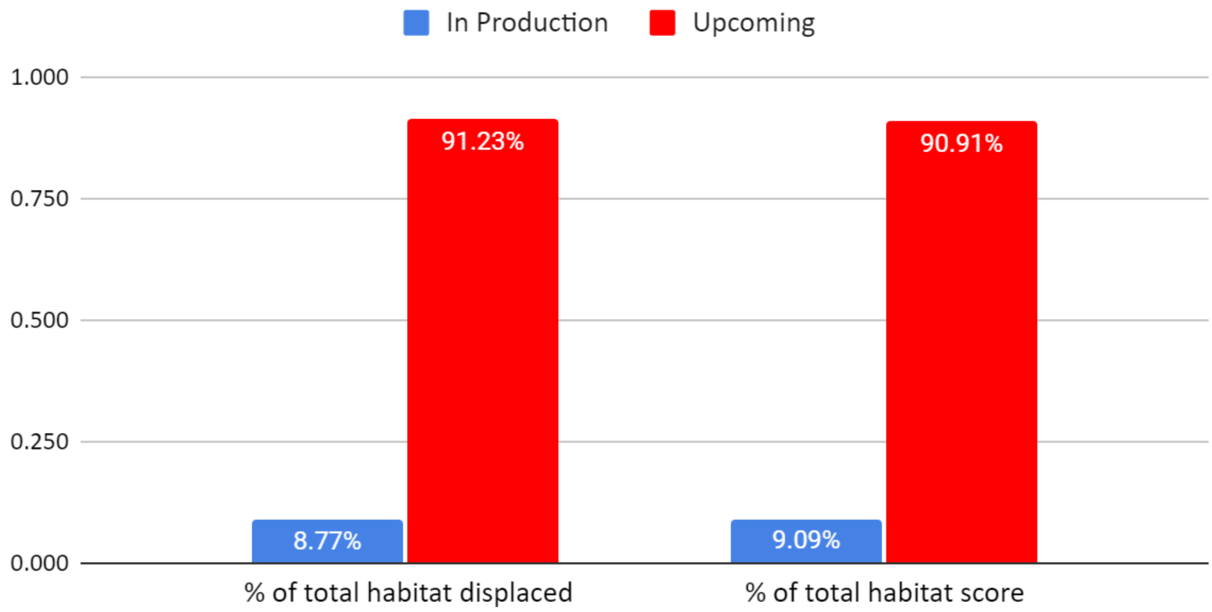

Figure 14. Percentages of hectares of habitat displaced & habitats scores. In productions & upcoming wind farms.

4.3 Scales of the quantity and quality habitat taxes

Not all the wind farms in production were profitable to begin with according to the calculations of this thesis. Out of 140 wind farms with the capacity of 2597 MW, 18 farms were non-profitable before any habitat taxes. The net present value of wind farms in their lifetime ranged from a profit of 6.2 Meur per megawatt to a loss of 1.8 Meur per megawatt, with a average profitability over the lifetime of the wind farm per megawatt being 1.3 Meur, and the median profitability per megawatt being 1,1 Meur. Non-profitable wind farms equaled 143 MW, which accounts for 5.5 % of the total capacity in production. Out of the 143 MW, two farms (Tervola, Varevaara & Pyhäjoki, Oltava) totaled 121 MW of capacity. Other non-profitable farms each had a capacity of 5 MW or less. 2454 MW of the total capacity (94.5%) was profitable. Non-profitable farms were excluded from the calculations regarding the taxes.

Quantity tax based on the hectares of habitat displaced

Figure 15 shows the wind farm profitability per hectare of habitat displaced and the total hectares of habitat displaced as a demand function for wind farms. Each black dot presents a single wind farm, and the gray area below presents the total net present value. The tax is shown as a red line, and the red area below the line shows the total tax paid for wind farms. Dots under the red line are made non-profitable by the habitat tax. The quantity of habitat displaced based lump sum tax, which makes 25 % of the turbines non-profitable came in at 2.5 Meur per hectare of displaced habitat for the whole lifetime (25 years) of the wind farm. This tax made 31 wind farms non-profitable, which equaled 615.5 MW of capacity (25.1 % of total profitable capacity). These 31 wind farms displace approximately 185 hectares of habitat.

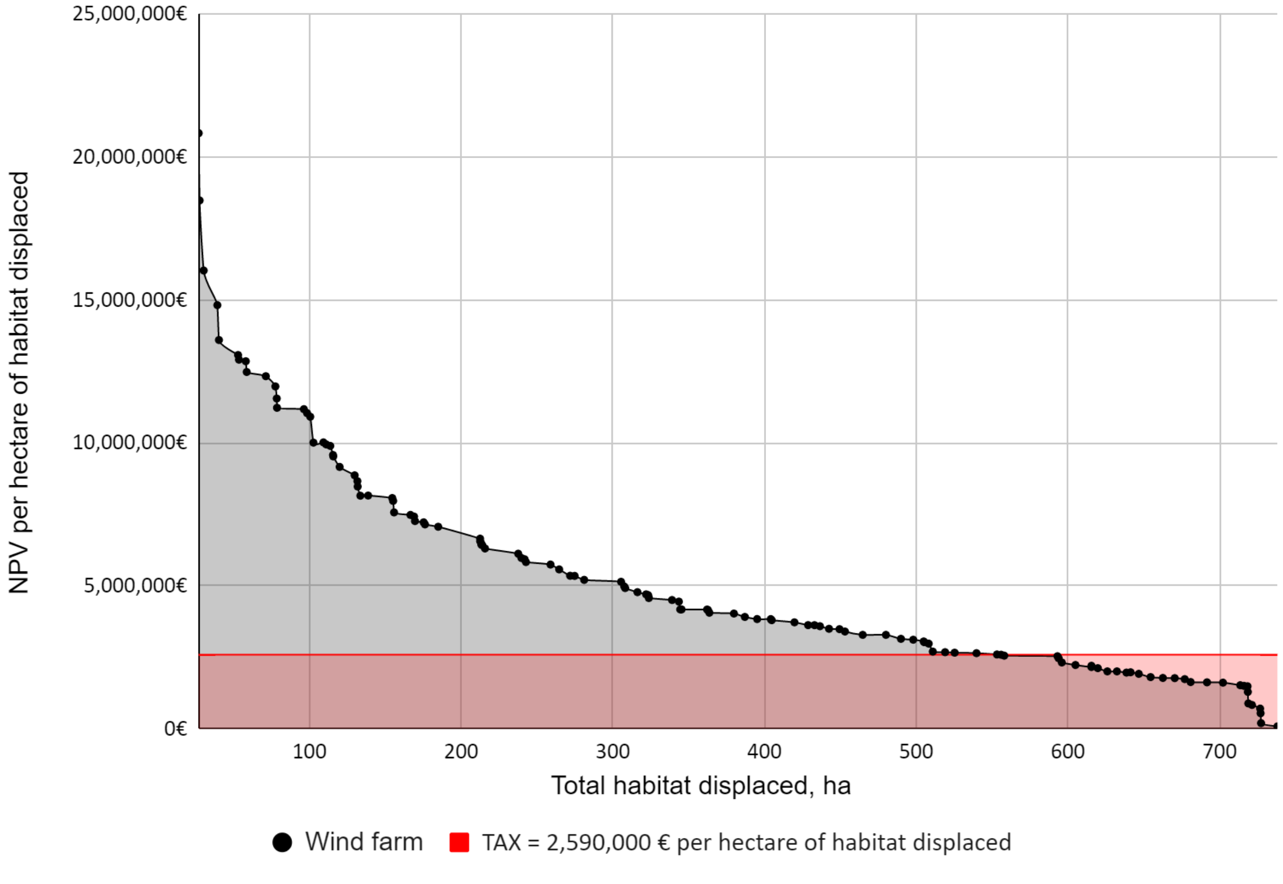

Figure 15. Net present value (€) of wind farms per hectare of habitat displaced with quantity-based tax, making 25 % of wind farms non-profitable.

Figure 16 shows the demand function with the lower tax rate, which would make only 10 % of the wind farms non-profitable. The lower rate lump sum tax based on habitat displaced came in at ~1,6 Meur per hectare displaced. This tax would make 13 wind farms non-profitable, equaling 204 MW of capacity (8.3% of total profitable capacity). These 13 wind farms combined displace around 61 hectares of habitat.

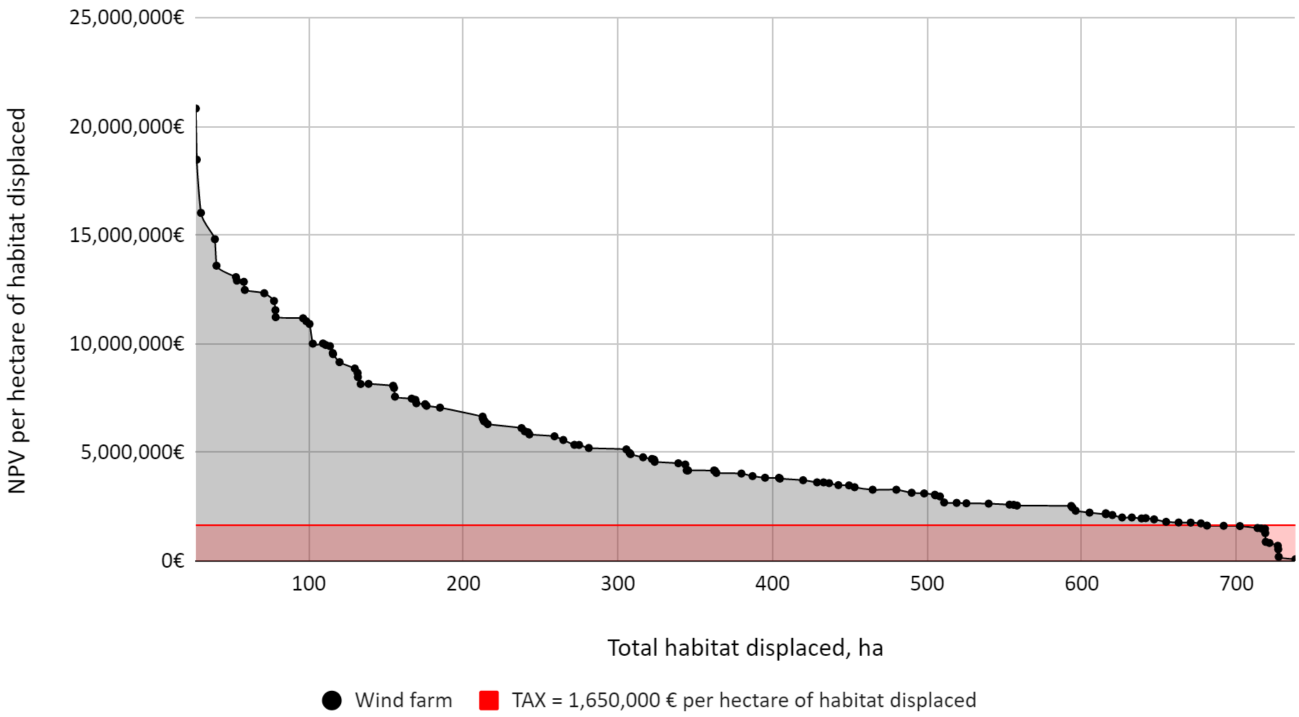

Figure 16. Net present value (€) of wind farms per hectare of habitat displaced with quantity-based tax, making 10 % of wind farms non-profitable.

Quality tax based on the habitat score of the habitat displaced by the wind farm

Demand function seen as figure 17 was drawn for the quality habitat tax, based on the habitat scoring system. As mentioned before, only wind farms with a total habitat score over zero are considered for the quality tax. There were 99 profitable wind farms with a habitat score over zero. A lump sum tax for the lifetime of the farm which displaces 25 % of the turbines came in at ~750,000 € per habitat point. This tax made 25 wind farms non-profitable, which equaled 583.5 MW of capacity (23,8% of total profitable capacity). Combined, these 25 wind farms displace total of ~175 hectares of habitat. The demand function for quality tax looks different compared to the quantity tax, as the NPV per habitat point is displayed, instead of NPV per hectare of habitat displaced. As with the other tax, black dots are presenting the wind farms, with dots under the red line being made non-profitable after the quality tax.

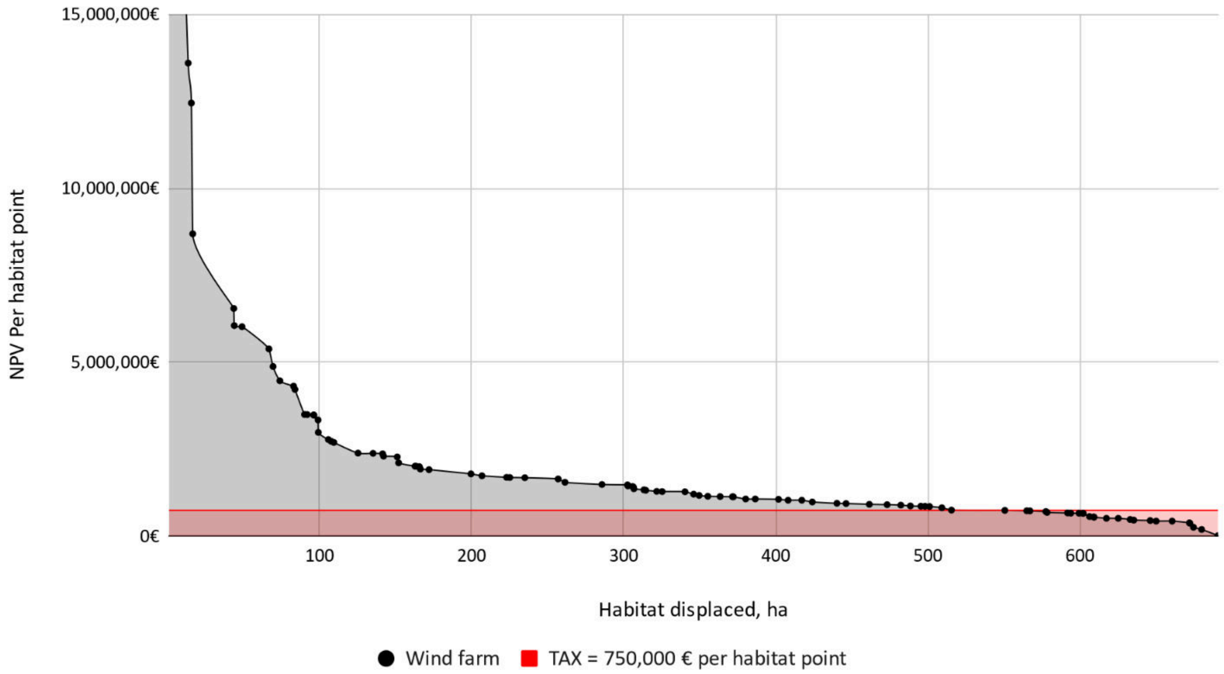

Figure 17. Net present value (€) of wind farms per habitat point with quality-based tax, making 25 % of wind farms with more than 0 habitat points non-profitable. Wind farms with a habitat score of zero are not included.

Lump sum tax with a tax rate which would make only 10% of the wind farms considered non-profitable was ~510,000 € per habitat point, as seen on figure 18. The tax made 10 wind farms non-profitable, which equaled 218 MW of capacity (9% of total profitable capacity). Overall, these 10 wind farms displaced approximately 65 hectares of habitat. Wind farms made non-profitable are located under the red line presenting the quality habitat tax. Wind farms with zero habitat points were not included in quality taxes, thus cannot be seen in the quality tax graphs.

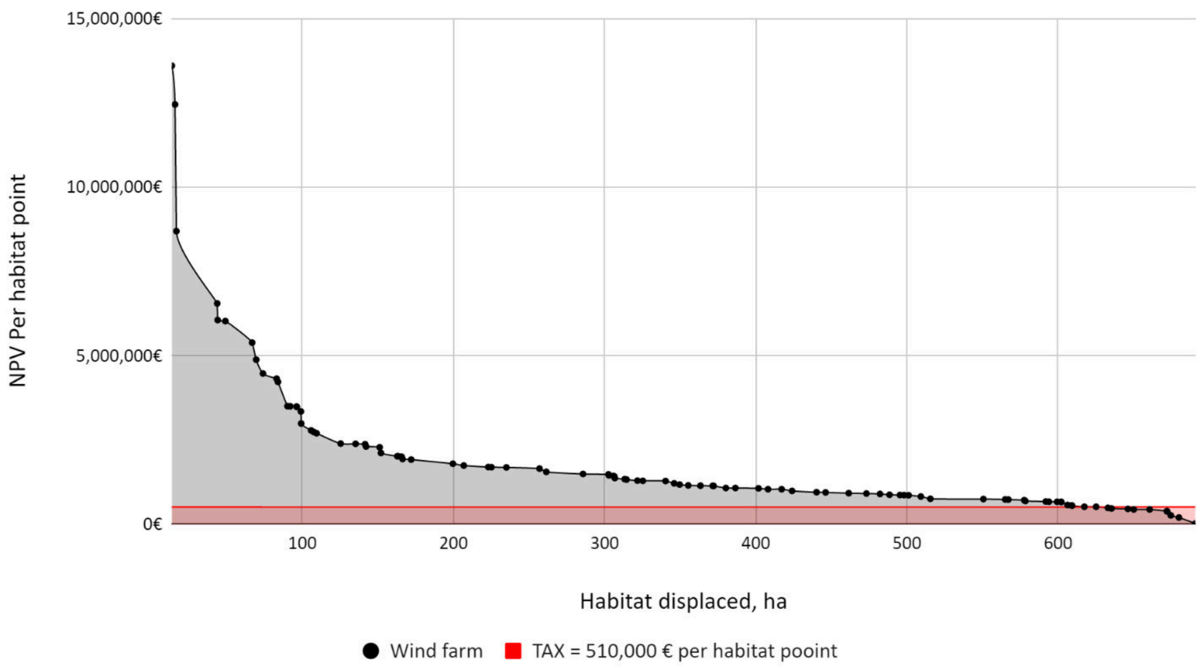

Figure 18. Net present value (€) of wind farms per habitat point with quality-based tax, making 10 % of wind farms with more than 0 habitat points non-profitable. Wind farms with a habitat score of zero are not included.

Comparison between the taxes

The quality tax based on habitat score was 510,000 € (10 %) or 750,000€ (25 %) per habitat point. To compare this with the quantity, the average habitat score per hectare of habitat displaced of a wind farms with higher score than zero was 3.07. This means that on average, per hectare the tax would be around 1.57 Meur with the lower 10 % rate, and 2.3 Meur with the higher 25 % rate. This means that on average, quantity tax would be slightly higher compared to the quality tax, as 25 % tax rate for the quantity tax per hectare was 2.5 Meur and 10 % tax rate was 1.6 Meur.

The wind farms made non-profitable with 25 % quantity tax had 26 % of the total habitat score. On average, these wind farms had a habitat score of 18.7. Wind farms made non-profitable with the lower 10 % had on average a lower habitat scores of 16.1, which had 9.4 % of the total habitat score. This means that the lower tax rate made wind farms with a lesser average impact non-profitable according to the habitat score system.

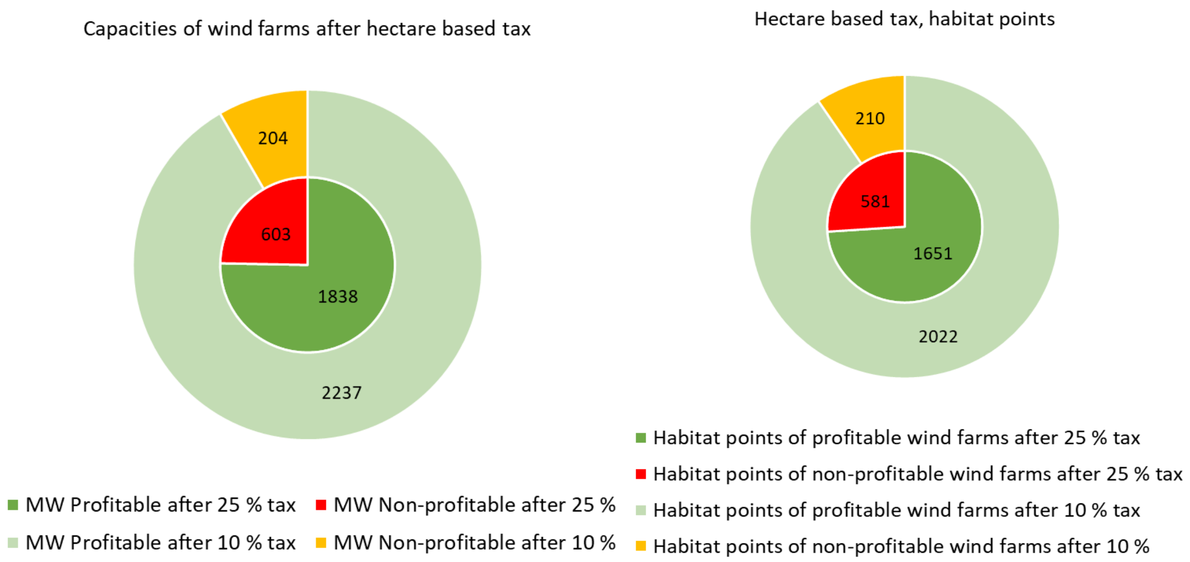

Figure 19. Capacities and habitat points of pre-tax profitable wind farms after the hectare-based (quantity) tax.

As the quality-based tax increased with a higher habitat score, it would be expected that the wind farms made non-profitable would have on average a higher habitat score compared to the quantity-based tax. This was exactly the case, as the wind farms made non-profitable with 25 % quality tax had on average a habitat score of 24.6, which had 27.6 % of the total habitat score. In comparison, non-profitable wind farms under 25 % quantity tax had an average habitat score of 18.7. The average habitat score of a wind farm was also higher under 10 % tax rate compared to the quantity tax, as the average score was 23.8, which was 10.7 % of the total habitat score.

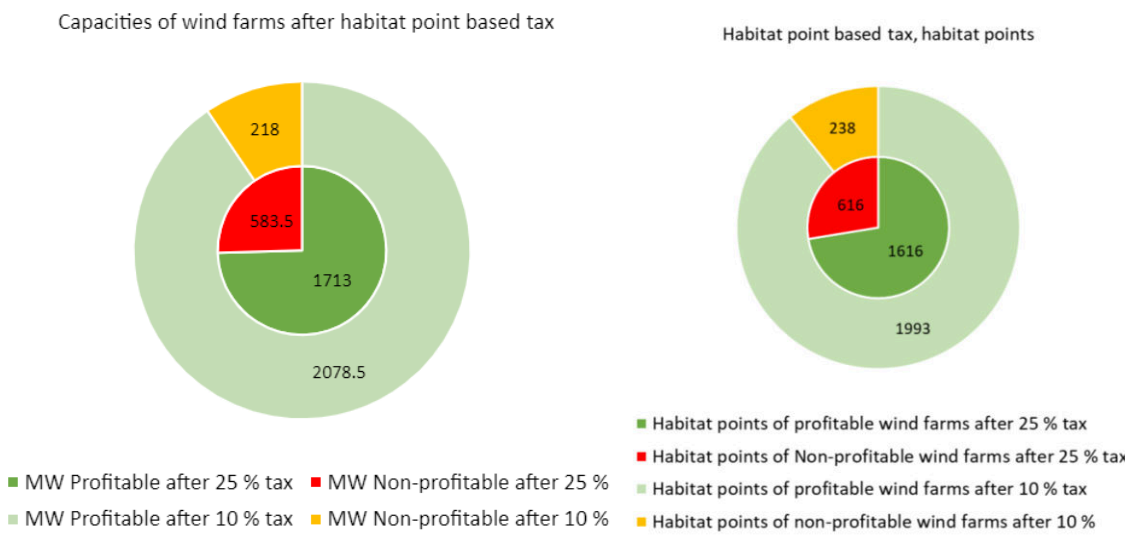

Figure 20. Capacities and habitat points of pre-tax profitable wind farms after the habitat point based (quality) tax.

Out of the 25 wind farms made non-profitable under 25 % quality tax, 23 were also made non-profitable under quantity tax. Under 10 % quality tax, all ten wind farms were also non-profitable under quantity tax. If we look at the farms made non-profitable under 10 % quantity tax, we can see that there is at least some difference between the wind farms made non-profitable. Out of 13 wind farms made non-profitable under 10 % quantity tax, 10 were made non-profitable also under quality tax.There was still a lot of overlap between the taxes, meaning the same wind farms produce the highest habitat impact compared to profit under both indicators. Table about the wind farms made non-profitable under the taxes can be found in the appendices section.

5 Sensitivity analysis

Sensitivity analysis tells us how different values for a specific independent variable effect the model output. For example, if a certain variable has uncertainty, we can test how it contributes to the overall uncertainty of the model. In this case sensitivity analysis was done for the discount rate to see how changes affect the net present value of wind farms. Sensitivity analysis was done using discount rates between 0–7 %. The discount rate used in the thesis was 5.6 %.

The sensitivity analysis shows that the NPV per hectare of habitat displaced increases as the discount rate goes down, mostly because the net present value of yearly revenues decreases as the discount rate increases. For the same wind farm, the largest difference between net present values per hectare of habitat displaced between 0 % and 7 % discount was 24 MEur, and the lowest 170,000 €. Differences between net present values between different discount rates mostly increase as the total NPV of a wind farm increases. If we would assume a tax of 2.59 Meur (25 % quantity tax) would be implemented with different discount rates, out of 140 wind farms, only 10 would be non-profitable after such tax with 0 % discount rate. With a 3 % discount rate 15 wind farms would be made non-profitable after tax, and with 7 % discount rate 64 wind farms would be made non-profitable after tax. With the 5.4 % discount rate used in the thesis, 51 out of 140 wind farms were non-profitable after tax. It should be noted that the scale of the tax would also change if the whole analysis would have been done with a different discount rate.

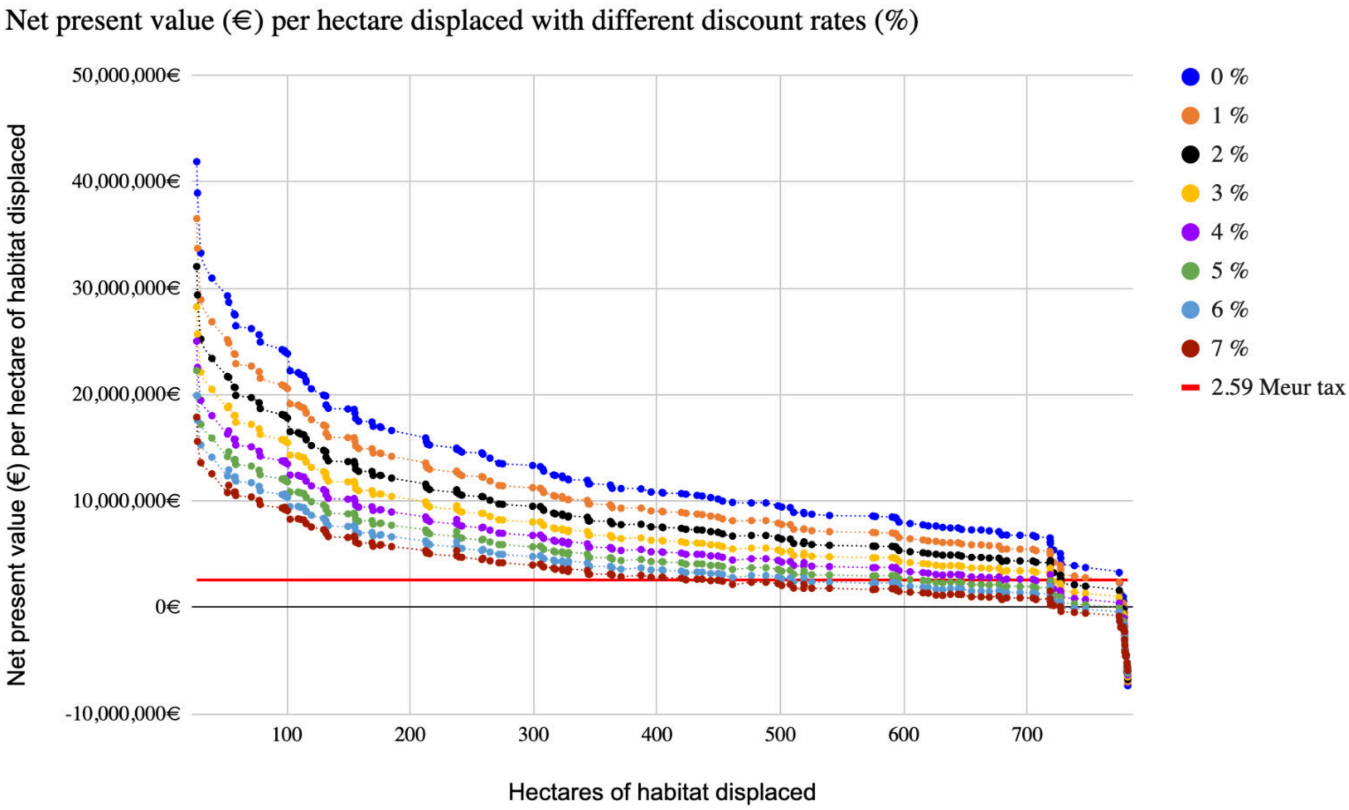

Figure 21. Net present value of wind farms per hectare of displaced habitat with different discount rates with 25 % quantity tax (2,590,000 €) for reference.

6 Discussion

Are wind farms danger to threatened habitats?

Natural terrestrial and freshwater habitats (habitats with code B, C, D, E, G and H) accounted for approximately 7782 hectares of displaced habitat by wind farms in Finland. To give some context to this, in the past 30 years the annual forest loss caused by construction in Finland has been around 10,000 hectares per year (Kärkkäinen et. al. 2019). This means that wind farms displace almost as much natural terrestrial habitat as the annual construction on forest land does, thus the amount habitat loss caused by wind farms is moderately substantial in the bigger picture. Still, it is important to notice that the habitat displacement caused by these wind farms has and will occur over multiple decades.

Overall, most habitat displacement happened in habitats which had a habitat score of 1–2. Some of the level 2 habitats with the highest score (3 or more) such as estuaries (X1), coastal lagoons (X2), valley mires, poor fens, and transition mires (D2), dry grasslands (E1) & Inland saline and brackish marshes and reedbeds (D6) were not displaced at all by wind farms. Also, the habitats with a higher score than three only displaced a small portion of the total habitats displaced, which tells that the most threatened habitats play only a minor role in the overall area displaced. Still, the threatened habitats are also most likely rarer, so even an overall minor displacement of these habitats could be serious threat for them.

There are also more things we should worry about. For level 3 habitats, the score of 3 or more was considered threatened. Level 2 habitats with a score over 3 displaced only 0.5 % of the total habitat. Still, we should be a bit concerned about the results of the thesis. For example, the most common level 2 habitat displaced (coniferous woodland), had two level 3 habitats out of four total habitats included in it, which were considered threatened, even though the total habitat score of the level 2 habitat was only 2. We could think that if the habitat score of level 2 habitat was over one, there was at least one or more threatened habitat included in it, which means that there is some reason to be concerned about the displacement of threatened habitats. This sort of analysis could be improved if more detailed GIS-information about probability of the level 3 habitats was available.

The habitat scoring system gives us one way of understanding the overall picture level of endangerment of the habitats displaced, it is still a flawed system. The artificial habitat scores assigned to each conservation status assume in simplifying fashion the importance of each habitat, and do not consider for example vulnerable local species living in each area. Also, as we do not know which level 3 habitats would be displaced in practice, it can paint distorted picture about the endangerment of the habitats displaced. Another flaw in the methods is the buffer zone used for habitat displaced. Realistically, the area displaced and disturbed is more spread out, thus habitats actually displaced by wind farms might be different, as now they depended on a lot about which habitats happened to be near the disclosed location of the wind farm. To get more realistic picture of the biodiversity effects, figures showing the larger “habitat impact area” could be used to determine more generally which areas are disturbed, or a more sophisticated way to determine the spread of direct habitat impact area could be developed.

Habitat taxes, restoration costs and ways to improve

The hectare-based lump sum tax came in at 1,650,000 € and 2,590,000 € per hectare of displaced habitat for the whole lifetime of the wind farm. If we compare these figures to biodiversity restoration price equilibriums of pine mires and herb rich forests related to biodiversity offsetting estimated by Kangas & Ollikainen (2019), we can see that the taxes are quite high. According to the paper of Kangas & Ollikainen, pine mires restoration buyer prices would range between 8509 €–10,665 € per hectare, while herb rich forest restoration buyer prices would range from 12,533 €–14,667€ per hectare. If a lower tax of 15,000€ per hectare of displaced habitat based on the restoration costs would be applied on the wind farms, none of the profitable wind farms would be made non-profitable after the tax.

The quality-based tax takes the conservation status of the habitats into account, so it would be more suitable for protecting threatened habitats. Quality based tax would be better with the knowledge of level 3 habitats, as we could avoid the issues regarding the scoring system. Still, as mentioned before, the ecosystems of Europe data used in the thesis does not include the information about locations level 3 habitats, thus determining habitat score for each habitat tax this way would not be that viable. As accurate GIS-data for level 3 habitat does not exist, the transaction costs related to this tax would be high, as each habitat would have to be verified by authorities.

For both taxes, more precise results could be produced if more precise data related to wind farms was used. For example, Weibull's distribution could be used instead of Rayleigh's distribution to have less assumptions in the model. More detailed cost functions could be used, as now investment costs were only dependent on the MW of the wind farm and if the farm were offshore or onshore. Things such as distance to roads and electricity grids could be accounted for in the investment costs. Also, things such as wind direction, icing, wind cut-in and cut-out speeds could also be accounted for when calculating the energy production. Upcoming wind farms could also be considered in the future to get a more comprehensive picture about the tax.

Outlook on wind farm locations

Overall, the locations of wind farms could be planned out on a larger scale. For example, Kati, Kassara, Vrontisi & Moustakas (2021) suggest that new wind farm investments could be located in fragmented areas for wind energy to be more sustainable. The thought of wind farm planning is similar to the one Toivanen & Remes (2022) presented in their opinion piece in Helsingin Sanomat, where they suggested that wind farms should be built in constructed habitats, to reduce the impact on natural habitats.

Building wind farms on constructed habitats might bring up other problems. Instead of building wind farms far away from human settlements to natural habitats, building them to degraded or constructed habitats would most likely bring them closer to residential areas. This could bring about other issues, as wind farms can cause negative impacts on humans by causing visual and noise pollution (Saidur et. Al. 2011; Nazir et al. 2019). Finnish law does not have any restrictions on how close wind turbines can be built from housing, but many municipalities have made their own restrictions, most likely to minimize negative impacts on humans, as these negative impacts would increase if wind energy were to be built closer to residential areas. These impacts could be considered as another negative externality of wind energy, as some studies have found that wind turbines near residential areas have decreased the value of houses (Gibbons 2015; Dröes & Koster, 2016; Jarvis, 2021).

One option which would not harm terrestrial habitats would be to build wind offshore wind farms on the sea. Offshore wind turbines would not disturb terrestrial species and would mostly be quite far away from human residential areas. Offshore wind turbines have their own negative (and positive) impacts on biodiversity, which are different from the onshore farms. These impacts might or might not be more severe compared to onshore turbines. There is also still a lack of knowledge about the impacts of offshore wind farms (Kaldellis et. al., 2016). The role of marine habitats and offshore turbines was partly overlooked also in this thesis. More attention could be paid in the future how wind farms interact with marine habitats to get more comprehensive picture on the pros and cons of offshore wind farms.

The negative impacts of every options bring up questions about the trade-offs. Which one is best for society: offshore wind farms, onshore wind farms on degraded habitats near humans or onshore wind farms far away from humans on natural habitats? One way to find this out would be to value the negative and positive impacts of all three options. Realistically, all three options are needed, but there could be some consideration on the general direction of where the future wind farms should be built on, as upcoming wind farms will displace considerably more habitat current wind farms in production.

7 Conclusions

According to the thesis, upcoming and in production wind farms Finland displace approximately 8900 hectares of habitat. Most habitat displaced had a habitat score of 2 (max score 5) according to the habitat scoring system used. This tells us that habitats displaced are not the most endangered, but still caution should be paid to the habitats being displaced, as the scoring system has flaws, and areas disturbed by wind farms larger than the area displaced. Two kinds of taxes (quantity and quality taxes) were calculated which would reduce the habitat impact of wind farms. For both taxes, two rates were calculated, a tax which makes 10 % of wind farms non-profitable and a tax which makes 25 % of the wind farms non-profitable. Quantity taxes were 1.65 Meur (10 %) and 2.59 Meur (25 %) per hectare of habitat displaced and quality taxes were 510,000 € (10 %) and 750,000 € (25 %) per habitat point.

Taxing externalities can be used as a tool to figure out wind farms with least benefits in different types of wind farms. As society tries to minimize the negative impacts of wind farms, we can find some sort of solutions for the green-green dilemma. The taxes calculated in this thesis are larger compared to the restoration costs of habitats by Kangas and Ollikainen (2019), but for the tax to have sufficient effect, it needs to the large enough to influence the economic decisions of wind farm developers. As wind farms are not the only source of habitat displacement, it would be better for habitat protection if a habitat tax would be applied to every kind of land use change causing a loss of natural habitat, just like in the Norwegian ecosystem service tax mentioned earlier. If it were up to the Finnish wind energy developers, they would rather pay for mandatory restoration of habitats than a higher habitat tax proposed in this thesis.

Green-green dilemma is not easy to solve with just taxation. For example, there could also be resistance from the wind energy developers for using taxation to solve the green-green dilemma. A study done in Germany by Voigt, Straka and Fritze (2019) found that members of wind energy sector were the only stakeholders regarding wind energy, that considered wind energy development to be higher priority than biodiversity protection. The wind energy sector also did not see loss of revenue from wind energy production as acceptable, even if the green-green dilemma could be solved. It remains to be seen how Finnish wind energy developers would react to habitat tax type of solutions for the issue, as Finnish wind power industry is used to getting subsidies from the government instead of being taxed.

In this thesis, two scenarios were for the tax were explored. Few outlier wind farms were identified, as wind farms made non-profitable were mostly same under both taxes. This tells that even a simple tax like this could be one way of decreasing overall biodiversity impact of wind farms by eliminating most harmful wind farms that produce only little benefits. Other options for the tax could be a Pigouvian tax, where tax would equal to the cost of negative externality, giving a more economically efficient solutions. If any kind of habitat tax would be implemented in practice, more attention should be paid to which is the desired outcome of the habitat tax, which would most likely affect the scale of the tax. The revenue from the tax could be also used to habitat restoration to increase the positive biodiversity effects of the tax.

Taxation is just one tool for solving green-green dilemma. There are multiple other regulatory, economic, and technical tools that could be used. For example, mandatory habitat restorations could improve overall habitat situation, technical improvements for reducing noise and visual pollution caused by wind turbines could allow us to build more wind farms closer to humans and further away from natural habitats. Even painting wind turbine rotors black could decrease avian fatalities (May et. al., 2020) and help solve the green-green dilemma. All these tools could be used on parallel to make wind farms more biodiversity friendly option for energy generation, while mitigating climate change.

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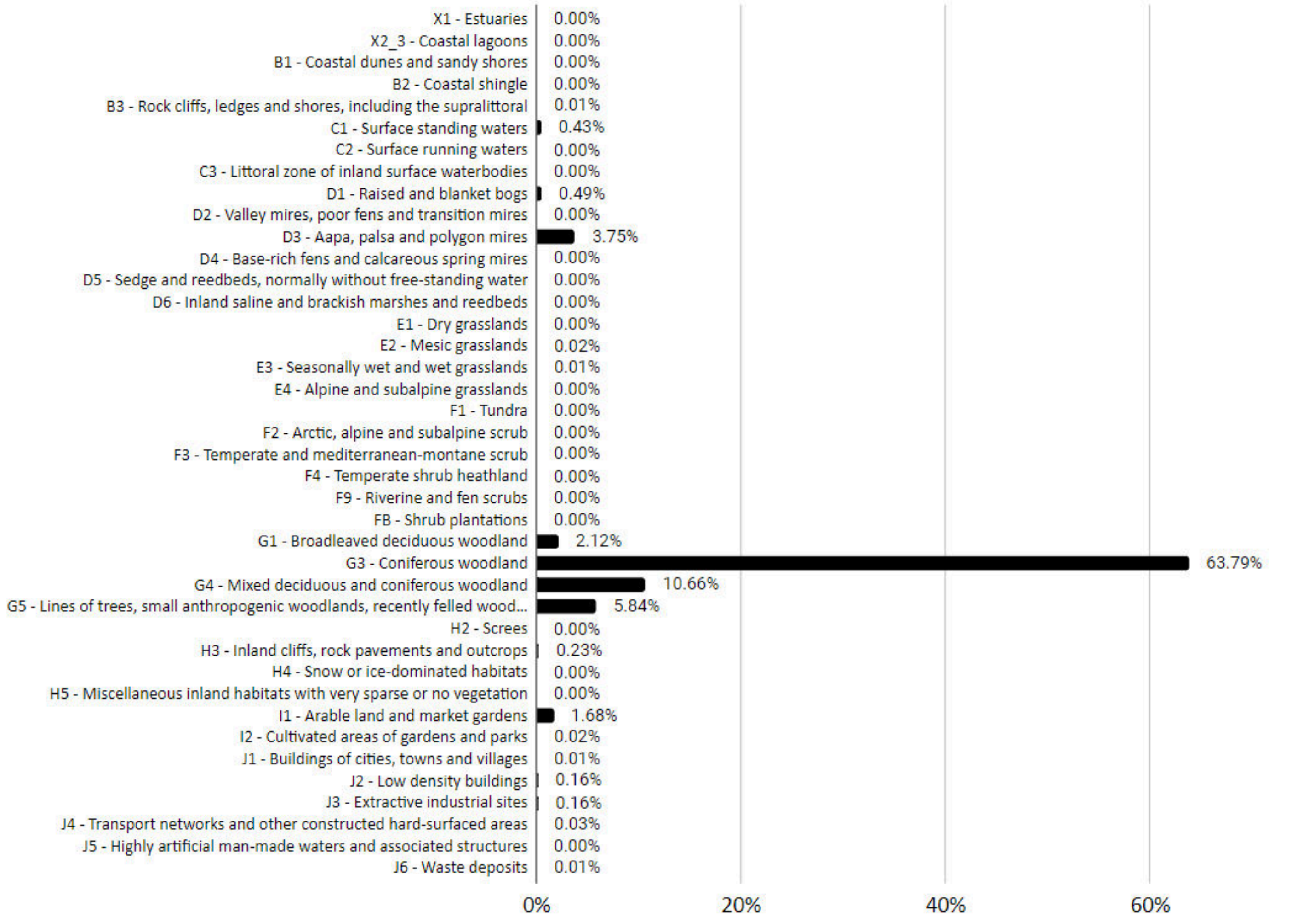
9 Appendices

Appendices 1. Percentages of Level 2 habitats displaced by wind farms in Finland



Appendices 2. Habitat scoring system for level 2 habitats.

EUNIS2007 code	Red List code	EUNIS2020 habitat name *OR* EUNIS2007 habitat name *OR* Red list habitat name	RED LIST EU28 CONSERVATION STATUS	RED LIST SCORE OF LEVEL 3 HABITAT	HABITAT SCORE OF LEVEL 2 HABITAT	HABITAT LEVEL	DETAILS		
B	**B**	**Coastal habitats**				1			
B1	B1	Coastal dunes and sandy shores			2,00	2		**SCORING**	
B1.1; B1.2	B1.1a	Atlantic, Baltic and Arctic sand beach	VU	3,00		3		**RED LIST CATEGORY**	**SCORE**
B1.31; B1.311; B1.321	B1.3a	Atlantic and Baltic shifting coastal dune	NT	1,00		3		CR	5
B1.4	B1.4a	Atlantic and Baltic coastal dune grassland (grey dune)	VU	3,00		3		EN	4
B1.5; B1.51	B1.5a	Atlantic and Baltic coastal Empetrum heath	VU	3,00		3		VU	3

B1.6	B1.6a	Atlantic and Baltic coastal dune scrub	LC	0,00		3		NT	1
B1.7; B1.72	B1.7a	Atlantic and Baltic broad-leaved coastal dune forest	LC	0,00		3		LC	0
B1.7; B1.71	B1.7c	Baltic coniferous coastal dune forest	VU	3,00		3		DD	-
B1.8	B1.8a	Atlantic and Baltic moist and wet dune slack	VU	3,00		3			
B2	B2	Coastal shingle			0,00	2			
B2.1; B2.2; B2.3; B2.4	B2.1a	Atlantic, Baltic and Arctic coastal shingle beach	LC	0,00		3			
B3	B3	Rock cliffs, ledges and shores, including the supralittoral			0,00	2			

B3.2; B3.3	B3.1a	Atlantic and Baltic rocky sea cliff and shore	LC	0,00		3			
D	**D**	**Wetlands**				1			
D1	D1	Raised and blanket bogs			4,00	2			
D1.1	D1.1	Raised bog	EN	4,00		3			
D2	D2	Valley mires, poor fens and transition mires			3,00	2			
D2.2; D2.3	D2.2a	Poor fen	VU	3,00		3			
D2.2	D2.2c	Intermediate fen and soft-water spring mire	VU	3,00		3			

D2.3	D2.3a	Non-calcareous quaking mire	VU	3,00		3			
D3	D3	Aapa, palsa and polygon mires			2,50	2			
D3.1	D3.1	*Palsa mire	CR	5,00		3			
D3.2	D3.2	Aapa mire	LC	0,00		3			
D4	D4	Base-rich fens and calcareous spring mires			3,60	2			
D4.1	D4.1a	Alkaline, calcareous, carbonate-rich small-sedge spring fen	EN	4,00		3			
D4.1	D4.1a	Extremely rich moss–sedge fen	EN	4,00		3			

D4.1	D4.1b	Tall-sedge base-rich fen	EN	4,00		3				
D4.1	D4.1c	Calcareous quaking mire	VU	3,00		3				
D4.2	D4.2	Arctic–alpine rich fen	VU	3,00		3				
D5	–	Sedge and reedbeds, normally without free-standing water			1,50	2				
C3.2; D5.1	C5.1a	Tall-helophyte bed	LC	0,00		3				
C3.2; D5.2	C5.2	Tall-sedge bed	VU	3,00		3				
D6	–	Inland saline and brackish marshes and reedbeds			4,00	3				

D6.2	C5.4	Inland saline or brackish helophyte bed	EN	4,00		2			
E	**E**	**Grasslands and lands dominated by forbs, mosses or lichens**				1			
E1	E1	Dry grasslands			3,33	2			
E1.1	E1.1b	Cryptogam- and annual-dominated vegetation on siliceous rock outcrops	VU	3,00		3			
E1.1	E1.1d	Cryptogam- and annual-dominated vegetation on calcareous and ultramafic rock outcrops	VU	3,00		3			
E1.2	E1.2a	Semi-dry perennial calcareous grassland (meadow steppe)	VU	3,00		3			
E1.7	E1.7	Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta	VU	3,00		3			

E1.9	E1.9a	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	EN	4,00		3			
E1.9	E1.9b	Inland sanddrift and dune with siliceous grassland	EN	4,00		3			
E2	E2	Mesic grasslands			3,00	2			
E2.1	E2.1	Mesic permanent pasture of lowlands and mountains	VU	3,00		3			
E2.2	E2.2	Low and medium altitude hay meadow	VU	3,00		3			
E3	E3	Seasonally wet and wet grasslands			4,00	2			
E3.4	E3.4a	Moist or wet mesotrophic to eutrophic hay meadow	EN	4,00		3			

E3.4	E3.4b	Moist or wet mesotrophic to eutrophic pasture	EN	4,00		3				
E3.5	E3.5	Temperate and boreal moist or wet oligotrophic grassland	EN	4,00		3				
E4	E4	Alpine and subalpine grasslands			1,50	2				
E4.1	E4.1	Snow-bed vegetation	VU	3,00		3				
E4.3	E4.3a	Boreal and Arctic acidophilous alpine grassland	LC	0,00		3				
F	**F**	**Heathlands, scrub and tundra**				1				
F2	F2	Arctic, alpine and subalpine scrub			0,25	2				

F2.1	F2.1	Subarctic and alpine dwarf Salix scrub	NT	1,00		3			
F2.2	F2.2a	Alpine and subalpine ericoid heath	LC	0,00		3			
F2.2	F2.2b	Alpine and subalpine Juniperus scrub	LC	0,00		3			
F2.3	F2.3	Subalpine and subarctic deciduous scrub	LC	0,00		3			
F3	F3	Temperate and Mediterranean montane scrub			0,00	2			
F3.1	F3.1a	Lowland to montane temperate and submediterranean Juniperus scrub	LC	0,00		3			
F4	F4	Temperate (shrub) heathland			3,00	2			

F4.2	F4.2	Dry heath	VU	3,00		3			
F9	F9	Riverine and fen scrub			0,50	2			
F9.1	F9.1	Temperate riparian scrub	LC	0,00		3			
F9.2	F9.2	*Salix fen scrub*	NT	1,00		3			
G	**G**	**Forests and other wooded land**				1			
G1	G1	Broadleaved deciduous forests			1,50	2			
G1.1	G1.1	Temperate Salix and Populus riparian forest	NT	1,00		3			

G1.2	G1.2a	*Alnus glutinosa–Alnus incana forest on riparian and mineral soils*	LC	0,00		3			
G1.4	G1.4	Broadleaved swamp forest on non-acid peat	VU	3,00		3			
G1.5	G1.5	Broadleaved mire forest on acid peat	VU	3,00		3			
G1.8	G1.8	Acidophilous Quercus forest	VU	3,00		3			
G1.9	G1.9a	Temperate and boreal mountain Betula and Populus tremula forest on mineral soils	LC	0,00		3			
G1.A	G1.Aa	*Carpinus and Quercus mesic deciduous forest*	NT	1,00		3			
G1.A	G1.Ab	Ravine forest	NT	1,00		3			

G3	G3	Coniferous forests			2,00	2			
G3.A	G3.A	Dark taiga	NT	1,00		3			
G3.B	G3.B	*Pinus sylvestris light taiga*	LC	0,00		3			
G3.D; G3.E	G3.Da	*Pinus and Larix mire forest*	VU	3,00		3			
G3.D; G3.E	G3.Db	*Picea mire forest*	EN	4,00		3			
G4	–	*Mixed deciduous and coniferous woodland		*Averages of red list scores	1,64	2	*Mixes of possible Forest and woodland habitats habitats		
G4.1	–	Mixed swamp woodland	VU, VU, VU, EN	3,25		3	G1.4, G1.5, G3.D & G3.E		

G4.2	–	Mixed taiga woodland with Betula	NT, LC, LC	0,33		3	G3.A, G3.B & G1.91			
G4.3	–	Mixed sub-taiga woodland with acidophilous Quercus	NT, LC, VU	1,33		3	G3.A, G3.B & G1.8			
G5	–	Lines of trees, small anthropogenic forests, recently felled forest, early-stage forest and coppice			0,00	2				
G5.6	–	*Early-stage natural and semi-natural forest and regrowth		#N/A		3				
G5.7	–	*Coppice and early-stage plantation		#N/A		3				
G5.8	–	*Recently felled areas		#N/A		3				
I	**–**	**Vegetated man-made habitats**				3				

I1	–	Arable land and market gardens			0,00	2			
I1.1	–	Intensive unmixed crops		#N/A		3			
I1.2	–	Mixed crops of market gardens and horticulture		#N/A		3			
I1.3	–	Arable land with unmixed crops grown by low-intensity agricultural methods	EN*	#N/A		3	*Not taken into account		
I1.4	–	Inundated or inundatable cropland, including rice fields		#N/A		3			
I15	–	Bare tilled, fallow or recently abandoned arable land		#N/A		3			
I2	–	*Cultivated areas of gardens and parks			0,00	2			

I2.1	–	*Large-scale ornamental garden areas		#N/A		3			
I2.2	–	*Small-scale ornamental and domestic garden areas		#N/A		3			
I2.3	–	*Recently abandoned garden areas		#N/A		3			
I3	–	Artificial grasslands and herb-dominated habitats			0,00	2			
E2.6	–	*Agriculturally improved, re-seeded and heavily fertilised grassland, including sports fields and grass lawns		#N/A		3			
E1.6	–	Mediterranean subnitrophilous annual grasslands		#N/A		3			
E1.C	–	Dry Mediterranean lands with unpalatable non-vernal herbaceous vegetation		#N/A		3			

E1.E	–	Trampled xeric grassland with annuals		#N/A		3			
E2.8	–	Trampled mesophilous grassland with annuals		#N/A		3			
E4.5	–	*Alpine and subalpine enriched grassland		#N/A		3			
E5.1	–	Annual anthropogenic herbaceous vegetation		#N/A		3			
E5.1	–	Dry perennial anthropogenic herbaceous vegetation		#N/A		3			
E5.1	–	Mesic perennial anthropogenic herbaceous vegetation		#N/A		3			
FA	–	*Hedgerows			0,00	2			

FA.1	–	*Hedgerows of non-native species		#N/A		3			
FA.2	–	*Highly-managed hedgerows of native species		#N/A		3			
FA.3	–	*Species-rich hedgerows of native species		#N/A		3			
FA.4	–	*Species-poor hedgerows of native species		#N/A		3			
FB	–	*Shrub plantations			0,00	2			
FB.1	–	*Shrub plantations for whole-plant harvesting		#N/A		3			
FB.2	–	*Shrub plantations for leaf or branch harvest		#N/A		3			

FB.3	–	*Shrub plantations for ornamental purposes or for fruit, other than vineyards		#N/A		3			
FB.4	–	*Vineyards		#N/A		3			
G5	–	*Tree dominated man-made habitats			0,00	2			
G1.D	–	*Broadleaved fruit and nut tree orchards		#N/A		3			
G2.9	–	*Evergreen orchards and groves		#N/A		3			
G5.1	–	*Lines of planted trees		#N/A		3			
G5.2	–	*Small deciduous broadleaved planted other wooded land		#N/A		3			

G5.3	–	*Small evergreen broadleaved planted other wooded land		#N/A		3			
G5.4	–	*Small coniferous planted other wooded land		#N/A		3			
H, I	H	**Sparsely Vegetated Habitats**				1			
H2	H2	Screes			0,00	2			
H2.1	H2.1	Boreal and arctic siliceous scree and block field	LC	0,00		3			
H3	H3	Inland cliffs, rock pavements and outcrops			0,00	2			
H3.1	H3.1a	Boreal and arctic iliceous inland cliff	LC	0,00		3			

H4	H4	Snow or ice-dominated habitats			3,00	2			
H4.1	H4.1	Snow Pack	VU	3,00		3			
H5	H5	Miscellaneous inland habitats with very sparse or no vegetation			1,00	2			
E4.2; H5.1	H5.1a	Fjell field	NT	1,00		3			
C	C	**Freshwater habitats**				1			
C1	C1	Surface standing waters			1,00	2			
C1.1;C3.4	C1.1a	Permanent oligotrophic waterbody with very-soft water species	NT	1,00		3			

C1.1;C1.2	C1.1b	Permanent oligotrophic Permanent oligotrophic to mesotrophic waterbody with soft-water species	LC	0,00		3			
C1.1;C1.2	C1.2a	Permanent oligotrophic to mesotrophic waterbody with Characeae	VU	3,00		3			
C1.2;C1.3	C1.2b	Mesotrophic to eutrophic waterbody with vascular plants	NT	1,00		3			
C1.4	C.1.4	Permanent dystrophic waterbody	NT	1,00		3			
C1.6	C1.6a	Temperate temporary waterbody	LC	0,00		3			
C2	C2	Surface running waters			2,00	2			
C2.1	C2.1a	Base-poor spring and spring brook	VU	3,00		3			

C2.1	C2.1b	Calcareous spring and spring brook	VU	3,00		3			
C2.2	C2.2a	Permanent non-tidal, fast, turbulent watercourse of montane to alpine regions with mosses	LC	0,00		3			
C2.2	C2.2b	Permanent non-tidal, fast, turbulent watercourse of plains and montane regions with Ranunculus spp	VU	3,00		3			
C2.3	C2.3	Permanent non-tidal, smooth-flowing watercourse	NT	1,00		3			
C3	C3	Littoral zone of inland surface waterbodies			2,40	2			
-	C3.5a	Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation	NT	1,00		3			
C3.5/C.37	C3.5b	Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation	VU	3,00		3			

C3.5	C3.5d	Unvegetated or sparsely vegetated shore with mobile in montane and alpine regions	VU	3,00		3			
C3.1; C3.4	C5.1b	Small-helophyte bed	NT	1,00		3			
C3.1; C3.2	C5.4	Inland saline or brackish helophyte bed	EN	4,00		3			
X2_3	–	Coastal Lagoons*	EN	4,00	4,00	2	HELCOM CLASSIFICATION *		
X1	–	Estuaries*	CR	5,00	5,00	2	HELCOM CLASSIFICATION *		

Appendices 3. Wind farms made non-profitable by both types of habitat taxes. Wind farms highlighted in yellow were made non-profitable under both taxes.

Non-profitable wind farms after habitat score-based (quality) tax **(included in 10 % tax*)**	Non-profitable wind farms after hectare displaced based (quantity) tax **(included in 10 % tax*)**
Haapajärvi, Sauviinmäki	Haapajärvi, Sauviinmäki
Hanko, Sandö*	**Hanko, Sandö***
Huittinen, Huittinen	Honkajoki, Kirkonkallio
Ii, Olhava*	Huittinen, Huittinen
Ikaalinen, Aljonvuori*	**Ii, Laitakari***

Jalasjärvi, Haukineva	**Ii, Olhava***
Kankaanpää, Kooninkallio	**Ikaalinen, Aljonvuori***
Kauhava, Isonnevanmäki	Jalasjärvi, Haukineva
Kristiinankaupunki, Metsälä	Kankaanpää, Kooninkallio
Luhanka, Latamäki	Kauhava, Isonnevanmäki
Merijärvi, Pyhänkoski*	Kristiinankaupunki, Metsälä
Merijärvi, Ristiveto	**Kurikka, Jylisevä***
Närpiö, Öskata	Lappeenranta, Muukko
Pyhäjoki, Silovuori*	Luhanka, Latamäki
Raahe, Annankangas	**Merijärvi, Pyhänkoski***
Raahe, Nikkarikaarto*	Merijärvi, Ristiveto
Raahe, Sarvankangas	**Närpiö, Öskata***
Seinäjoki, Kankaanpää*	**Pori, Reposaari I***
Siikainen, Jäneskeidas	Pyhäjoki, Silovuori
Simo, Halmekangas*	Raahe, Annankangas
Simo, Leipiö*	Raahe, Kopsa I
Simo, Leipiö II	**Raahe, Nikkarikaarto***
Simo, Onkalonperä	Raahe, Pirttiselkä
Simo, Putaankangas	**Seinäjoki, Kankaanpää***
Tornio, Kitkäisvaara*	Siikainen, Jäneskeidas
	Simo, Halmekangas*
	Simo, Leipiö*
	Simo, Onkalonperä
	Simo, Putaankangas
	Tornio, Kitkäisvaara*
	Ylivieska, Pajukoski I