Norwegian University
of Life Sciences

Master's Thesis 2021 30 ECTS
School of Economics and Business

Taxation of Wind Power in Norway

An analysis of possible effects of taxation on resource rent and environmental damages from Norwegian wind power plants

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Acknowledgements

It has been highly interesting to combine economic theory and environmental economics with a current topic and its ongoing discussions. Throughout the work, I have gained a deeper insight and more knowledge about wind power in Norway and both sides of the debate. It will be interesting to continue to follow the discussion and possible settlements with more and deeper understanding.

I would like to thank my main supervisor Knut Einar Rosendahl. His in-depth insights into climate, environmental and resource economics have been advantageous for my work. I am grateful for his great ability to motivate and communicate climate economics throughout my studies in general, and through the work with this thesis in particularly.

Further, I would like to thank my co-supervisor Cathrine Hagem for her valuable advice and useful knowledge from previous research on similar topics related to wind power. I would also like to thank the WINDLAND project and associated project participants for data sources, supervision and guidance, and a lot of useful complementary research. The same goes for Cicero's ENABLE projects for helpful insights and financial support.

Thanks to Stian for support and motivation, as well as helpful discussions and feedback. Lastly, but not the least, I would like to thank a lot of good friends for moral support through these months. Thanks for making the years at NMBU wonderful, filled with great memories, adventures, and bubbles!

Abstract

Wind power production in Norway has increased rapidly over the past decades, and so has the associated discussions related to nature conservation. The dilemmas are substantial, with the growing need of renewable energy, but also a desire to protect pristine nature and wildlife. Today, there is little profitability related to the industry, but with future expectations of both lower cost and higher electricity prices, profitability may increase, i.e., there may be a significant resource rent from wind power production. Based on the encroachment and possible resource rent, both resource rent taxation and environmental taxation may be relevant to consider for Norwegian wind power. A tax on the resource rent is already used for other nature resources in Norway. Environmental taxation related to nature encroachment is not used in Norway, but it has been proposed for several industries. An environmental tax aims to achieve a more efficient level of production and spatial allocation of wind power plants. This paper analyses potential effects of these two tax schemes for wind power in Norway. The analysis uses detailed information about projects holding a license with their respective costs and two scenarios for future electricity prices.

The resource rent tax scheme for hydro power is used as a base, with a tax rate at 37%. With the data set used, a total annual resource rent at 170 million NOK would be generated in the base scenario with production at 3.4 TWh. In the high-price scenario, the annual resource rent would increase to 513 million NOK with production at 8.2 TWh. The environmental tax is divided into a CO_2 tax and an encroachment tax. If a CO_2 tax on emissions is introduced alone, it does not change the total amount of power produced, but it will reduce the profitability for several of the projects. With total environmental taxation, CO_2 and encroachment tax, the production is reduced with 35% and 38% in the base and high-price scenario, respectively. After introduction of environmental taxation, the resource rent is reduced by about 35% in both scenarios. If a resource rent tax is combined with environmental taxation, the resource rent tax income would be reduced, but the total effect is increased tax income, compared to a situation with only resource rent taxation.

The recommendations to draw from this analysis is to work towards environmental taxation on wind power in Norway. For this to be possible, more research is necessary, especially related to valuation and damages from production. A CO_2 tax could be considered as a first step towards full environmental taxation. Further, the resource rent from production should be followed closely, and a tax on this should be introduced when the resource rent gets substantial.

Sammendrag

Vindkraft har økt kraftig i Norge over de siste tiårene, og det har også den tilhørende debatten knyttet til naturvern. Dilemmaene er betydelige, med økende behov for fornybar energi, men også et ønske om å verne uberørt natur og dyreliv. I dag er det lite lønnsomhet knyttet til industrien, men med fremtidige forventninger om både lavere kostnader og høyere kraftpriser kan lønnsomheten øke og det kan bli en betydelig grunnrente knyttet til vindkraftproduksjon. Basert på naturinngrepene og grunnrenten, kan både grunnrenteskatt og naturavgift være relevant å vurdere for norsk vindkraft. En skatt på grunnrente er allerede brukt for andre naturressurser i Norge. Naturavgift relatert til naturinngrep er ikke brukt i Norge i dag, men det har blitt foreslått for flere sektorer. En naturavgift sikter på å oppnå et mer effektivt produksjonsnivå og allokering av vindkraftverk. Denne oppgaven analyserer potensielle effekter av disse to skattesystemene for vindkraft i Norge. Analysen bruker detaljert informasjon om prosjekter som har fått lisens med tilhørende kostnader og to scenarioer for fremtidig kraftpris.

Grunnrenteskatten for vannkraft er brukt som et utgangspunkt, med en skattesats på 37%. Med dataen som er brukt her, vil det genereres en årlig grunnrente på 170 millioner NOK i et basisscenario med produksjon på 3,4 TWh. I et høyprisscenario vil grunnrenten øke til 513 million NOK med en produksjon på 8,2 TWh. Naturavgiften er delt inn i en CO_2-avgift og en avgift på naturinngrep. Dersom CO_2-avgiften er introdusert alene vil ikke produksjonsnivået endre seg, men dette vil redusere lønnsomheten for flere av prosjektene. Med en total naturavgift, CO_2 og naturinngrep, vil produksjonen reduseres med henholdsvis 35% og 38% i basis- og høyprisscenarioet. Etter introduksjonen av naturavgiften vil grunnrenten reduseres med omtrent 35% i begge scenarioene. Dersom en grunnrenteskatt er kombinert med naturavgiften vil grunnrenteskatten reduseres, men totaleffekten er økt skatteinntekt sammenliknet med en situasjon med kun grunnrenteskatt.

Anbefalinger som kan trekkes fra denne analysen er å jobbe mot en naturavgift på vindkraft i Norge. For at dette skal bli mulig er det nødvendig med mer forskning, spesielt relatert til verdsetting og ødeleggelser fra produksjonen. En CO_2-avgift kan vurderes som et første steg i retning av en fullstendig naturavgift. Videre så bør grunnrenten fra produksjonen observeres tett, og en skatt på dette bør introduseres når grunnrenten blir betydelig.

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List of acronyms and abbreviations

CAT	Cap and trade
CBA	Cost benefit analysis
CE	Choice experiment
CO_2e	CO_2 equivalent
CV	Contingent valuation
EU ETS	European Union Emissions Trading Scheme
FOC	First order condition
HP	Hedonic pricing
kWh	Kilo watt hours
LCA	Life cycle analysis
LCOE	Levelized cost of energy
MW	Mega watt
NIMBY	"Not in my back yard"
NPV	Net present value
PMC	Privat marginal cost
SMC	Social marginal cost
WTA	Willingness to accept
WTP	Willingness to pay

1. Introduction

Wind power production in Norway has increased rapidly over the past decades as a source of renewable energy, but the debate related to nature conservation has also been large. The dilemmas are substantial. On one hand, wind power is an important element for transition into renewable energy to reach climate goals such as the Paris Agreement. On the other hand, wind power often includes major encroachments on nature, both for construction of new wind turbines and for supporting infrastructure, such as grid connection. The turbines are visible from far away, something that can destroy the nature experience for many. A new report done by the Norwegian Institute for Natural Research, NINA, finds that only 11.8% of planed or operating wind power plants in Norway meets all four nature-based criterions, and 2% do not meet any of the criterions (Nowell et al., 2020). This gives an indicator of the large nature encroachments from wind power production. The production is related to many negative externalities, and today, these externalities are not paid for by anyone.

Economic theory proposes taxes as one instrument to correct for market failures, such as negative externalities. If an environmental tax were introduced, it could make utility companies pay for their use of the ecosystem services. In this case, an environmental tax would tax the use of natural resources and specific areas, not emissions. With a good environmental tax, firms would be forced to take the external costs into account, and new wind power plants would be located where it is most efficient. Efficiency in this case is related to none or little nature destruction, emissions, impact on wildlife etc. Such a tax could also result in fewer projects, thus reduce the overall encroachment, but this would reduce the renewable power production. An environmental tax on degradation of nature was proposed in a report from Green Tax Commission, but has not yet been implemented (NOU 2015: 15, 2015). Such a tax on degradation of nature could be relevant for wind power. One of the major problems with creating such a tax scheme is the lack of valuation studies on this area in Norway, and large differences in the value of nature from different locations, but this has increased over the past few years.

Recently, wind power plants have been criticised for not emphasising the CO_2 emissions from destruction of areas such as peatland. Most of the projects that have received licenses for production in Norway are in areas with peat, and the reduction in potential carbon sequestration in these areas is not accounted for in the license applications or impact assessments (Helledal et al., 2020). If the bog is punctured it will release CO_2, and the destruction of just a small part can puncture the whole area of peat. A CO_2 tax has been proposed as a first step in the direction of environmental taxation on degradation of nature (NOU 2015: 15, 2015), and could be used as a part of or as a step towards a full environmental tax of wind power.

Wind power is a renewable natural resource, and for many natural resources there exists a resource rent. Resource rent is the extra value added from exclusive ownership (or use) of a natural resource or ecosystem services. A tax on the resource rent has been introduced for hydro power and petroleum in Norway, other natural resources, and might be relevant to evaluate for wind power as well. The additional tax on profit is not intended to affect firms' behaviour, and the same projects will be profitable/unprofitable with and without the tax scheme. Fairness is a good argument for such a tax, as it does not have the same negative impact on incentives as other tax schemes. Until 2020 wind power production has been subsidized and do not earn much extra resource rent. However, with a potential further increased electricity price and reduced investment costs from improved technology, a resource rent and taxation of this could be more relevant. A resource rent tax scheme on wind power could be designed similarly to the resource rent taxation on hydro power and petroleum in Norway, and it could be introduced alone or together with an environmental tax.

1.1. Research questions

In this paper I will study the possible effects of environmental and resource rent taxation on wind power in Norway. The topic is divided into three research question, presented below. I will examine possible effects of the tax schemes separately and combined for different projects and electricity price scenarios. The environmental tax would change the behaviour of firms by prompting them to consider the externalities as well as the existing operating and investment costs. This could make profitable projects less, or not at all, profitable. The resource rent tax would become more relevant when the profitability of the projects increases, either because of technological development and reduced investments costs, or increased electricity price due to increased demand for power and higher CO_2 prices. Increased CO_2 prices give higher cost of fossil fuel-based electricity production, resulting in higher prices in a common electricity market.

Each research question is supplemented by sub questions. These are meant to highlight all parts of each research question. For each research question, one or two of the sub questions are theoretical questions related to the design of the tax schemes and optimality in theory. The last sub question for each research question is related to the numerical analysis and will be analysed using data and simulations. These questions focus on the effects of the different tax schemes, both on each other, the location of the wind power plants and the total production.

The research questions to be studied are as given:

1. Does there exist a resource rent on Norwegian wind power and what would be the effect of a resource rent tax?
    a. How can and should a resource rent tax scheme be designed?
    b. What will the resource rent be under different price scenarios and how large would the associated tax income be?
2. What is the effect of an environmental tax for wind power in Norway?
    a. How should an optimal environmental tax be design for wind power?
    b. How will an environmental tax affect the total power production?
    c. How will an environmental tax affect development of wind power plants and their locations?
3. What is the effect of a tax scheme with both a resource rent tax and an environmental tax on wind power in Norway?
    a. What is the optimal design of the combination of resource rent taxation and environmental taxation?
    b. How will the environmental tax affect the resource rent tax?

1.2. Organization of the thesis

Chapter 2 provides necessary background information and puts the topic in a wider context. This includes an introduction to wind power and the power market in Norway, resource rent taxation and environmental damages. In chapter 3 the theoretical framework is presented, and the theoretical research questions are discussed. Data and methods are presented in chapter 4, before the results are given in chapter 5. The simulations take first resource rent taxation alone, followed by environmental taxation alone, and finally a combined tax scheme is presented. Due to a lot of uncertainty in the assumptions, chapter 6 provides a sensitivity analysis. At the end, chapter 7 gives some concluding remarks and provides recommendations for further work on this area.

2. Background

2.1. The Norwegian power system

A power market differs from other markets because it needs to be an exact balance between how much power is used and how much is produced at all points in time. In 1990, the Norwegian power market was liberalized into a market-based system for production and distribution of power (Cretì & Fontini, 2019). Because of this liberalization, there are many different actors in the production sector of the market. Even though the market is liberalized and there is competition, firms need a production licence for both hydro and wind power in Norway. Whether a project gets a license or not is based on impact assessments.

Today, around 94% of all power production in Norway comes from hydro power and 4% from wind power (NOU 2019: 16, 2019). An advantage of hydro power is that the water can be stored in reservoirs and used to produce power at a later point in time when demand is higher. This flexibility keeps the power market in balance. In contrast, wind and solar power cannot be stored, so the electricity needs to be used immediately, resulting in high production when the wind blows or the sun shines, and low production otherwise. Despite this, the amount of wind power has increased rapidly over past decades. Figure 1 illustrates the development in installed capacity, measured in MW, of wind power and hydro power in Norway from 1997 to 2019.

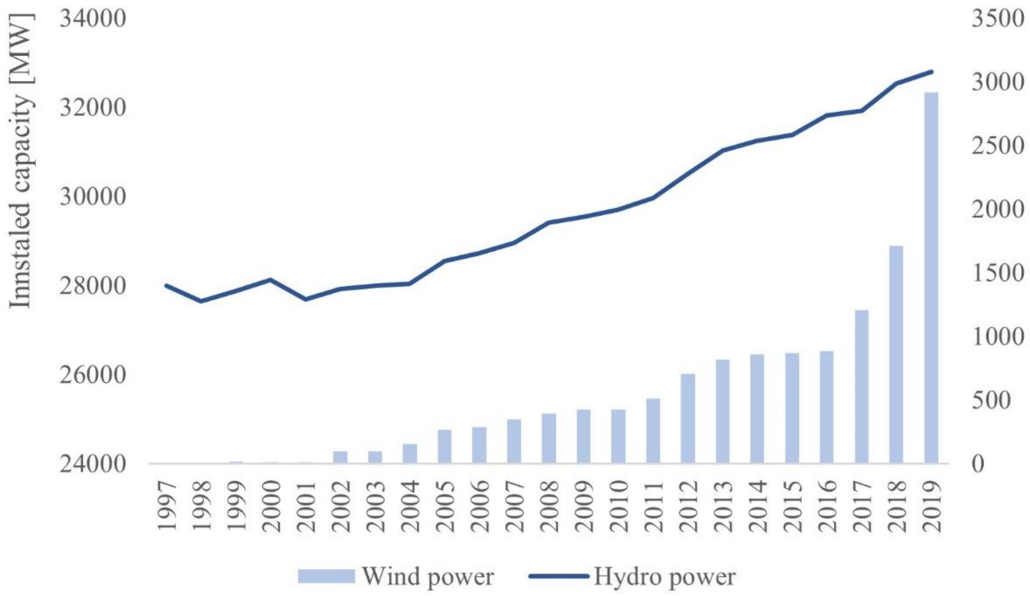

Figure 1: Installed capacity (MW) of hydro power (left axis) and wind power (right axis) (Statistics Norway, 2020a).

The Nordic power market is divided into price zones. The price depends on zone-specific supply and demand. Power can be transported between areas, usually from areas with high production and/or low demand, to areas with lower production and/or higher demand. Transportation between areas is limited by the capacity of the transmission network. If the limit is reached, a bottle neck occurs, resulting in different prices in the different zones. Norway is divided into five such zones, as Figure 2 illustrates.

Figure 2: Price zones in Norway (NVE & Statnett).

The development in new power production in Norway has increased rapidly through the last century. For wind power this is due to the subsidising of renewables through electricity certificates and decreased costs of production from technological development. Electricity certificates is a collaboration between Norway and Sweden where new projects of renewable power can get approved for electricity certificates. With this approval, power plants will receive one certificate per MWh produced over the first 15 years (NVE, 2021d). Power providers are required to buy a given share of their power with electricity certificates. In this way, consumers subsidize renewable energy producers, increasing their profitability with this extra source of income from sale of certificates. In Norway, this system is phased out from 2020, but will still be relevant until 2035, the last year with certificates for producers starting in 2020.

2.2. Development of wind power in Norway

Because of the extensive coastline, Norway has one of Europe's best conditions for wind power production. As Figure 1 illustrated, the installed capacity has increased rapidly over the last years. In 2020, the capacity increased by 60% after 15 new power plants were put into full operation (NVE, 2021a). The total production of wind power in Norway in 2020 was 9.9 TWh, an increase of 80% from the year before (NVE, 2021b). Both the increase in installed capacity and power production gives an indicator of the rapid growth in Norwegian wind power. In Europe, there has also been increased development of offshore wind, and in 2020, the first area in Norway for offshore wind was opened (Ministry of Petroleum and Energy, 2020). Offshore wind could contribute to a further boost in wind power production in Norway from its high energy potential (NVE, 2019b, p. 17).

Together with the increasing trend in the number of wind power plants, there has been productivity growth in the sector, contributing to the increased total production. The productivity growth comes from technological progress with taller turbines and longer rotor blades, giving the possibility to capture more power from one turbine. From this development, a typical turbine built in 2019 is twice as productive as a typical turbine built in 2012 (NVE, 2019a, p. 21). There is ongoing research in this field, and it is expected that the productivity will increase even further from the technological advancements stemming from the research (Ministry of Petroleum and Energy, 2016, p. 161). This research and development contribute to decreasing costs for wind power.

Increasing the number of power plants and increased efficiency is related to the power supply, but it is also expected to be a boost on the demand side. The electrification of Europe and Norway will increase the demand for electricity over the next decades. The Norwegian government presented its climate plan towards 2030 in January 2021. The plan focuses on reduced emissions from sectors outside of the EU Emissions Trading System (EU ETS), especially transport (Ministry of Climate and Environment, 2020). To be able to reach the goals, there will be a large shift from fossil fuels towards electricity from renewable sources. These goals are similar to what is set in the EU, with the Green Deal that focuses on the integration of sustainability in all areas of politics (European Commission, 2020). Increased demand will result in increased prices of electricity, and this together with the increased CO_2 price and increased export of electricity, makes analysts expect the electricity price to increase by 50% by 2030 (Statnett, 2020, p. 28). The increased price together with the decreased costs from technological progress, will increase the profitability and competitiveness for wind power production in Norway.

2.3. Resource rent taxation in Norway

Resource rent is the extra value added from exclusive ownership (or use) of a natural resource or ecosystem services. Today, the resource rent on Norwegian wind power is small, but this will become more relevant in the future. For both hydro power and petroleum, there is a resource rent tax in Norway today, and a resource rent tax for aquaculture has been discussed in recent years. These are all industries that uses public resources exclusively, preventing others from using it.

In Norway, all companies pay a corporate tax at 22%, and a resource rent tax comes in addition to this. For petroleum, the extra special tax is set to 56% (Ministry of Finance, 2020a), giving a total tax on profit at 78%. The reason behind the introduction of this tax was that the petroleum deposits, a scarce resource, belong to the public. Petroleum has the largest tax rate on the resource rent in Norway because of the extraordinary profitability in this industry.

Hydro power is the biggest source of power in Norway, and it has been expanding for the last century. A resource rent tax on hydro power was proposed for the first time in Norway in 1992 (NOU 1992: 34, 1992). The production profits from the use of a common national resource and has done so for a century. In the assessment from 1992, the focus was on hydro power as a national resource that should be taxed and the assessment argued for a flat resource rent taxation to prevent wrong incentives and twisting (NOU 1992: 34, 1992). A resource rent tax on hydro power was introduced in 1997, and is presently set to 37% (NOU 2019: 16, 2019).

A committee proposed in 2019 a similar tax on the aquaculture industry, based on the natural conditions and regulation resulting in resource rent for the producers (NOU 2019: 18, 2019). There exists a natural advantage for this production in Norway, characterized by excellent conditions. The production is also regulated to prevent overproduction, giving an advantage for those with a license. In the report, the authors found extraordinary profit in the sector, indicating that a resource rent exists. The authors recommend taxation of this, based on the principle that the community should get a part of the return on common resources (NOU 2019: 18, 2019). After resistance from the industry, this proposed tax was put on hold, and still is.

Today there is no such resource rent tax for wind power, but it has been proposed (NOU 2019: 16, 2019). With higher profitability from reduced investment costs due to technological progress, combined with higher forecasted electricity prices, a resource rent tax can be relevant for wind power in the years to come.

2.3.1. Details on the resource rent taxation of hydro power in Norway

The resource rent tax on hydro power is designed as an accrued tax, meaning that the investment costs are depreciated over the lifetime of the project. For this tax to be fair and neutral, an uplift is necessary together with other deductions. The uplift will ensure a normal rate of return and is calculated as a risk-free return. This will ensure fully deducted investment costs. In that case, the net present value of the deductions and uplift should be equal to the investment costs (NOU 2019: 16, 2019). Other taxes related to hydro power, like corporate tax and property tax, are deducted before the resource rent is calculated. The calculation of the taxable resource rent on hydro power could be written as:

$$\begin{aligned} \text{resource rent} = {} & \text{spot price} * \text{actual production} - \text{operating costs} \\ & - \text{license fee} - \text{property tax} - \text{deductions} - \text{uplift} \end{aligned} \tag{1}$$

After calculating the resource rent as given in equation (1), the 37% tax is calculated. If the operating costs, tax expenses and deduction exceed the market value of the production in one specific year, the resource rent is negative. As the resource rent tax scheme is designed as a neutral tax, a negative resource rent indicates a negative tax expense. In such a case, the government would need to pay the companies in periods with negative cash flows, as a negative tax (Lund, 2002). If one company owns several power plants, a negative resource rent from one power plant will be deducted from a positive resource rent of another power plant. These deductions and potential negative tax are necessary to obtain a neutral tax scheme.

2.4. Environmental damages from wind power production

2.4.1. Nature encroachment

Building a wind power plant requires large natural encroachments. The Norwegian Environment Agency has estimated that the land use is 2 500 m^2 per MW after covering and restoration (Norwegian Environment Agency, 2019). This gives a total land use of 250 000 m^2 for a power plant with a total effect of 100 MW, equivalent to a squared area of 0.5 km in each direction. This is the size of the used areas, but the licensed area is usually much larger because areas between the turbines and roads are not calculated as land use. Most of the land use related to wind power is roads and infrastructure needed to install and maintain the power plant, together with the actual foundation for the turbine.

The estimated land use is the area with direct impact where vegetation is destroyed over the lifetime of the power plant. In addition to this, the power plant will have impact on the wildlife and visibility in a much larger area. Turbines can be visible in a distance up to 30 km, depending on the terrain in the area (Norwegian Environment Agency, 2019). This can have negative impacts, because it impairs the nature experience for people, especially if it is an area with pristine nature. For wildlife, habitat loss is the largest damage (NVE, 2019a, p. 43-45). In Norway, there is also a large discussion related to grazing and migration areas for mountain reindeer. In addition to the impact on wildlife from the land use, the turbines can have negative impact on bird life from collision with the turbines (Dahl, 2015). Wind power production can also have a negative impact on drinking water, agriculture and noise for neighbours (NVE, 2019a, p. 32).

2.4.2. CO_2 emissions

There are several sources of emissions of CO_2 from wind power plants, even though there are no direct emissions from production. First, there are emissions from the construction and transportation. Scientists has done life cycle analyses (LCA) of the power production, taking the whole life cycle into account. This includes emissions from construction, building, transportation, maintenance, and closure. It is estimated that, from a life cycle perspective, wind power production has emissions of 3-46 gCO_2/kWh (NVE, 2019a, p. 85-86). For comparison, coal power has a carbon footprint of around 1000 gCO_2/kWh while gas power has a carbon footprint of around 500 gCO_2/kWh. The factors that influence the footprint the most for wind power are transportation of turbines and concrete production (NVE, 2019a, p. 85-86).

Emissions from construction is one part of the LCA, but the largest source of emissions from wind power plants is related to emissions from bog and peatland, a source that is little emphasised in Norway today. Scientist are concerned that the expected savings in emissions from a switch from fossil fuel towards wind power is offset by the increased carbon losses (emissions and loss of carbon storage) associated with the development and construction of wind power plants (Nayak et al., 2010). The carbon loss from development of wind power is related to peat removal and changes in drainage, both from turbine foundation and roads. Nayak et al. (2010) calculated that the loss in storage of greenhouse gasses can be between 9% and 34% of the emission savings from renewable energy, dependent on the management. More recent research by Smith et al. (2014) shows that most constructions and projects located in peatland sites will give negative carbon saving. The new findings are related to updated emission factors with less carbon savings towards 2050, when fossil fuels will take a minor proportion. The research implies that the savings from use of renewable energy is offset by the loss from destruction of peatland.

Nayak and Smith's research are from Scotland, but there are many similarities to wind power in Norway. Most of the projects holding a license for production in Norway are in areas with bog and peatland (Helledal et al., 2020). These areas are not in conflict with agriculture, have good wind potential and are located further away from residential areas. It is estimated that around 950 million tons of CO_2 is stored in the Norwegian peatland (Grønlund et al., 2010). The emissions if these areas are destroyed can be large.

3. Theory

3.1. Levelized Cost of Energy (LCOE)

Levelized Cost of Energy is an indicator of total unit cost, including both capital and operating costs. This is used to measure competitiveness and profitability for renewable energy projects (Cretì & Fontini, 2019, p. 312-313), and it gives an indicator on the constant electricity price that is necessary to make the project profitable. The LCOE can be written as:

$$\mathrm{LCOE} = \frac{\sum_t \left[\frac{(\mathrm{Capital\ Expenditure})_t}{(1+\mathrm{r})^t} + \frac{(\mathrm{O\&M})_t}{(1+\mathrm{r})^t} + \frac{(\mathrm{Fuel\ Costs})_t}{(1+\mathrm{r})^t}\right]}{\sum_t \frac{\mathrm{Q}_{i,t}}{(1+\mathrm{r})^t}} \tag{2}$$

Where $t = 1, \ldots, T$ denotes the year over the lifetime, T. For wind power plants the lifetime is usually set to 25 years (NVE, 2015). r is the discount rate and $Q_{i,t}$ is the electricity sold in the market in period t. The numerator includes the total discounted cost of the plant, while the denominator is the overall quantity of electricity that can be sold, also discounted. The costs consist of the capital expenditure, fixed and variable operations and maintenance costs (O&M) and fuel costs. For wind power, the fuel cost can be excluded. Wind power also has small variable O&M costs, and the capital cost is the most important one (Cretì & Fontini, 2019, p. 312-313). The estimated LCOE represents the cost per kWh from building and operating the plant over the lifetime. To be able to more easily assess each cost item, equation (3) gives the same LCOE expression but divided into each cost item and excluded fuel costs. The capital expenditure is the investments done in $t = 1$ and these would need to be divided out on all production over the lifetime, discounted. The O&M costs occurs each year, and when this fraction is divided by the production, both being discounted, the discounting is zeroed out.

$$\mathrm{LCOE} = \frac{\text{Capital Expenditure}}{\sum_t \frac{Q_{i,t}}{(1+r)^t}} + \sum_t \frac{\mathrm{O\&M}}{Q_{i,t}} \tag{3}$$

3.1.1. Discount rate

The discount rate of the calculation is an important element, both in the calculation of the LCOE, and other NPV calculations. It is important to be able to compare costs and benefits in different time periods, and for calculation of LCOE specifically, discounting is useful for evaluating all future costs and production. The discount rate is especially important for capital intensive production, such as wind power, where a large share of the costs are investments in capital before production begins. One approach to decide on a discount rate for the calculation is to use the market rate the firms are facing, as the discount rate on their debt. This approach illustrates firms costs of financing, for example the discount rate they need to pay on a loan to finance the capital investments.

The choice of discount rate depends on the purpose of the analysis. In this case, the purpose of calculating LCOE is to observe the market behaviour under new policies and tax schemes. For this, the market interest rate is most relevant to use, as this is the interest rate the firms use themselves, to reflect the required rate of return. The rate of return includes a risk-free rate of return combined with a risk premium related to the project. In the Norwegian power sector, a market rate at 6% is recommended by Ministry of Petroleum and Energy (2016). In the calculations of LCOE to observe market behaviour, this discount rate will be used.

If the purpose were rather to evaluate the LCOE from a societal perspective the choice of discount rate would be different. A societal perspective could for example be a costs benefit analysis (CBA) of wind power as government measures. The Norwegian Ministry of Finance have made a guidance for CBA in Norway. CBA takes both future costs and benefits for the society into account when evaluating projects. In the guidance, they provide a risk adjusted discount rate, given in Table 1.

Table 1: Discount rate for government measures in Norway (Ministry of Finance, 2014).

	0-40 years	40-75 years	After 75 years
Risk adjusted discount rate	4.0%	3.0%	2.0%

For wind power with a 25-year time horizon, a discount rate of 4% is recommended from the guidance (Ministry of Finance, 2014). This discount rate will be used in discounting in the societal perspective, like discounting of future valuations of damages and NPV of tax income.

The choice of discount rate will affect the profit assessment of projects. An increased discount rate will decrease the profitability of the project, and opposite for a decreased discount rate. This difference will be evaluated further in a sensitivity analysis in chapther 6.2.

3.2. Resource rent taxation

In nature-based industries, there is often an extraordinary profitability related to scarce resources and varying conditions. The purpose of a tax on this resource rent is to capture some of the profit related to the use of a common good, without affecting the firms' behaviour. This is illustrated further below. Resource rent taxation was at first highly discussed in the 1970s. At that time, a lot of the research was related to mining and resource rent from minerals (Campbell & Lindner, 1983). How much of the resource rent that should be taxed and what the tax rate should be are the most discussed questions (Land, 2008). There is not one good answer to this, and it varies between industries and countries. One important factor and argument for taxes in general is the neutrality, meaning that the tax should not affect the decisions on investment, production, or trade. This is the case for a resource rent tax, a tax deducted from the profit (Garnaut, 2010).

In the 1990s, Norwegian tax authorities were searching for a viable tax system for hydro power. Amundsen et al. (1992) proposed the introduction of a resource rent tax on hydro power, instead of the existing percentage electricity tax. The arguments for this taxation are the neutrality, sensitivity to economic rent generated and ease of implementation, in theory. The same arguments could be valid for wind power production.

The main purpose of a resource rent tax is to increase public revenue to be able to finance public goods and services. No one should be able to enrich themselves on common resources, and with a tax on the resource rent the distributional aspect is valued. A tax on profit, like the corporate tax or resource rent tax, will not change firms' behaviour. This presupposes that they keep some profit equivalent to or greater than their required rate of return. In Figure 3, the blue area illustrates the resource rent from production. Because wind power production is a part of a larger power market, the demand, D, is horizontal and equal to the price. S is the supply of wind power, here illustrated by installed capacity. The supply is increasing, because as the electricity price increases, the quantity will increase as well, more capacity will be installed if the price is higher. The tax will reduce the after-tax profit for the firms, the size of the blue area, but production at Q' will still maximize profit. In contrast, a tax on emissions will change behaviour into sectors or products with less impact; however, this is one of the intentions with an emission tax.

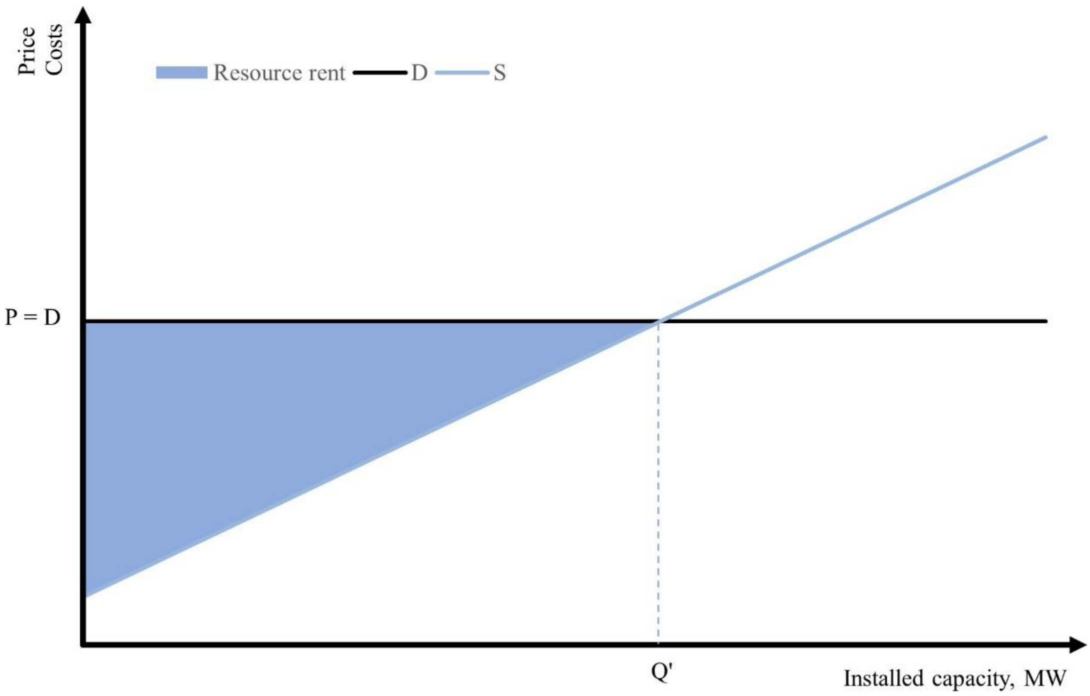

Figure 3: Resource rent from installed capacity.

Today, there is little research related to resource rent taxation of wind power. Skalka (2008) propose a resource rent tax on wind power in Vermont, instead of a tax on production. The tax on production does not encourage increased production, and it argued that Vermont should encourage the production of renewable energy. In that sense, a resource rent tax on profit is more efficient. The article proposes a progressive tax, with increased tax rate for increased profit. This is different from the existing tax schemes on resource rent in Norway, with a flat tax rate for both hydro power and petroleum. A public committee proposed in 2019 to consider a resource rent tax on wind power in Norway, with expectations of decreasing costs and increasing electricity price (NOU 2019: 16, 2019). In the report, a neutral resource rent tax on wind power is proposed for similar reasons as for hydro power, but they recommend further assessment on this area.

3.2.1. Behavioural response to resource rent taxation

Resource rent taxation is a tax on profit and one of the goals is that the behaviour of the companies is unaffected by the tax. This implies that the firm chooses the same production with and without the tax, when maximizing their profit. The following example will illustrate this. In a simplified example, the production of wind power consists of input of two goods: capital, x_1, and an area, x_2. The two inputs have a given input prices at w_1 and w_2, equivalent to the price of capital and property prices, respectively. The output produced, y, is a function of the two inputs, $y = f(x_1, x_2)$ and the market price of the output is p. Because the end product from wind power production is sold in a common market for power, the electricity price is assumed constant and not affected by the amount of wind power production. The firm wants to maximize profit, π, with an optimal combination of the two inputs, given the maximization problem:

$$\max_{x_1,x_2} \pi = pf(x_1, x_2) - w_1x_1 - w_2x_2 \tag{4}$$

To solve this, the first order condition (FOC) is used by taking the partial derivative with respect to x_1 and x_2 and this is set equal to 0.

$$\begin{aligned} \frac{\partial \pi}{\partial x_1} &= p\frac{\partial f(x_1, x_2)}{\partial x_1} - w_1 = 0 \; \rightarrow \; pMP_1 = w_1 \\ \frac{\partial \pi}{\partial x_2} &= p\frac{\partial f(x_1, x_2)}{\partial x_2} - w_2 = 0 \; \rightarrow \; pMP_2 = w_2 \end{aligned} \tag{5}$$

The partial derivative of the production function, f, with respect to x_1 is the marginal product of factor 1, MP_1, and similar for input 2. Optimal level of the two inputs is where the value of the marginal product equals the cost of one extra unit of input.

Now, a resource rent tax is introduced, and the firm needs to pay a tax, t, on its profit. The new, after tax maximization problem is:

$$\max_{x_1,x_2} \pi = (1-t)\pi' = (1-t)(pf(x_1, x_2) - w_1x_1 - w_2x_2) \tag{6}$$

The FOC gives:

$$\frac{\partial \pi}{\partial x_1} = (1-t)\left(p\frac{\partial f(x_1,x_2)}{\partial x_1} - w_1\right) = 0$$
$$\frac{\partial \pi}{\partial x_2} = (1-t)\left(p\frac{\partial f(x_1,x_2)}{\partial x_2} - w_2\right) = 0 \qquad (7)$$

Solving this gives the optimal solution:

$$(1-t)pMP_1 = (1-t)w_1 \;\rightarrow\; pMP_1 = w_1$$
$$(1-t)pMP_2 = (1-t)w_2 \;\rightarrow pMP_2 = w_2 \qquad (8)$$

From the calculation, the result is equal in equation (5) and (8). Firms will choose the same optimal solution after the introduction of the resource rent tax, as they did before. This would not be the case if, for example, a tax on production was introduced. The effect and behavioural response of a production tax is illustrated in Appendix 1. The example in the appendix illustrates that a tax on production would change the optimal solution and firms' decisions, while that is not the case for the resource rent tax.

3.2.2. Challenges with implementation of resource rent taxation

A resource rent tax is neutral and does not affect firms' behaviour, as illustrated by the optimization problem. Profitable projects before the tax scheme are also profitable with the tax, and likewise, unprofitable projects before the tax scheme are not profitable with the tax. Because of this, the tax scheme could seem easy in theory. This neutrality illustrated here is an important, but discussed element related to resource rent taxation, making it more difficult in practice. Some of the difficult elements related to resource rent taxation on hydro power were discussed in chapter 2.3.1, with both negative resource rent, deductions, and uplifts. For example, if one firm has large deductions and uplift, the taxable profit can become negative in one given year. When a negative profit is multiplied with a constant tax rate, the tax expense becomes negative as well. In that case, the firm will receive a tax compensation, rather than paying resource rent tax. Conditions related to neutrality, deductions and uplifts are necessary, but can lead to problems if the premises are wrong.

The Norwegian petroleum tax scheme has been criticised for having too large deductions and ending up subsidising the Norwegian petroleum sector. After new regulations in 2020 related to the decline in oil price and the Coronavirus pandemic, the deduction and postponed tax expense is expected to give incentives to invest in petroleum projects that would have been unprofitable without the resource rent tax scheme (Lund, 2020). This is just one example of complex discussions and possible problems related to resource rent taxation in Norway.

In Norway, the resource rent tax comes in addition to the regular corporate tax, both for petroleum and hydro power. This combination makes it hard to get an all-neutral resource rent tax. The level of the uplift is also discussed for hydro power. Without the uplift, the tax will not be neutral when the uplift reflects a risk free return (NOU 2019: 16, 2019). Most of the resistance towards a resource rent taxation on aquaculture industry was related to loss of new investments. Osmundsen et al. (2019) argued that the uplift in both hydro power and petroleum is too low, and a similar tax on aquaculture would slow down new investments. As the discussions have demonstrated, it is important to design a neutral tax; however, neutrality can be difficult to balance.

3.3. Environmental taxation

Polluter pays principle (PPP) is the principle where those who pollute (or use natural resources) pay all the related costs. This is the principle behind an environmental tax, where the goal is to transfer the costs of the pollution or use over to the polluter. Negative externalities are the common threads for all cases where environmental taxation could be useful. Externalities are costs not paid for by the producers, like pollution or destruction of pristine nature (Perman et al., 2011, p. 121-129).

A tax on externalities, like environmental taxation, can often meet opposition in the population. A lot of this opposition is related to the invisibility of the costs, and that much of the damages occur later in time. One of the factors of success to these taxes is shown to be beliefs about environmental consequences, when the polluter understand the damages related to the action (Kallbekken & Sælen, 2011). Today, the most common forms of environmental taxation are fuel taxation and other taxes aiming to reduce air pollution. With increased focus on pollution and research related to this, the common understanding about emissions from fuel and other sources has been strengthened, making the tax schemes more successful. Research on the effect of environmental taxes on air pollution in the EU and Norway suggest a negative relationship between these, where increased tax reduces the pollution (Morley, 2012).

Taxes and fees to preserve biodiversity is another form of environmental taxation. This is scarcely used in Europe and in the rest of the western world, but the scope and size varies (Eco logic, 2006). These instruments are useful tools to limit damage to existing biodiversity, similar to the goal in the case of wind power. Because of the limited use of such taxes, the related science is also limited, but the theoretical arguments propose the use of it.

An environmental tax on wind power was proposed by the same committee who proposed a resource rent tax on wind power in Norway. The report does not provide a clear framework for a potential environmental tax system (NOU 2019: 16, 2019). The Green Tax Commission proposed a general environmental tax on nature encroachment in 2015, but the valuation was still an unknown question making taxation difficult (NOU 2015: 15, 2015). A tax on nature encroachment in general could also include wind power construction or production. An environmental tax on wind power has been proposed several times, but a clear framework is still missing.

Grimsrud et al. (2020) try to create an environmental taxation scheme for wind power in Norway. The goal of such a tax scheme is an efficient spatial distribution of new wind power production when both production and environmental costs are accounted for. In the analysis Grimsrud et al. (2020) assume a given level of desired wind power production and use subsidies together with the tax to achieve this level. In their analysis, they use an environmental cost for turbines, local power lines and transmission lines for both local and national population. The environmental cost of the wind power plant is calculated dependent on the number of households in the municipality, giving the use value of the area. The non-use value is calculated using national population, making this equal for two projects of same size, with different locations. A weakness with this approach is that the valuation is highly dependent on the size and population of the municipality. This might not consider the value of a more pristine area in a municipality with few households.

3.3.1. Optimal environmental taxation for wind powers

Projects with negative externalities have greater total economic costs than the private costs the firms consider in the project planning. Today, this value is not paid for by the firms, and therefore, it is not considered in their profit assessment. In such a case, the project can be profitable for the firm, but not for society. This is illustrated in Figure 4, where PMC is the private marginal cost or the cost the firms consider, while SMC is the social marginal cost including externalities. The graph illustrates total installed capacity (MW) from all wind power plants on the horizontal axis, and the electricity price and costs on the vertical axis. It is assumed a constant relationship between investments in installed capacity and the firms' production, by the linear graphs. SMC and PMC are assumed parallel, where the increasing trend is related to increased PMC, and the external cost is equal over all levels of capacity. As the graph illustrates, firms will install capacity at Q’, greater than the optimal one at Q*, because firms do not consider the externalities.

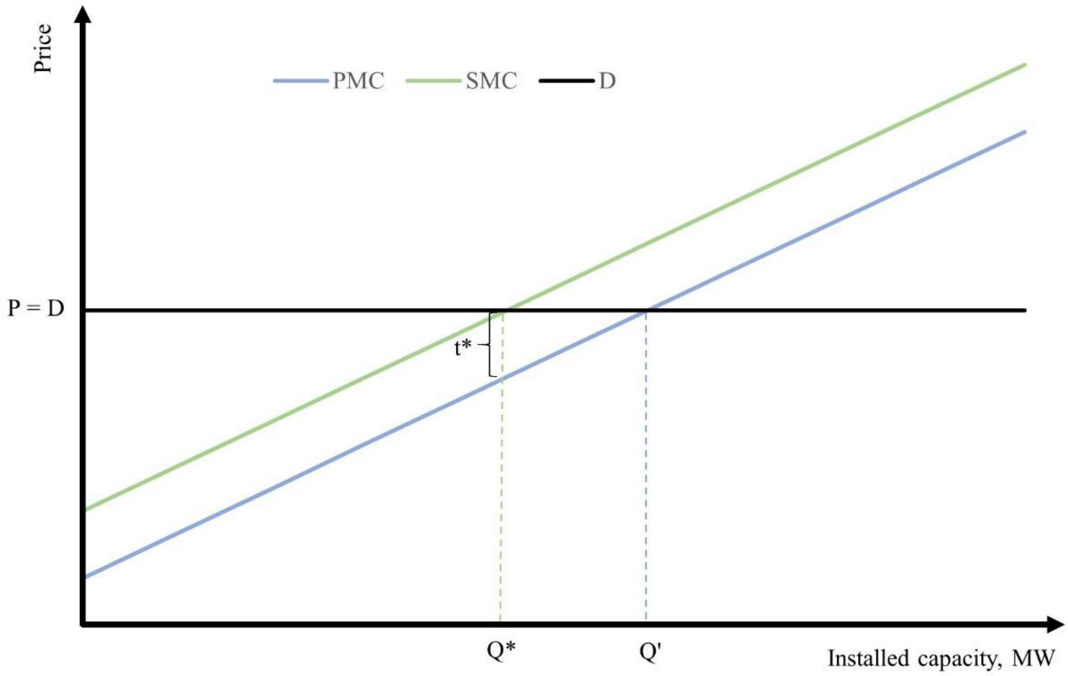

Figure 4: Private vs. social cost.

A Pigouvian tax could be a useful tool to correct such a market failure. This is a tax directly related to the externalities. If an environmental tax were introduced on the polluter at an appropriate rate, the market equilibrium would shift to the fully efficient equilibrium (Perman et al., 2011, p. 165). Going back to Figure 4, an optimal Pigouvian tax would be equal to the difference between PMC and SMC at Q*, illustrated as t*. In such a case, the marginal cost for the firm would move to the SMC curve, and the total wind power production would decrease, to the optimal level at Q*.

Figure 4 is a simplified model to illustrate private and social marginal costs. In reality, PMC and SMC would most likely not be parallel nor linear. One could expect the external cost to be increasing rather than constant, making the SMC steeper so that the difference between PMC and SMC would increase. This expectation is related to the low-hanging fruit principle, where the most accessible or non-protected areas are used first. After these areas are used for wind power, firms would need to turn to more protected areas or areas with more pristine nature, increasing the external costs.

3.3.2. Behavioural response to environmental taxation

An environmental tax will affect firms differently, depending on their nature encroachment. From the optimization problem without any tax schemes in equation (5), firms will choose inputs where the value of the marginal product of one factor equals the marginal cost of this input:

$$\begin{aligned} pMP_1 &= w_1 \\ pMP_2 &= w_2 \end{aligned} \tag{5}$$

When an environmental tax is introduced, the optimization problem in equation (4) is extended to a new optimization problem:

$$\max_{x_1, x_2} \pi = pf(x_1, x_2) - w_1 x_1 - w_2 x_2 - tz(x_1, x_2) \tag{9}$$

Where t is the tax rate related to the environmental tax and z is the nature encroachment and destruction of pristine nature as a function of the two inputs. The destruction is related to both inputs, but in this case, it is expected to be greater for x_2, the area. If the area is increased, the encroachment increases too. The FOC gives:

$$\begin{aligned} \frac{\partial \pi}{\partial x_1} &= p\frac{\partial f(x_1, x_2)}{\partial x_1} - w_1 - t\frac{\partial z}{\partial x_1} = 0 \\ \frac{\partial \pi}{\partial x_2} &= p\frac{\partial f(x_1, x_2)}{\partial x_2} - w_2 - t\frac{\partial z}{\partial x_2} = 0 \end{aligned} \tag{10}$$

Solving this gives:

$$\begin{aligned} pMP_1 - t\frac{\partial z}{\partial x_1} &= w_1 \\ pMP_2 - t\frac{\partial z}{\partial x_2} &= w_2 \end{aligned} \tag{11}$$

The firms' decision is not only related to the value of the marginal product and the marginal cost of the input. The decision is also related to the marginal encroachment or marginal destruction from an extra unit of input used together with the tax rate on this. If one of the inputs is related to large nature encroachment or destruction of pristine nature, as the area is in this case, the firm will choose a different combination than before, to reduce the new tax expense.

Different combination of the two inputs for wind power can be a smaller area with fewer turbines but increasing the capital investment by increasing the size of the turbines. In that way the power plant can be able to produce the same amount of power with less encroachment. There will be a tax increase related to increased capital and larger turbines, but this increased tax expense is likely lower that the tax reduction from minimizing the area. The marginal destruction may vary between firms, related to the location, landscape and wildlife in the area. Firms with higher tax expenses because of large marginal destructions, might not even be profitable after introduction of the environmental tax scheme, making some projects withdraw or shut down.

3.3.3. The effect on the Norwegian power market

An environmental tax on wind power will not only affect wind power production, but the whole power sector, competing in a common market for power. Supply and demand for power is illustrated in Figure 5. Supply is divided into wind power and other sources of power production. This is a simplified illustration of the Norwegian power market where trade with other countries is excluded. Before an environmental tax on wind power is introduced, the price in the power market is $P(0)$, where total supply equals demand. The environmental tax will affect firms' production costs of wind power and move the supply to the left, to the dotted line. As wind power is a part of the total power production, this will also move the total supply to the left. The new price in the power market is $P(1)$, with lower total power production. With a higher price and everything else equal, the production from other power sources than wind, will increase. Due to this increased production from other power sources, the reduction in total power production is less than the reduced production of wind power.

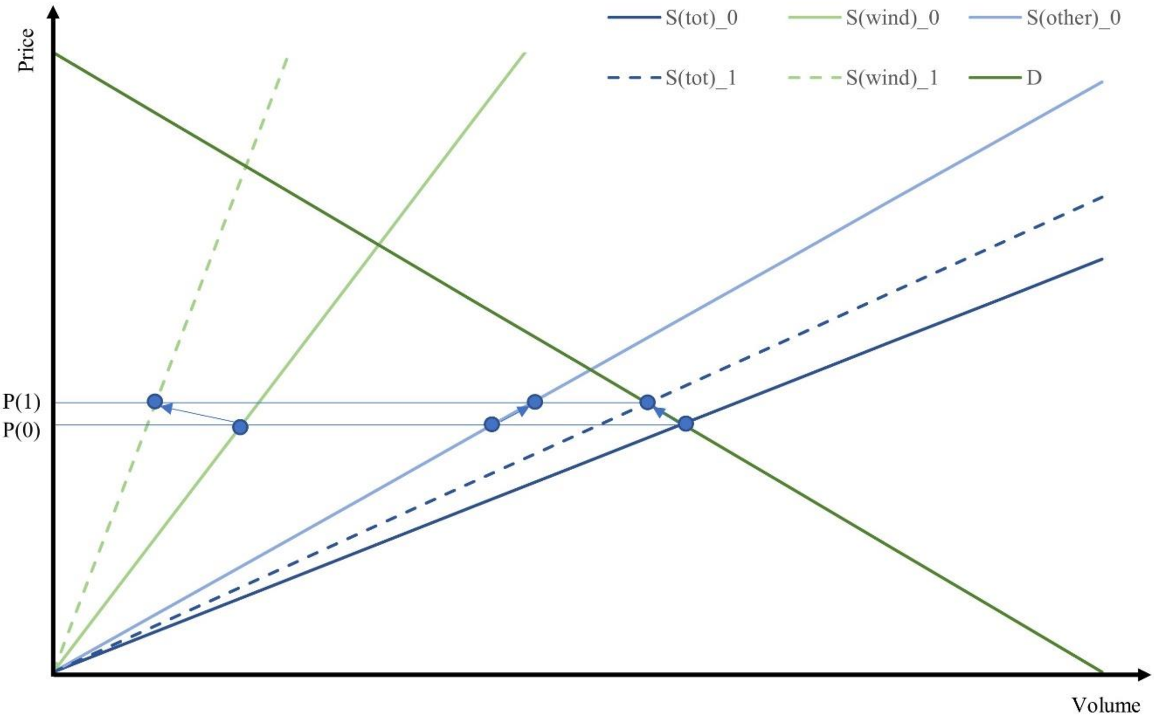

Figure 5: Total power supply and demand.

Overall, the environmental taxation will reduce production of wind power and total power production and consumption. The reduction in wind power is greater than the reduction in total power production. The price in the market will increase, leading to higher production of power from other sources.

If this simplified model were to be expanded to include trade between Norway and other countries, there are two possible outcomes related to transmission capacity. If the transmission capacity is constrained, the model will be quite similar to Figure 5 with trade included. It is not possible to increase import (or decrease export) because of constrained capacity, and the price in Norway will increase compared to other countries. On the other hand, if the capacity is not constrained, the price in Norway is affected by the prices in the other countries. The reduction in wind power production after introduction of the tax scheme, will result in increased import (or decreased export), rather than increased production from other power sources in Norway. In this case the price in Norway will remain quite equal to the price in other countries and the total production in Norway is reduced as much as the reduced wind power production.

3.3.4. From "optimal" to reality

The optimal environmental tax as described above is hard to implement in practice. This "first-best" option requires knowledge of both damages and costs to set an appropriate and correct rate. “First-best” pricing is also hard to combine with multiple market failures, because all the focus is on one specific failure to correct (Perman et al., 2011, p. 129-130). In the real world, the economy consists of many market failures at the same time, such as monopolistic markets, lack of transparency, and distortionary taxes. For example, previous research has indicated that the optimal environmental tax rates are below the Pigouvian tax in presence of distortionary taxes (Bovenberg & Goulder, 1996). These complications make it hard to design and introduce one optimal environmental tax.

In discussions and design of environmental taxes, another large issue to obtain the optimal tax rate is the valuation. The goal with an environmental tax is to make the polluter pay; how much they should pay is the question. To impose a correct tax, a lot of information is required. This includes information on the devastation in the landscape and the value of these devastations. The concern related to valuation of damages for wind power is discussed further in the next chapter.

3.4. Valuation of damages

3.4.1. Valuation of nature and encroachment

Destruction of pristine nature has a value for many. The value is related to both the possibility to use the area, the idea of pristine nature, and visibility in the landscape. For people living in the same area as the wind power plant, this area might be an area for outdoor activities. Either the area is used for skiing, hiking, grazing for reindeer or other things, this has a use value for those people. For people living nearby, the visibility and noise from the wind power plant could also reduce their quality of life.

People living further away might not have a use value off that specific area, but for many, it has a non-use value. This is the value assigned to goods even if the person never have or never will use the area (Tol, 2014, p. 76-80). For example, many Norwegians valuate that there is a lot of pristine nature in the country. Together with the use and non-use value for people, the areas also have a value when it comes to preserving landscape, habitats, and animal species.

Scientists try to value all the externalities from wind power plants through valuation studies. With a value in economic terms, this can be compared to other costs and revenues from the projects. In valuation studies, there are many tools to evaluate both use and non-use value. One can distinguish between revealed and stated preferences, and between indirect and direct costs. Revealed preferences are observed through other factors like replacement costs or averting costs, and stated preferences are stated in surveys and similar. Indirect costs are observed through costs or payments for other products or services, while direct costs could be market prices or willingness to pay (WTP) to avoid destruction in the neighbourhood (Perman et al., 2011, p. 411-453).

For valuation of externalities from wind power contingent valuation (CV) is the most used. CV is a technique using surveys to ask a representative sample about their WTP or willingness to accept (WTA) (Perman et al., 2011, p. 415). In the case of wind power, one could for example ask question about WTP to avoid wind power plants in the municipality. Even though CV is the most used method, there are some problems with the method. First, this does not give one correct answer. Another problem with the method is that people can have difficulties with assigning a number or a price to the problem. Respondents might also be influenced into thinking that the good is important, just because the interview takes place. An alternative method for valuation of wind power is choice experiments (CE), where respondents are confronted with several discrete alternatives and rank these by preference (Perman et al., 2011, p. 429-434). Hedonic pricing (HP) has also been used, where the WTP is observed through housing prices, by for example comparing the price of a house close to a wind power plant, and one without, trying to keep other factors alike (Perman et al., 2011, p. 442-450).

The different methods, locations and assumptions gives different results. Because of this, it is preferred to use studies evaluating people with similar culture and nature with similar surroundings. A choice experiment from Sweden discover that people are willing to pay 0.6 Euro cent per kWh to avoid wind power in a mountainous area (Ek & Persson, 2014). In Denmark, Jensen et al. (2014) did a HP study, comparing residential sales price in areas with and without wind power. They find that the sales price was reduced by up to 3% from the visual pollution and between 3% and 7% from noise pollution.

In Norway, there is still limited research in this area. The first Norwegian CV study on wind power was done by Navrud (2004). The study gives a WTP at 855 NOK per household per year to avoid development of 1.5 TWh. If the size is increased to 6.7 TWh, the WTP increases to 1 009 NOK per household per year. Another study indicates that Norwegians are willing to pay more for locally produced renewable energy, rather than imported coal power, but they also tested for the NIMBY effect (not in my back yard), and found significant effect related to this (Navrud & Bråten, 2007). This is similar to the study by García et al. (2016). They find that the wind power plants impose a welfare loss both to local residents and non-locals, but the WTA is almost 5 times larger for the locals than non-locals. For local residents who uses the area, the WTA for an extra wind turbine is 230 NOK per year per household, while for non-local who does not use the area, the WTA is 51, giving the non-use value. Dugstad et al. (2020) did a CE which found an increased WTA with increased numbers of turbines. For 600 turbines, the WTA is 302 NOK per household per month, for 1 200 turbines, the WTA is 403 NOK per household per month, and for 3 000 turbines, the WTA is 415 per household per month. They also finds that acceptance decrease with exposure, i.e., people who are already exposed to wind power have higher WTA that those who are not (Dugstad et al., 2020). This could result in increased WTA over time if wind power development increases and more people get exposed to it.

Regardless of the choice of valuation method and result, it is recommended to adjust for growth by the growth in GDP per capita from the guidance on CBA in Norway (Ministry of Finance, 2014). The most recent paper on long term perspectives on the Norwegian economy gives an estimate on the annual GDP growth at 1% in the period from 2020 towards 2060 (Ministry of Finance, 2021, p. 72). This growth rate will be added to the valuations for the period of interest.

3.4.2. Valuation of CO_2 emissions

CO_2 pricing is another kind of Pigouvian tax, aiming to make the polluter of CO_2 pay for this emission. Over the past years, CO_2 pricing has increased, through cap and trade (CAT) systems and tax schemes. Norway uses both CAT, through the EU ETS, and CO_2 taxes on sectors not included in the EU ETS, but emissions from peatland is not included in any of these.

A CAT system sets a quota level, the maximum amount of total emissions. Firms are given quotas for free or buy them through auctions. If they want to emit more, they will need to buy more quotas, and if they can reduce emissions, they can sell their quotas. Through supply and demand in a market for tradable quotas, the price is set. In 2019 and 2020, the price of one quota in the EU ETS has mostly fluctuated between 20 and 30 € per ton CO_2. However, the price has increased drastically through the beginning of 2021, exceeding 50 € per ton CO_2 in May 2021 (Ember, 2021), corresponding to 500 NOK per ton CO_2[1].

Some sectors, like transport and agriculture, are not included in the EU ETS. For these sectors, each country has national goals for emission reduction, and need to use national measures to reach these. In Norway, this is done through a CO_2 tax. Today the tax is 591 NOK per ton CO_2 (Ministry of Finance, 2020b), but from the Norwegian government's climate plan towards 2030, they want to increase the price to 2 000 NOK[2] per ton CO_2 by 2030 (Ministry of Climate and Environment, 2020, p. 58).

[1] Exchange rate (NOK per 1 Euro) on May 7th 2021 at 10.0125 (Norges Bank, 2021a).
[2] 2020-NOK.

An alternative approach for a CO_2 price is to use the shadow price, the marginal cost of reaching the climate goals. In a report to the European Investment Bank (EIB), Rosendahl and Wangsness (2021) reviewed a carbon price that can be used for cost-benefit analysis. The carbon price is related to the cost of carbon i.e., it is the shadow price of reaching the climate goal at 1.5°C and for the EU to become carbon-neutral by 2050. They propose one alternative of using the median from a sample of integrated assessment models (IAMs). From this, they formulate a main trajectory from 2020 to 2050, with an associated high and low-price trajectory. This gives a cost of carbon at 141 Euros per ton CO_2[3] in 2025. In 2050, it will have increased to 806 Euros per ton CO_2 (Rosendahl & Wangsness, 2021), corresponding to 8 112 NOK per ton CO_2[4]. With CO_2 prices equal to the cost of carbon implemented towards all sources of emissions (and no other climate policies), the climate target is exactly reached. From this estimate, the price in the EU ETS would need to increase extensively from today's level, and the Norwegian CO_2 tax would need to increase further from the 2030 climate plan if the goal of 1.5°C global warming and carbon-neutrality by 2050 is to be reached.

3.5. Combination of the two tax schemes

In a combined tax scheme, the environmental tax is added before the resource rent is calculated. The extra tax will reduce the resource rent compared to a situation without environmental taxation. As illustrated in the example of behavioural response to environmental taxation in chapter 3.3.2, the profit (and resource rent) will decrease. The environmental tax will, as if it were introduced alone, result in a more efficient partial allocation when external costs are accounted for. The effect of more efficient allocation will be equal when environmental taxation is combined with a resource rent tax. Imposition of an environmental tax will result in a backward shift in the supply curve as illustrated in Figure 6. When the price is unchanged, this reduces the resource rent by the green area. This green area below Q* are the difference between PMC and SMC, to be captured by the environmental tax. The blue area is the remaining resource rent after introduction of the environmental taxation.

[3] Prices in 2016-Euros.
[4] Prices in 2020-NOK. First converting 2016-Euro to 2016-NOK using the average exchange rate of 2016 (1 Euro = 9.2899 NOK), then adjusting 2016-NOK to 2020-NOK using the Norwegian price inflation (8.34%).

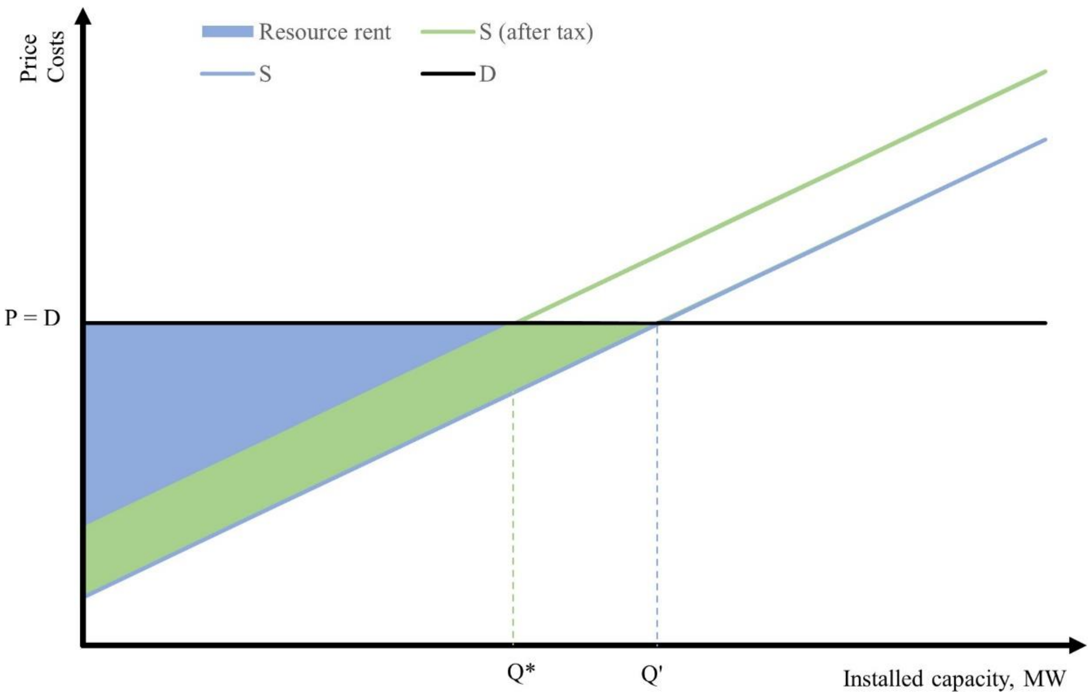

Figure 6: Resource rent before and after environmental taxation.

A resource rent tax can be introduced together with the environmental tax, at the same size as if it were introduced alone. Because of the reduced resource rent, the tax income from a resource rent tax will be reduced. The resource rent taxation will not affect the optimal production at Q* and this will be equal to a case with only environmental taxation. This is explained further in the following example.

3.5.1. Behavioural response to a combined tax scheme

When an environmental tax is introduced, equation (4) is extended further to a new optimization problem in equation (12). This is a combination of the optimization problem with only resource rent taxation and the one with only environmental taxation:

$$\max_{x_1, x_2} \pi = (1 - t_r)(pf(x_1, x_2) - w_1x_1 - w_2x_2 - t_e z(x_1, x_2)) \tag{12}$$

Where t_r is the tax rate on the resource rent tax and t_e is the tax rate related to the environmental tax. The FOC gives:

$$\frac{\partial \pi}{\partial x_1} = (1 - t_r)\left(p\frac{\partial f(x_1,x_2)}{\partial x_1} - w_1 - t_e\frac{\partial z}{\partial x_1}\right) = 0 \tag{13}$$

$$\frac{\partial \pi}{\partial x_2} = (1 - t_r)\left(p\frac{\partial f(x_1, x_2)}{\partial x_2} - w_2 - t_e\frac{\partial z}{\partial x_2}\right) = 0$$

Solving (13) for w_1 and w_2 gives:

$$(1 - t_r)\left(pMP_1 - t_e\frac{\partial z}{\partial x_1}\right) = (1 - t_r)w_1 \rightarrow\ pMP_1 - t_e\frac{\partial z}{\partial x_1} = w_1$$
$$(1 - t_r)\left(pMP_2 - t_e\frac{\partial z}{\partial x_2}\right) = (1 - t_r)w_2 \rightarrow\ pMP_2 - t_e\frac{\partial z}{\partial x_2} = w_2 \quad (14)$$

This is the same result as in equation (11), the response with only an environmental tax. This proves that the resource rent tax does not affect the behavioural response.

The optimal production level is equal as a case with only environmental taxation, but it differs from the optimal production level before any taxes. This is a desired effect of the environmental taxation. When the environmental tax is added, the profit and the tax expense related to the resource rent taxation is reduced. Equation (15) illustrates the tax expense related to the resource rent taxation for a firm. The environmental tax is subtracted from the income together with the costs before the resource rent is calculated. In that sense, the firms face the environmental tax first, and then the resource rent tax. The tax rate is constant, but with a reduced profit compared to resource rent taxation alone, the tax expense for the firm is reduced, thus the tax income for the government also decreases.

$$TE_r = t_r * \pi = t_r * \left(pf(x_1, x_2) - w_1x_1 - w_2x_2 - t_ez(x_1, x_2)\right) \quad (15)$$

For the neutrality of the resource rent tax, the same deductions and uplift as discussed in chapter 2.3.1 and 3.2.2 would need to be included. With an extra tax added in a combined tax scheme, the tax is subtracted from the profit together with the deduction and uplift. This increases the possibility of negative taxes.

4. Data and methods

Data from existing or planned wind power plants in Norway is used to illustrate and analyse effects of a potential tax scheme, based on the theoretical framework described above. First, project costs, production, number of turbines, location etc. is essential to calculate the LCOE. Secondly, a method for the environmental tax base and associated data is described. The environmental tax rate can be based on previous valuation, while the tax rate for the resource rent tax could use similar taxation in other sectors as a starting point. Finally, price scenarios are presented, together with simulations of how an implementation of the tax schemes could look.

4.1. License applications

Firms need to apply for a license if they want to build and run power installations in Norway, like wind power plants. The Norwegian Water Resources and Energy Directorate (NVE) are responsible for the evaluation of the applications. All documents from the applications and evaluation are available from NVE's licensing database. This includes information on projects who have received a license, projects in the application stage, and rejected projects.

To receive a licence, projects need to be evaluated by NVE. An application is either approved or rejected, based on their impact assessment. Some of the factors evaluated by NVE are wind resources in the area, proximity to transmission and distribution network with available capacity and the environmental impact of the project. In this analysis, only projects who has received a license will be evaluated, since this is a necessity to operate. Projects in the application stage could have been included because some of these may be approved, but many will also be rejected. Approved license applications give a total of 88 projects to analyse, either already in operation or in the planning phase. Appendix 2 gives a summary of the data used for the 88 power plants, where each is given an identification code to anonymize the power plants. Some offshore wind projects have received licenses from NVE, but these are excluded in this analysis, because the costs related to offshore and onshore wind differs greatly, make cross-analysis challenging.

4.2. Calculation of LCOE

Data on investment and operating costs, installed capacity and estimated annual production is necessary to calculate the LCOE. Investment costs are provided from NVE's licensing database, together with installed production capacity (MW) and estimated production (GWh/y). Most project applications also have an assumed operating cost. Where this is not available, NVE's estimated average cost is used, at 10 øre/kWh (Norwegian øre per kWh) (NVE, 2017). This number was updated after earlier estimates at 15 øre/kWh (NVE, 2015). Installed capacity, estimated production, assumed investment costs and operating costs for each power plant are given in Appendix 2.

The lifetime of wind power projects are on average 25 years (Schlömer et al., 2014). In NVE's first estimates from 2015, they used a lifetime of 20 years, from the certifications (NVE, 2015), but NVE have later updated the expected lifetime to 25 years, because of improved technology and more experience (NVE, 2017). The increased lifetime makes investments more profitable over the lifetime, since the same investment costs are distributed over an increased lifetime with a higher total production. A 6% discount rate is used in the calculation, as discussed in chapter 3.1.1. All costs are adjusted for inflation from the year of costs to 2020-NOK[5].

It is worth noting that almost all costs are estimated in the period 2000 to 2015. The estimates are related to the license applications, completed before license approval. Because of this, the latest technological development and cost decrease from 2015 until today, is not captured by the analysis. While the latest developments are not captured, the data set contains estimates over a period of around 15 years. This period is the first period with wind power in Norway. It could be expected a price reduction within this period, as technology has evolved, and it could therefore be necessary to adjust the costs for technological developments in addition to the inflation adjustments.

Price development in the analysed period is difficult to observe because of the small size of the data set. After adjusting for inflation, the investment costs follow a slightly decreasing trend over the period, while the operating costs follow an increasing trend. There are large differences within each expense year, and with few observations related to each year, it is hard to conclude upon a trend in any directions. The best suited and least costly areas would probably be the first to be developed, making the expected cost decrease invisible. This could be areas closer to existing power grids, easier accessibility for construction work, or better wind resources giving higher expected production. The effect from harvesting the low-hanging fruits first might exceed the technological development, making this hard to observe in the data set. Because of this exceedance, projects with licenses from different years end up with somewhat similar cost situations, and a technological development is not calculated for the LCOE. Using this to examine future wind power projects might give overestimated costs and calculated LCOE.

For all the projects in the dataset, the average LCOE is 47.1 øre/kWh. The calculated LCOEs fluctuate between the lowest at 28.5 øre/kWh and the highest at 65.8 øre/kWh. The calculated LCOE for each power plant are presented in Appendix 2. The estimated average is higher than NVE's latest estimates from 2019, with an average LCOE at 31.8 øre/kWh for onshore wind. The differences can be related to the possible overestimation in this calculation as discussed

[5] Price inflation is calculated using Norges Bank's price calculator (Norges Bank, 2014).

above (NVE, 2021c). The calculation in this analysis is related to previous and existing projects, while NVE's estimate is related to expected future costs.

On average, almost 75% of the calculated LCOE comes from the investment costs, while 25% is related to annual operating costs. The wide range may be due large differences depending on location and technology. Many areas might also be located far away from existing infrastructure and power grids, and there are large costs related to this. Another factor that varies is the landscape and terrain, making it more difficult, thus costly, to build power plants in some areas. There are also differences related to the technology used for that specific power plant. For example, larger and more powerful turbines require more capital investments. All these factors related to location and technology causes differences in costs and the associated LCOE.

The differences in location and technology results in large differences in both operating and capital costs for the projects evaluated. The operating costs are ranging from 50 000 to 180 000 NOK/GWh (or 5 to 18 øre/kWh), while the capital costs have a range from 6 790 000 to 16 432 000 NOK/MW (equivalent to ca. 17 to 42 øre/kWh[6]). Operating costs are measured per GWh produced because this is dependent on the annual production and the day-to-day operation. Capital cost is related to the construction, and is not dependent on the annual production, therefore this is measured per installed capacity in MW. If a power plant manages to increase the lifetime and produce for 5 extra years, the capital cost will not change as the investments and construction is already done, but this will result in 5 extra years of operating costs. This would decrease the total LCOE because the capital cost is divided out on more total production, but the part related to the operating cost in the LCOE calculation would not change.

4.2.1. LCOE and resource rent

When the calculated LCOE for all firms are put together in ascending order, a long-term supply curve is created. Figure 7 illustrates this, where the supply curve shows the electricity price each firm could accept to break even. The graph also illustrates a linear supply curve, a trend line from the LCOEs. The price on the vertical axis is given in øre/kWh. On the horizontal axis annual production in GWh is given. A price at 38 øre/kWh is added to the graph to illustrate the resource rent. This is the average price in Norway in 2022 from NVE's forcast in a base scenario (NVE, 2020). With this price, the shaded area illustrates the resource rent. As the figure illustrates, the resource rent from Norwegian wind power is not huge at this point in time. Future

[6] This is calculated by dividing the cost per installed capacity out on an average production per installed capacity from this sample. In the sample, the average annual production (MWh) per installed capacity (MW) is 3083 hours. These annual hours of production were used to calculate the NPV over a lifetime of 25 years with the same discount rate at 6%, giving a total of 39 409 hours over the lifetime.

increased electricity prices will however give an upwards shift in the price-curve, while decreased costs, thus decreased LCOE would shift the supply out. Togheter, this would increase the resource rent.

For projects in operation, investment costs are seen as sunk costs. In such a case, the investment is already done, and the decission on whether to operate or not is based on the associated operating costs. In practice, these projects would produce even though the price is below the LCOE, as long as it is greater than the operating costs. The projects used in the analysis are analysed as if they have not started construction yet, so that the decision to operate or not includes the total investment costs.

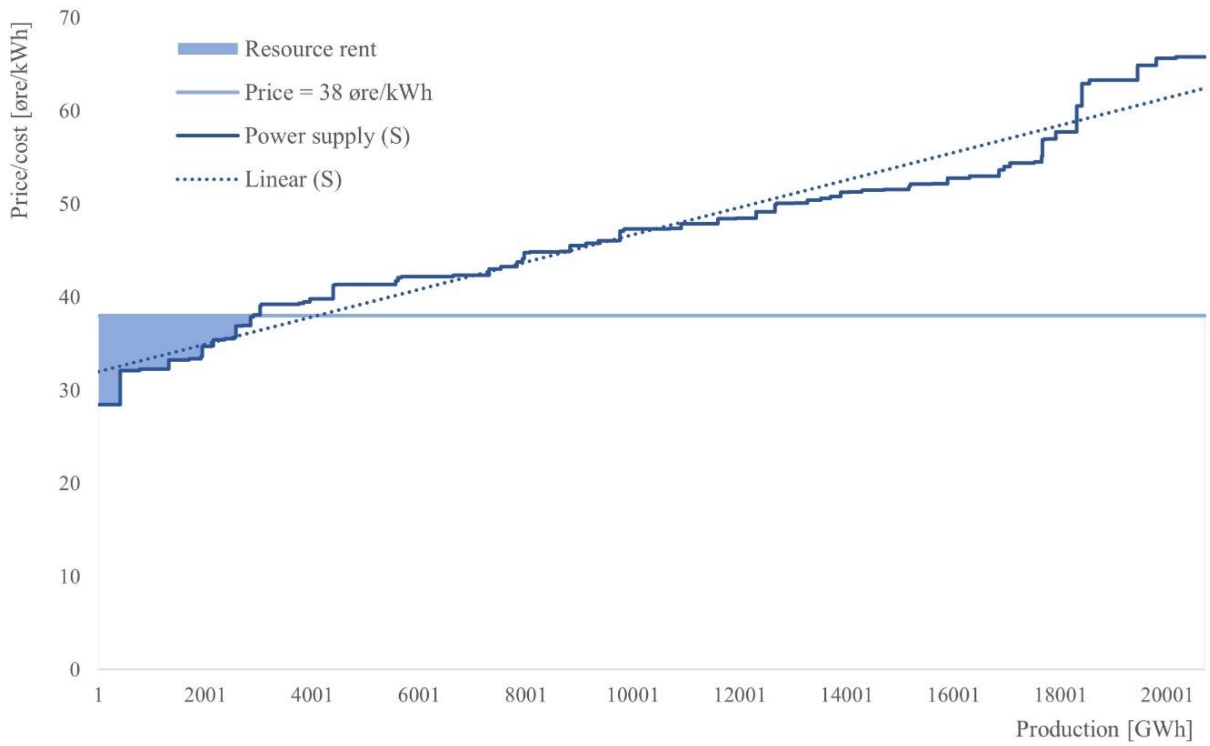

Figure 7: Power supply and resource rent.

4.3. Environmental tax base

An optimal environmental tax equals to the marginal damage costs. In practice, this demands detailed information and monitoring, together with valuation of the environment and damages. Information gathering, monitoring and valuation studies are costly to implement and difficult to follow up. Green tax commission suggested a tax on CO_2 emissions from nature encroachment as a first step towards a full environmental tax (NOU 2015: 15, 2015). For wind power, the CO_2 emissions from encroachment in peatland is calculated and this could be the basis of an CO_2 tax on the production. As an extension, to include all nature encroachment and destruction, a wider environmental tax could be implemented. Nowell et al. (2020) have categorized existing wind power projects based on achievement after four criterions. This categorization will be used as a starting point for a tax on nature encroachment that could be implemented together with a CO_2 tax.

4.3.1. NINA categorization

Nowell et al. (2020) evaluates which operating and planned wind power projects that met four nature-based criterions. The criterions are designed by WWF. They also categorise all the projects based on a value of how many criterions they violate, creating a scale from 0 (projects who meet all the criterions) to 4 (projects who violate all criterions). This scale makes a good basis for a stepwise encroachment tax. Nowell et al. (2020) have evaluated 101 wind power projects holding a license from NVE, both onshore and offshore. Within these 101 projects, some are calculated twice, because the license area is divided in two different areas. Seven of the projects are offshore wind power, not included in this analysis. Some projects have had their application approved at first, but then rejected after complaints. Those projects might then be included in NINA's evaluation but not in this analysis. After combining those calculated twice, removal of offshore wind power and those rejected after complaints, a total of 81 projects with categorization by NINA are included in this analysis. Figure 8 gives an overview of all the included projects, and their value, where 8.6% of the projects has a value of 0, meaning that they meet all the criterions, while 2.5% meet none, valued at 4. The value for each power plant is given in Appendix 2.

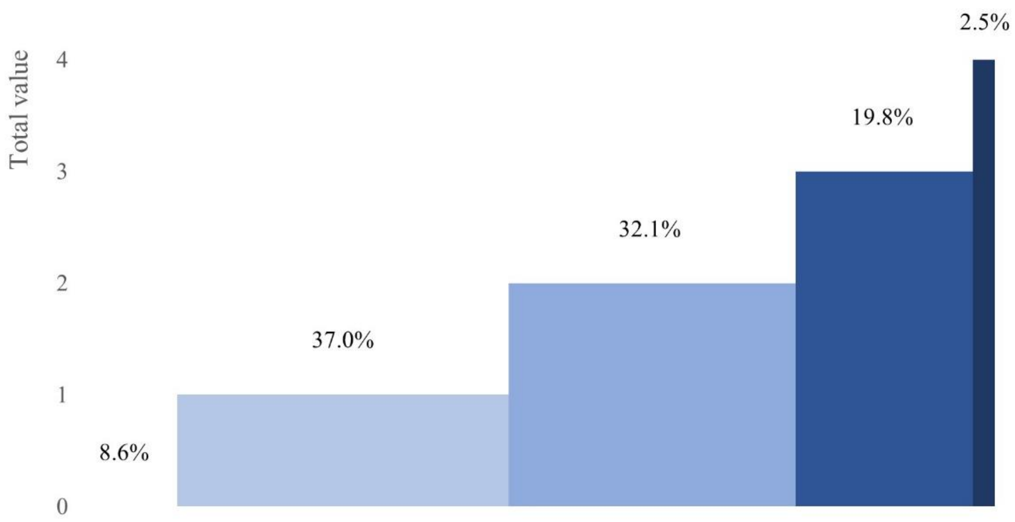

Figure 8: Total value according to NINA's categorization, after number of criterions violated (Nowell et al., 2020).

The four WWF evaluation criterions are: pristine nature, natural degradation, endangered species, and carbon emissions. WWF made these criterions as requirements for areas for wind power production. They believe projects should meet all these criterions to be able to build a power plant (WWF, 2020), and the project should:

1. Not reduce the amount of pristine nature.
2. Not deteriorate protected areas, habitats of national value, selected habitats, endangered habitats, nationally important outdoor areas and selected cultural landscapes.
3. Not split important habitats or migration areas for responsible species or endangered and priority species.
4. Not increase emissions because of loss of carbon storage.

The third criterion is where the most violations occur. Only 28 out of 101 met this criterion. 64 projects met the second, and 73 met criterion 1. Criterion 4 is the one violated by the least projects, with 77 projects meeting this one.

Even though there are differences in the criterions and projects achievements, Nowell et al. (2020) does not consider the criterions differently. One criterion is not called out as worse or better than other, therefore, it is reasonable to give them the same weight in this analysis. If one criterion were to be evaluated as worse than the others, this could have been given a greater weight or tax rate. This is not the case.

4.3.2. CO_2 emissions from peatland

The fourth WWF criterion is related to loss of carbon storage, but in the evaluation, Nowell et al. (2020) focus mostly on reduction of forest areas. They have included peatland in some cases where the construction affects it directly, but reduction in forest is the crucial factor for this criterion. The effect on carbon sequestration and emissions from peatland is greater than what is evaluated in this report (Helledal et al., 2020), and it could be necessary to either include this more effectively in the fourth WWF criterion, or calculate the actual emissions and tax this similar to other sources of emissions.

The emissions of CO_2 from peatland occurs for two reasons. First, peatland has a great carbon sequestration feature, and when the area is removed, covered up or drained, there is a loss of potential future carbon fixing capacity. This will increase the CO_2 concentration in the atmosphere over the whole period until successful habitat restoration. Second, when the peatland is destroyed, directly by infrastructure, or indirect by drainage, it will release the carbon that has already been captured over many years (Nayak et al., 2010).

To estimate the affected areas for each wind power project, the licensed area is used. NVE provides mapped areas for all license application. For each of these license areas, NIBIO's tool, Kilden, is used to estimate the area of peatland within the license area. Kilden uses AR5, an area resource map, to categorize areas by habitat, like a bog. In AR5, a bog is classified as area with at least 30 cm of peat (NIBIO, 2019). For some of the license areas, AR5 does not capture the whole area, and the estimated size of peatland could be underestimated. AR5 does not include mountain areas, areas above the tree line are omitted and it has a minimum area of 2 acres (5 in less productive areas) for registration of peatland (NIBIO, 2019). Because some areas are missing, there is reasons to believe that the actual size of peatland is larger. Figure 9 illustrates the size of peatland out of total license area, for all projects holding a license, in ascending order. The figure gives each project on the x-axis in ascending order of share of peatland. Each bar represents a power plant, and not the total production from these.

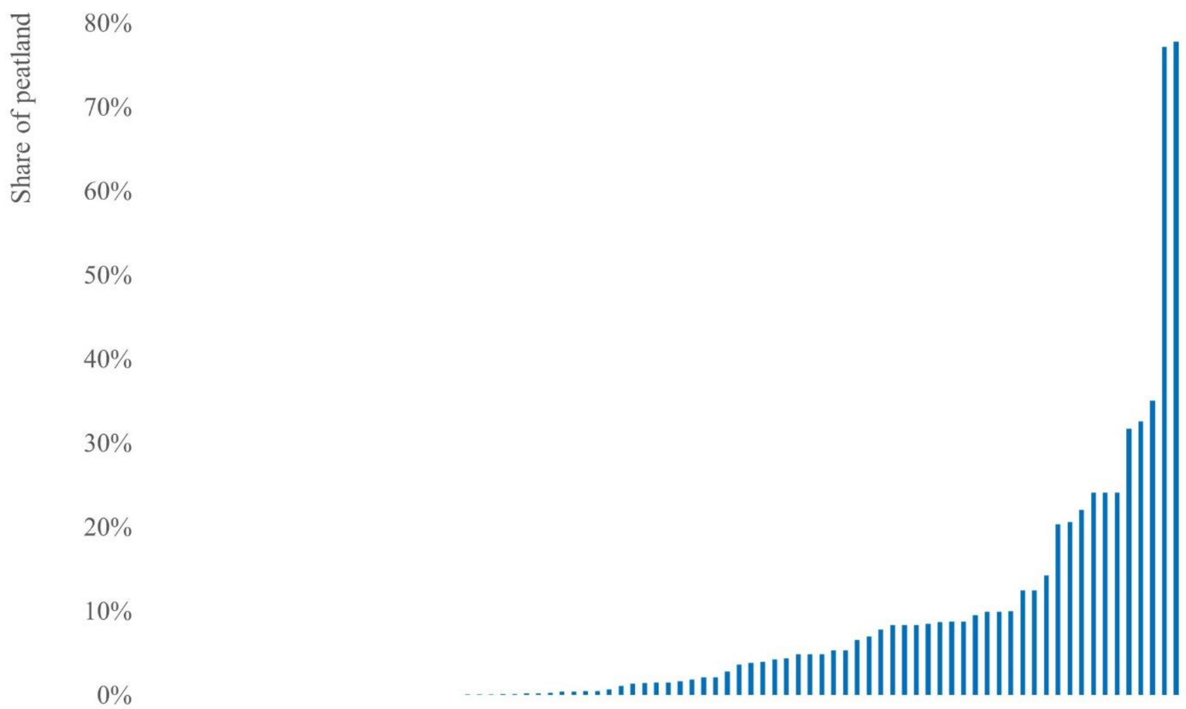

Figure 9: Share of peatland in total license area.

The emissions from peat in each license area is estimated using the method provided by Nayak et al. (2010). Calculations, data, and estimates are described in further detail in Appendix 3.

The calculations are a worst-case scenario, where all peatland in the license area is destroyed through construction, roads, and drainage. This gives total emissions of 920 913 tons of CO_2e from all the projects in the data set, over the lifetime of the projects. For each power plant separately, the emissions vary between 0 and 150 000 tons of CO_2e. Figure 10 shows the emissions from each power plant in ascending order. Exact calculated emissions for each power plant are given in Appendix 2.

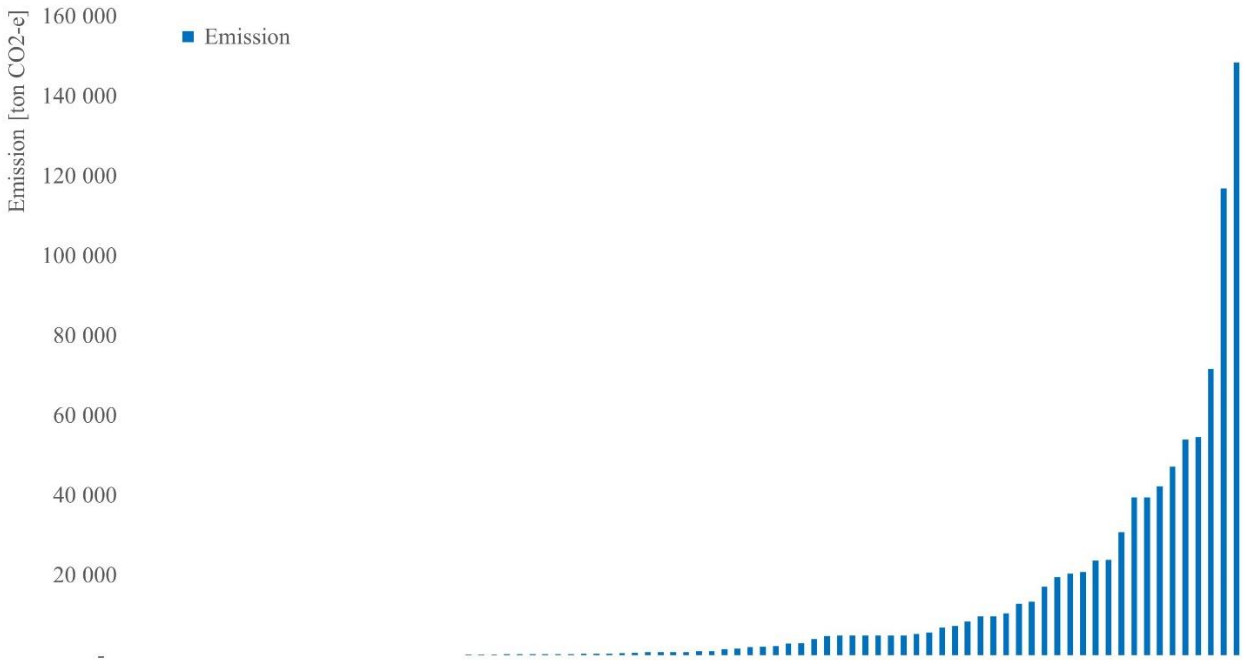

Figure 10: Emissions from peatland for each wind power plant.

4.4. Tax rate

4.4.1. Resource rent tax rate

The optimal tax rate for a resource rent tax is not given. On one hand, as discussed in chapter 3.2.1, the size of the resource rent tax will not affect firms' behaviour. Because of this, the government could increase the tax rate to increase tax income. On the other hand, the resource rent tax is introduced to capture the extraordinary profit from using a common resource, and it is not intended to create an unlimited large tax to increase tax income. These arguments should not influence the evaluation of a correct tax rate, but a first step could be to look at taxation of other industries.

Today, there is a resource rent tax on hydro power and petroleum in Norway, with a tax rate of 37% and 56% respectively. Of the two, wind power plants are most similar to hydro power plants, both in the use of common resources and end product. Because of this, it could be acceptable to introduce a resource rent tax on wind power equal to the tax scheme on hydro power. Power from these two sources compete in a common market for power in Norway, and an equal tax rate would lead to more fair competition between the two power sources. For these reasons, a resource rent tax rate at 37% is used in this analysis.

The resource rent from wind power in Norway is presently small, and a resource rent tax scheme is not fully investigated. Because of expectations of increased resource rent in the future, such an investigation should be completed with a thorough review of a correct tax rate. If this is below 37%, the difference from this analysis will be related to the tax income, and not the production. This makes this analysis relevant, even though the correct tax rate is uncertain.

Introduction of new tax schemes could be politically difficult, especially when there exist other tax schemes towards the same industry. This could be a challenge if the environmental tax is introduced after the resource rent tax, or opposite. To make the process easier politically, a reduction of one tax when another is introduced could be a settlement. In the case of resource rent and environmental taxation, the tax schemes are introduced to cover two separate issues, but from the view of the industry, the tax schemes could be argued to have an overlap when it comes to tax the use of the resource. Because of this, an alternative combined tax scheme will be evaluated, where the total tax income from the combined tax scheme is equal to the tax income from the case with only resource rent taxation (at 37%). These alternative tax rates will not affect the total product or the environmental tax, but the resource rent tax income and the total tax income.

4.4.2. Environmental tax rate

A good environmental tax scheme requires a correct tax rate together with the criterions and emissions discussed above. The shadow price of reaching climate goals could be a good base for a CO_2 price, as discussed in 3.4.2. At the same time, the CO_2 price will be the basis for a tax scheme in this case, and for that reason, a rate equal to the CO_2 tax for non-ETS in Norway could be a more appropriate base. As the government has indicated, an increased CO_2 tax at 2000 NOK is the price to expect in 2030 (Ministry of Climate and Environment, 2020). For that reason, this price will be used in the analysis of a CO_2 tax on wind power as well.

A scale from 0 to 4 from the categorization by Nowell et al. (2020) makes the base for the encroachment tax. For project with the value 0, with none or minor natural encroachment, the encroachment tax will be 0 as well. For the remaining scale, a corresponding scale for the tax rates is necessary. Valuation studies on wind power production in Norway gives an indication of the external costs from the production. The most recent one, by Dugstad et al. (2020) calculated the following WTA:

- 600 turbines: 302 NOK per month
- 1 200 turbines: 403 NOK per month
- 3 000 turbines: 415 NOK per month

A weighted average in WTA per turbine is 0.33 NOK per household per month. The WTA from Dugstad et al. (2020) is not specified to an area, it is the WTA for expansion of this size in Norway as a whole. The WTA increases if the respondent can exclude their own area of residence, indicating NIMBYism (Dugstad et al., 2020). For simplification, the average WTA without any excluded areas is used as an estimate for the per household WTA for all Norwegian households. The per household WTA is adjusted up for the number of Norwegian households in 2020 and over the expected lifetime of a project. This estimate is discounted with the CBA discount rate at 4% as discussed in 3.1.1 and a growth rate at 1% is added to the valuation, as discussed in chapter 3.4.1. This gives a WTA of 169 million NOK per turbine (equivalent to ca. 131 øre/kWh[7]).

The valuation by Dugstad et al. (2020) is a CE study related to society's WTA for wind power in Norway. The study is not directly connected to natural encroachment and damages from wind power production in Norway. It is not related to a worst outcome of the production, nor a best one. This makes it difficult to relate the valuation directly to the requirements in the report by Nowell et al. (2020). Since the valuation does not emphasises differences in encroachment from different power plants, it is assumed to be related to an average wind power plant in Norway. In the report by Nowell et al. (2020), the average value is 2, i.e. an average wind power plant violate two of the criterions, as illustrated in Figure 8. As the valuation is related to an average power plant, the total WTA over the lifetime of the projects, at 169 million NOK per turbine, is set as the tax rate for projects who violate two of the criterions. For the rest of the scale of values from the categorization by NINA, a linear scale is used, giving the tax rates in Table 2. This tax rate is a per turbine tax. When the total tax payment varies with number of turbines, a larger project with greater encroachment, will also get a higher total tax expense.

[7] This is calculated by dividing the WTA per turbine out on an average production per turbine from this sample. In the sample, the average annual production (MWh) per turbine is 10 120 MWh/turbine. This annual production is used to calculate the NPV over a lifetime of 25 years with the discount rate at 6%, giving a total of 129 368 MWh/turbine over the lifetime.

Table 2: Tax rate for each value from NINA categorization from weighted average WTA.

Value from NINA categorization	Tax rate per turbine in million NOK
0	0
1	84
2	169
3	253
4	337

Another alternative to the weighted average approach used above is to look at the marginal WTA for one extra turbine. In the data used with all projects who has received a license, there is a total of 2 278 turbines. From the valuation by Dugstad et al. (2020) it will be reasonable to use the marginal change in the interval from 1 200 to 3 000 turbines. This gives a monthly valuation of 0.6 øre per household per turbine. Adjusted upwards for the number of Norwegian households over the lifetime of a wind power project and discounted, this gives a WTA of 3.45 million NOK per turbine (equivalent to ca. 2.7 øre/kWh), almost 50 times lower than when using the weighted average. Using a similar linear trend, and the total WTA as the tax rate for projects who violate two criterions, the tax rates is as given in Table 3.

Table 3: Tax rate for each value from NINA categorization from marginal WTA.

Value from NINA categorization	Tax rate per turbine in million NOK
0	0
1	1.72
2	3.45
3	5.17
4	6.90

The latter approach given in Table 3 will be used as the environmental tax rate in the further analysis. Using the marginal WTA is most appropriate because this reflects the value of one extra turbine from today's level instead of the average, independent of numbers of existing turbines.

The environmental tax is calculated as a one-time tax, rather than an annual tax over the lifetime. The reason for this is that the greatest destruction is related to the implementation itself with the construction of the power plant. At that time, most of the nature is destroyed and occupied, and this is most relatable to the total external cost in valuation studies. The opposite, with an annual tax could be argued because the power plant occupies the area every year, and a potential restoration is postponed. A one-time tax will give incentives to increase the lifetime or re-establish the power plant rather than building a new power plant in an area without previous encroachment with higher external costs.

A one-time environmental tax, calculated from the marginal WTA for new wind power plants will be used in the following analysis. Tax rates as given in Table 3 will be imposed on the firms in the year the construction starts for the power plant. The total tax payment for the firm will depend on the encroachment from the power plant, an associated value based on the categorization by NINA, and the total number of turbines planned for the power plant.

4.5. Price scenarios

To analyse the effects from different tax schemes, it is useful to use price scenarios for the electricity price. It is difficult to predict future electricity prices, and scenarios are helpful to analyse different outcomes. NVE publishes an annual long-term power market analysis, with the latest one from October 2020. In this analysis, they study the developments in the power market towards 2040, both for Norway, the Nordics, and Europe, looking at both production, consumption and prices (NVE, 2020). They have projected the electricity prices for the period 2022-2040 in a base trajectory, together with high- and low-price trajectories. The high and low trajectories are related to uncertainty and trajectories for coal, gas, and CO_2 prices. Table 4 shows NVE's estimates for the average Norwegian electricity price measured in øre/kWh for the three different scenarios.

Table 4: Price trajectories (øre/kWh[8]) for the Norwegian electricity price towards 2040 (NVE, 2020).

Scenario	**2022**	**2025**	**2030**	**2040**
Base	38	42	39	41
High	44	49	46	48
Low	30	31	27	25

[8] 2020-NOK.

Today, there are different zonal prices within Norway from the division into price zones as discussed in chapter 2.1. The price difference between the zones is expected to increase. Prices in southern Norway are most affected by fuel and CO_2 prices in Europe, with transmission lines to both Denmark and the Netherlands, and extension to Germany and Great Britain in 2022 (NVE, 2020). For the northern parts of the country, the transmission capacity is constrained, and the prices are not expected to follow fuel and CO_2 prices. In this analysis, the prices for 2030 will be used, while in reality, the price over the 25 years of operation is relevant. 2030 is in the middle of this interval when looking at production start today and is used as a simplification. Table 5 gives NVEs estimates for the price trajectories in 2030 divided into the Norwegian power zones.

Table 5: Price trajectories for 2030 (øre/kWh) divided into price zones (NVE, 2020).

Scenario	NO1	NO2	NO3	NO4	NO5
B2030	41	42	37	34	41
L2030	28	29	25	23	28
H2030	48	49	43	40	47

As mentioned in chapter 4.2, the lowest LCOE in the data set used is 28.5 øre/kWh. This is higher than the average price in the low-price scenario. If the price where to become this low, none of the projects in the data set would be profitable. The production would be zero even without taxes in the low-price scenario, and therefore, only the base and high-price scenario will be evaluated in this analysis.

4.6. Simulation models

In the analysis, all projects with their costs are assumed to start operation simultaneously. As discussed in chapter 4.2, the effects from harvesting the low-hanging fruits first exceeds the technological development, and such developments are not accounted for. Using these costs and the calculated LCOE to evaluate the effects forward, with future price scenarios, might give overestimated costs and LCOE, and thus reduce the profitability and resource rent in the calculations.

The average price for the Norwegian power market, as given in Table 4, will be used for overall analysis and illustrations. To analyse the potential production before and after tax, the data is divided into price zones and evaluated together with the prices from Table 5. For all evaluations, the results will be given for each price scenario (base and high-price). Further, when total annual production is referred to, it is assumed that all profitable power plants produce at the maximum potential.

There is a lot of uncertainty, especially related to the environmental tax. It is uncertainty related to factors in the LCOE calculations, the valuation and appropriate tax rate, both for environmental tax and CO_2 tax, and there is uncertainty related to the actual CO_2 emissions from each project. After the results are presented in chapter 5, a sensitivity analysis for these factors will be implemented in chapter 6.

5. Results

5.1. Resource rent taxation alone

Firms' resource rent depends on costs and the market price. The costs are given by a firm specific LCOE and the market price is evaluated using price scenarios. A supply curve is created by sorting each firms' LCOE in ascending order, as illustrated in Figure 11. The figure gives the average price in Norway for each scenario, not individual prices in each price zone. In the base scenario, some of the firms earn a resource rent, and the resource rent increases in the high-price scenario. Some firms will not be profitable in any of the price scenarios due to high costs, and therefore would not operate without the presence of subsidies.

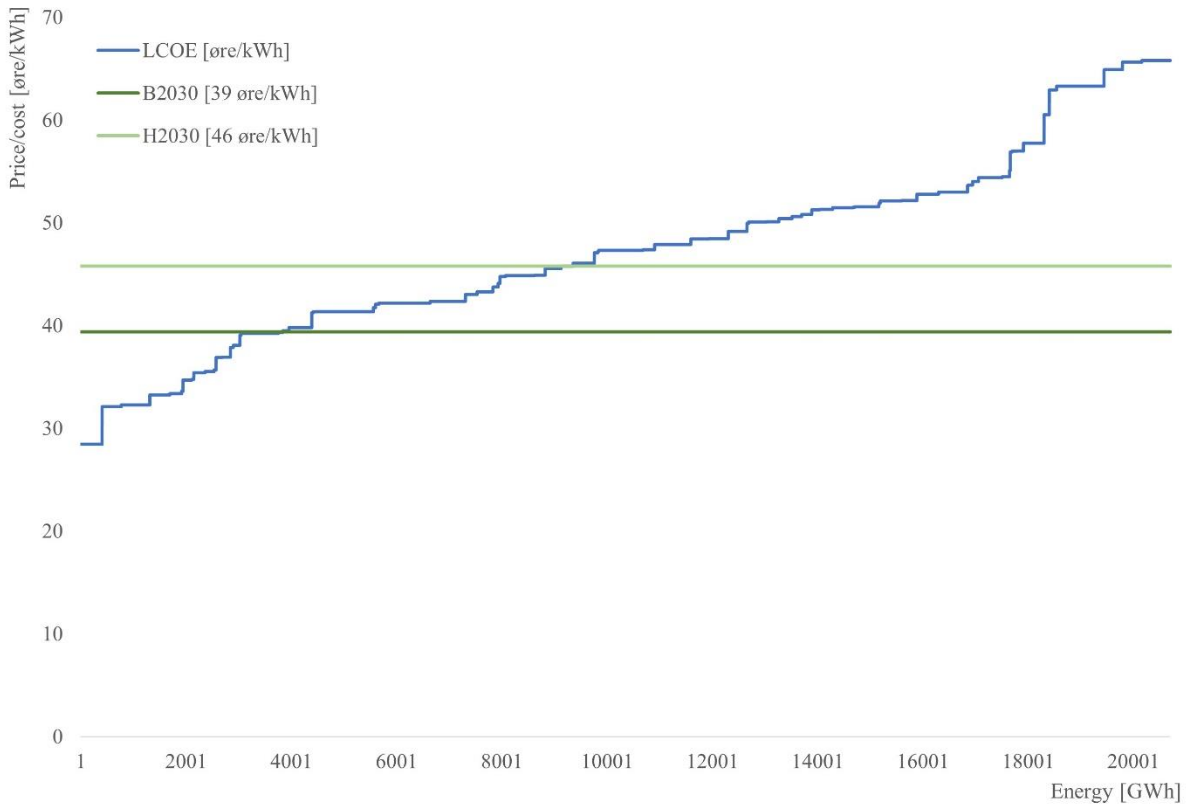

Figure 11: Resource rent in each price scenario.

The resource rent in each price scenario is illustrated in Figure 11. With an average price Norwegian electricity price of 39 øre/KWh, the annual production in the base scenario would be 3 838 GWh if every profitable power plant produces at the max potential. In the high-price scenario, more projects are profitable, and the production would be 9 354 GWh each year.

In Norway, firms face the price given in their price zone. As Table 5 illustrated, the prices vary between zones. When this variation is accounted for, the annual production in each scenario changes to the levels shown in Table 6. In both scenarios, the production is lower than with the uniform price shown in Figure 11. The variation is caused by a higher-than-average price in some price zones, and a lower price in others. For example, in NO3 and NO4 (central and norther Norway), the price is lower than the average price, resulting in lower production in both price scenarios. These are two of the zones with high potential production that might not be realised with the low prices.

The production accounted for in this analysis is the profitable production, meaning the projects with LCOE below the market price. In both price scenarios, NO2 accounts for most of the production. There is no production in NO1 and NO5[9] (eastern and parts of western Norway) in

[9] Only 2 projects with a license are located in NO5 (parts of western Norway).

neither of the scenarios. This is the areas that have the most wind power production today as well. The 2020 level of production in Norway was 9.9 TWh, higher than the total production in both scenarios here. As discussed earlier, the annual production has increased rapidly over the last years. There can be several reasons for a lower production in this analysis than in reality, for example related to subsidising through electricity certificates and decreased operating costs towards 2020.

Table 6: Production in each power zone [GWh per year].

	B2030	**H2030**
NO1	0	0
NO2	1 778	4 518
NO3	1 223	2 359
NO4	380	1 361
NO5	0	0
Total	3 381	8 238

With the production in Table 6, the wind power production generates a resource rent as given in Table 7. The total annual resource rent for all power plants in total is 170 million NOK in the base scenario. In the high-price scenario, the annual resource rent is 513 million NOK, three times higher than in the base scenario. This large discrepancy is partly caused by increased in production and partly caused by increased resource rent from increased price for those projects producing in both scenarios. Both of these effects can be seen from Figure 11 as well.

Table 7: Total resource rent [mill NOK per year].

Price scenario	**B2030**	**H2030**
Total resource rent	170	513

If a tax rate of 37% is used for the resource rent taxation as discussed in chapter 4.4.1, the tax income is given in Table 8. This is the total income from a resource rent tax scheme imposed on all wind power producers. The first line shows the annual tax income, and the third line shows the total tax income over the project lifetime. This is calculated as the net present value of the same annual income over a lifetime of 25 years and a discount rate of 4% as recommended for CBA and similar calculations, as discussed in chapter 3.1.1.

Table 8: Resource rent tax income [mill NOK].

Price scenario	**B2030**	**H2030**
Total annual tax income	63	190
Annual tax income per GWh	0.019	0.023
Total tax income over lifetime	982	2 963

Table 8 also gives the tax income in million NOK per GWh. This is calculated by the total annual tax income together with the total annual production from Table 6. To compare the resource rent tax income from wind power with the tax income form the same tax scheme for hydro power, Table 9 gives similar numbers for hydro power in the period 2015 to 2019. Over this period, the resource rent tax income has tripled, while the annual production is within the same range. In 2019, the resource rent tax income from hydro power was 140 times higher than the estimated tax income for wind power in the base scenario. The production of hydro power is also much higher, almost 40 times higher in 2019 than wind power in the base scenario. This also results in a 3.8 times higher annual tax income per GWh. If the high-price scenario is compared to hydro power in 2015, the tax income per GWh is almost the same. The increased resource rent tax income for hydro power from 2015 to 2019 is related to increased profitability and resource rent in this period, after a reduction in the resource rent in the period from 2010 to 2015 (Statistics Norway, 2021). The increased profitability is mainly due to increased electricity prices in the period.

Table 9: Resource rent tax income from hydro power (Statistics Norway, 2020b; Statistics Norway, 2021).

	2015	**2016**	**2017**	**2018**	**2019**
Resource rent tax income [mill NOK]	3 321	5 159	6 332	10 727	9 048
Annual production [GWh]	138 450	143 417	143 112	139 704	126 030
Annual tax income per GWh [mill NOK]	0.024	0.036	0.044	0.077	0.072

A lower per GWh tax income from wind power compared to hydro power is in line with expectations. Hydro power has an advantage of power storage capacity in reservoirs, meaning that power can be produced and sold when the demand and price is high. Wind power on the other hand needs to be produced when the wind blows, facing the given price at that time. This advantage can lead to higher profitability for hydro power than wind power. Conversely, with decreased costs of wind power over the past years, the LCOE for wind power has passed the LCOE of hydro power, making new wind power the cheapest source of new power production in Norway (NVE, 2021c). These effects draw in opposite directions and can make the tax income per GWh more equal between the two power sources in the years to come.

5.2. Environmental taxation alone

For the calculation of the environmental tax, some projects are omitted from the data set because of missing information about the license area. To be able to compare the production and tax income from the resource rent taxation and the environmental taxation, new numbers for the production before tax and total tax income from resource rent taxation are used as comparison in this section. This is calculated equally as above but with some power plants excluded. The results from Table 6 and Table 8 are reproduced with the decreased sample in Table A4.1 and Table A4.2 in Appendix 4.

As discussed before, there is great uncertainty related to both nature encroachment, CO_2 emissions, and the costs of these. These uncertainties will be discussed further in the sensitivity analysis in chapter 6.

5.2.1. CO_2 taxation

The CO_2 tax uses the calculated potential CO_2 emissions from peatland from chapter 4.3.2 and a CO_2 tax at 2 000 NOK as discussed in chapter 4.4.2. Divided out over the total production (per kWh), the CO_2 tax fluctuate between 0 and 7.7 øre/kWh for each project, as illustrated in Figure 12. In this figure, the bars on the x-axis represents individual power plants, not the total production. As the figure illustrates, many power plants have none or little potential emissions from peatland, however, there are some projects that may be heavily impacted by a CO_2 tax.

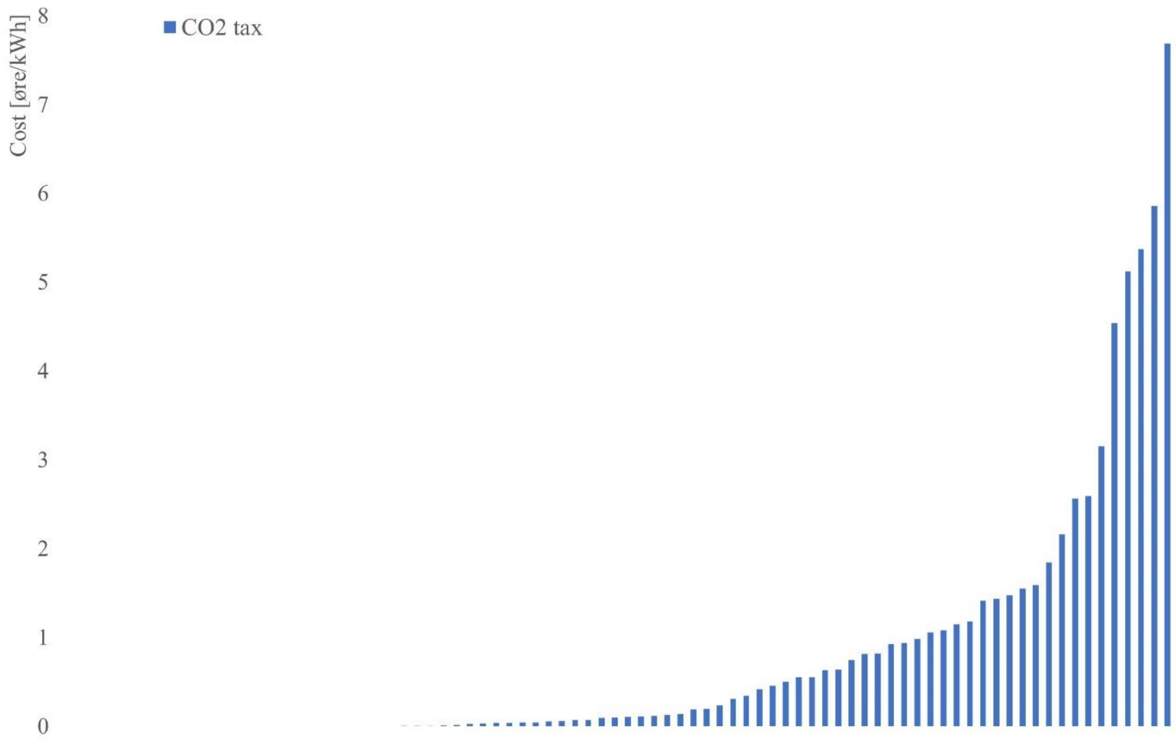

Figure 12: CO_2 tax [øre/kWh] on emissions from peatland for each power plant.

As Figure 12 illustrates, the CO_2 tax is below 1 øre/kWh for more than half of the projects. The CO_2 tax is very high only for a few projects. Because of this relatively low tax for most projects, this tax does not affect the total production at all. The production before and after the introduction of a CO_2 tax is given in Table 10.

Table 10: Production with and without CO_2 tax.

	B2030	**H2030**
With CO_2 tax	3 355	8 212
Without tax	3 355	8 212

In both price scenarios, production is equal as before the tax. Even though the CO_2 tax is not huge, it is not to be disregarded. The small outcomes from this could be a random effect from the different zonal prices and limited number of power plants. In Appendix 5, all projects are ranked after LCOE, and both environmental taxes are added, divided into price zones. In these figures, the prices in each scenario in the different zones are given, and as the figures illustrates, there are several projects with LCOE just below the price line when looking at the CO_2 tax (dark green) alone. This illustrates the somewhat random outcome where the production in both scenarios is unchanged. Even though the CO_2 tax does not change the total production, it will affect the costs and profitability for several firms. It also makes the firms pay for their potential emissions, reaching the goal of making the polluter pay.

5.2.2. Total environmental taxation

For the total environmental tax, the CO_2 tax is combined with a tax on nature encroachment. The encroachment tax is based on the valuation by Dugstad et al. (2020) and was given in Table 3 in chapter 4.4.2. The tax expense for each firm from this tax varies between 0 (for the project valued at 0 by NINA) up to 17 øre/kWh. It was only 7 projects with a value of 0 using NINA's categorization, meaning that all the remaining projects are taxed.

Figure 13 illustrates all projects in ascending order of LCOE (before tax), with the two environmental taxes are put on top. As the figure illustrates, the size of the total environmental tax widely varies. Some projects that looked profitable before a tax, would no longer be so with the tax. This will change the merit order of the projects into a more cost-effective order when externalities are accounted for together with the investment and operating costs. In Appendix 5, similar figures for each price zone are given. These illustrate the price in each zone, instead of an average price in Norway, and can be compared with the numbers in Table 11.

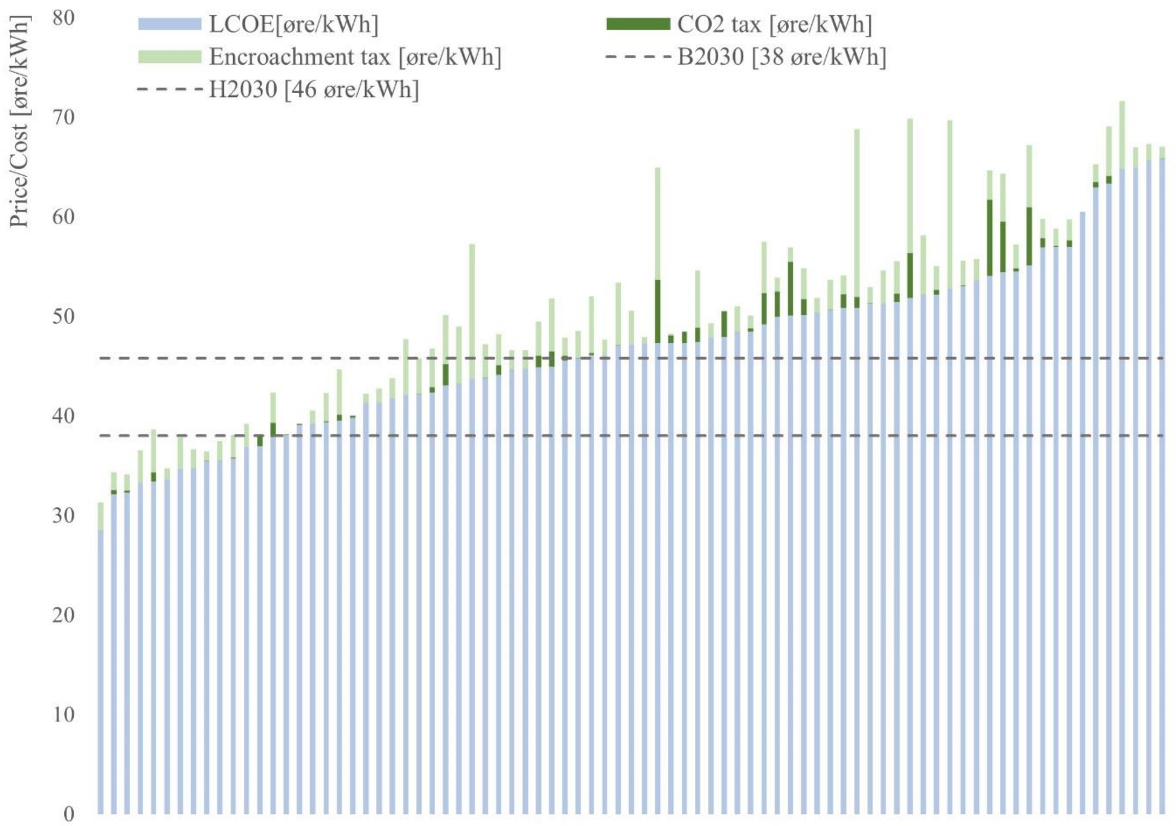

Figure 13: LCOE including CO_2 tax and encroachment tax.

After inclusion of the total environmental tax, there is an upward shift in the supply curve, as illustrated in Figure 14. For the new supply curves, projects are reorganized in ascending order, and they are not in the same order for the two curves. As Figure 13 illustrated, some projects get a high environmental tax and will move further to the right at the new supply curve. The figure gives the average price in Norway in each scenario.

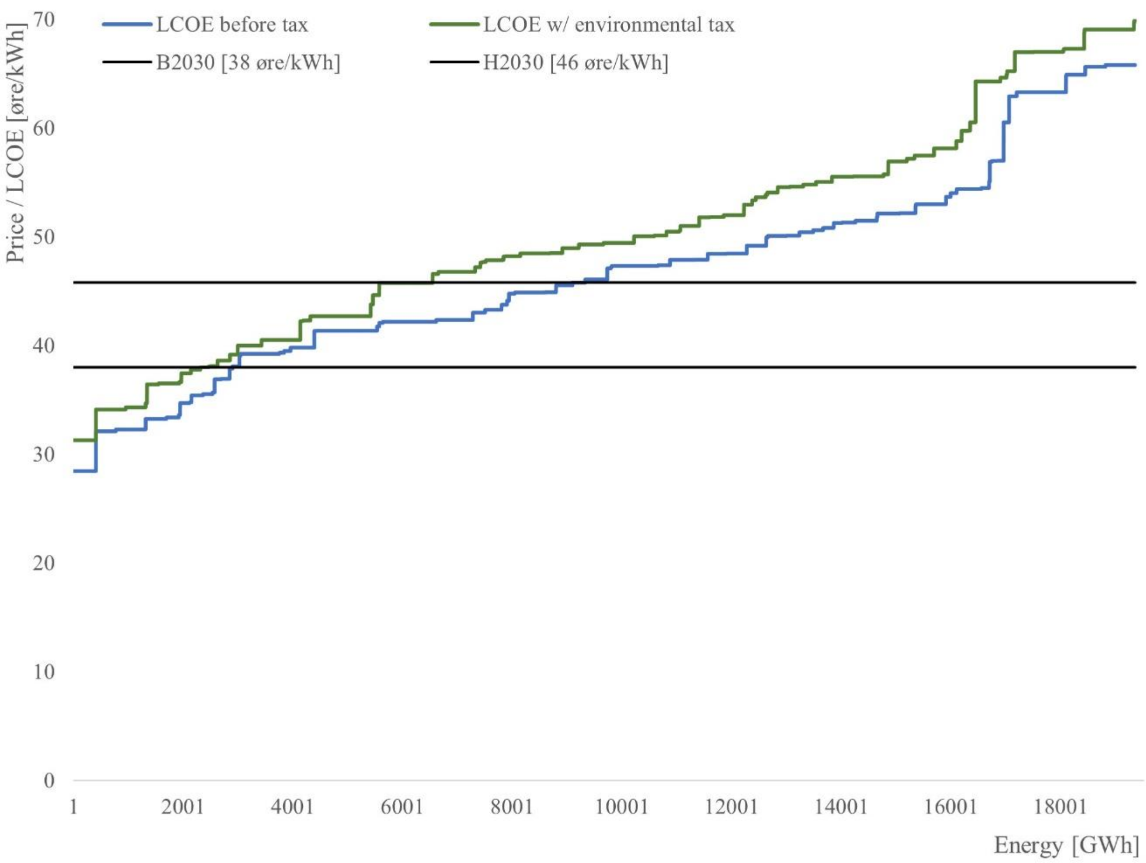

Figure 14: Supply before and after environmental tax.

The total production in each scenario after accounting for the different price zones and the environmental tax is given in Table 11. The trends are similar to the production discussed in chapter 5.1, with the most production in NO2 and the none in NO1 and NO5. In the base scenario the change from no-tax is greatest in NO3, mid-Norway, and NO4, northern Norway, where the production is reduced to zero. In the high-price scenario, the change in production is also largest in NO4, when looking at the percentage-wise reduction.

Table 11: Production in each power zone with environmental taxation [GWh per year].

	B2030	**H2030**
NO1	0	0
NO2	1 550	3 053
NO3	652	1 321
NO4	0	653
NO5	0	0
Total	2 202	5 027
Before tax	3 355	8 212
Difference	1 153	3 185

One reason for the large difference in NO4 could be the great emphasis on reindeer husbandry and its related debates. This element is considered and emphasised in the categorization by NINA. Because of this, many projects in northern Norway could face a greater environmental tax than projects located in other zones. The large differences could also be related to a coincidence. In NO4 it could be a result of having fewer profitable projects from the start. These effects are illustrated in Figure A5.4 in Appendix 5, where only one project in NO4 is profitable before any tax in the base scenario. It is also just one project going from profitable to not profitable in the high-price scenario, but this project has an estimated effect of 708 GWh, more than half of the production in this zone before the tax.

The combination of the different zonal effects and a random effect gives the production after tax as given in Table 11. With these environmental taxes alone and production as stated, the tax income in million NOK is given in Table 12. This is the total tax income over the lifetime of all projects from an environmental tax introduced as a one-time tax, as discussed in chapter 4.4.2.

Table 12: Environmental tax income [mill NOK].

Price scenario	B2030	H2030
CO_2 tax	49	196
Encroachment tax	390	1 412
Total	439	1 608

5.2.3. Alternative increased price

An alternative approach to analyse the effects of environmental taxation is to increase the price to a level where the total production is equal before and after the tax. This approach will illustrate the change in the merit order more effectively, and the shift from the “worst one” to the “better one”, in an environmental context. With environmental taxation the supply will decrease, and a higher price is expected. In an extreme event with inelastic demand, where the demand will be equal with changes in the price, and no other price responsive supply or trade, the price will increase until the supply is unchanged. Totally inelastic demand is not expected in the long run, but it can be a useful tool to analyse the change in the spatial allocation of wind power plants. This could also be relevant when there exists a political goal of a given level of renewable production, which has been used in Norway. Through electricity certificates for renewable energy, the goal was to achieve a higher level of power from renewable sources, but this system is now being phased out.

The average price in Norway in the base scenario is used to evaluate the change in the merit order and an unchanged total production. Without any tax schemes, the total profitable production is 3 022 GWh each year, with a price at 39 øre/kWh. When the price is increased to 40 øre/kWh, the annual production after environmental taxation is 2 992 GWh. This is as close to the production before the tax as possible assuming that if a power plant operates, it produces at maximum capacity, and not just half or parts of the potential capacity[10].

Figure 15 illustrates the change in the merit order of all the power plants. The figure is similar to Figure 13, but here, the total environmental taxation is merged into one bar on top of the LCOE before tax. The included prices are the base scenario (average in Norway), and the alternative price at 40 øre/kWh to obtain the same production after environmental taxation. The

[10] If the price were increased to 41 øre/kWh, two power plants with a total production of 1 142 GWh would be profitable. This would give 1 112 GWh higher production than before the tax, rather than 30 GWh below the before-tax production level, the case for the price at 40 øre/kWh.

power plant with red outline in the figure is no longer profitable after the tax, even with an increased price. To obtain the same production level, the red power plant will be replaced by the power plant with green outline. This one was not profitable before the tax given the price in the base scenario, but it is little affected by the environmental tax. One project, with a total production at 53 GWh, is replaced by another one, with a total production at 23 GWh, and the total production remains almost unchanged.

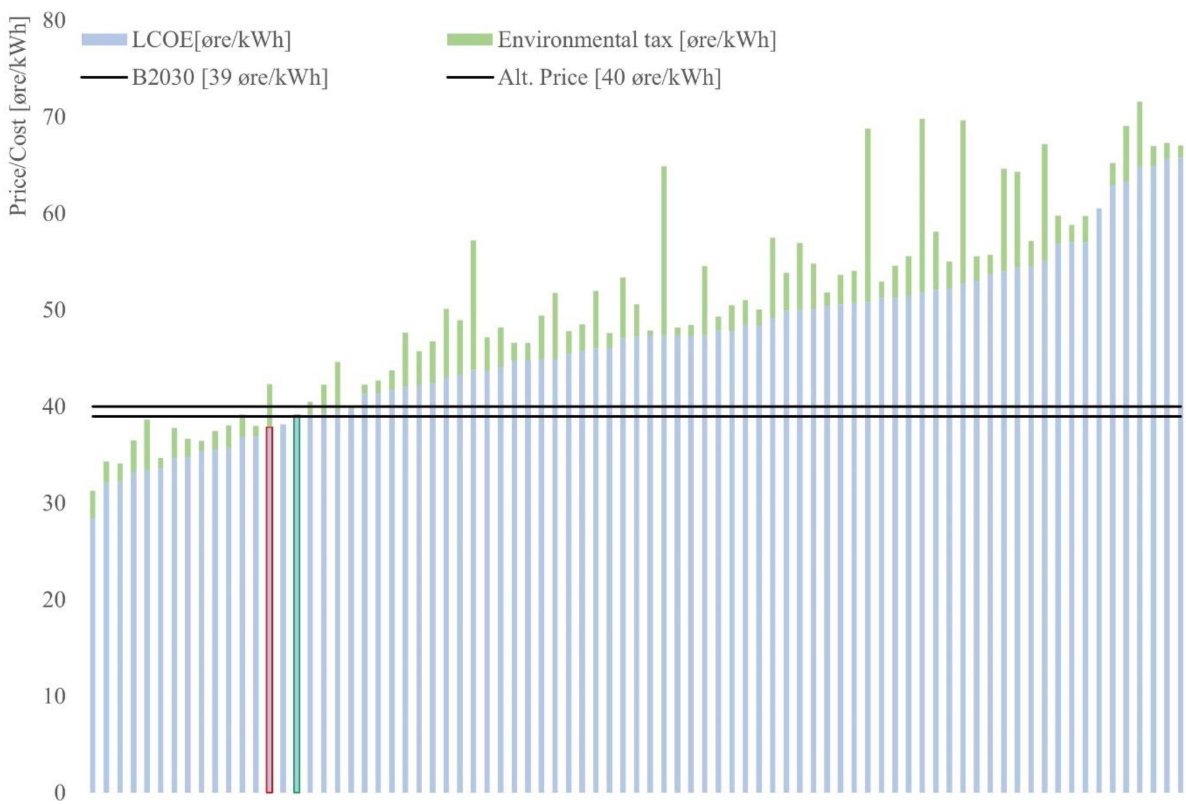

Figure 15: Merit order before and after environmental taxation in base scenario.

In the base scenario, the production is quite low, and it is only one project replacing another one. If a similar experiment is done related to the high-price scenario, the differences are greater. Without any tax schemes the production was 9 328 GWh with a price at 46 øre/kWh from the high-price scenario. To obtain almost the same production after the tax scheme is introduced, the price would need to increase to 49 øre/kWh.

Figure 16 illustrate the changes in the merit order in this case. Similar as for Figure 15, the ones with red outline are those who are no longer profitable after the tax. These would be replaced by the ones with green outline to obtain the same level of production. Three projects with the total production of 977 GWh are replaced by four other projects with a total production of 842 GWh.

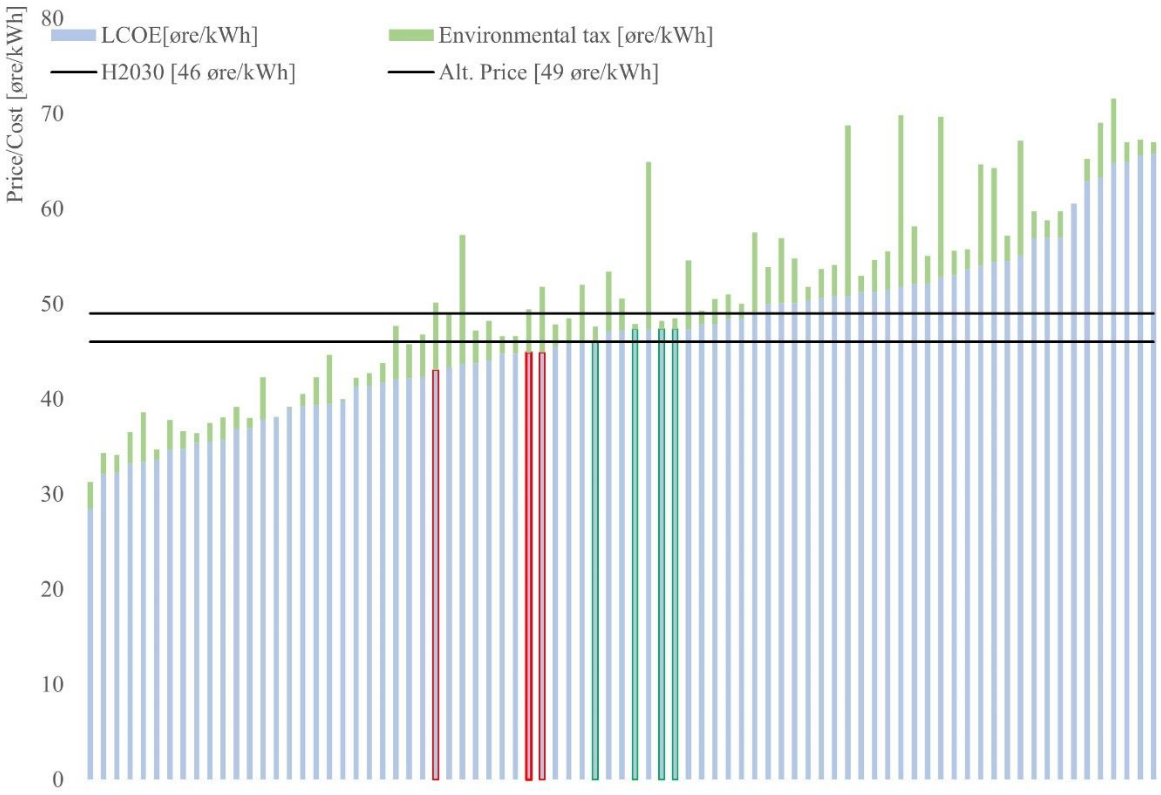

Figure 16: Merit order before and after environmental taxation in the high-price scenario.

5.3. Combination of the two tax schemes

The effects of a tax scheme with both environmental taxation and resource rent taxation are described in chapter 3.5, where the main effect is the reduced resource rent. The power plants will first face the environmental tax in the same way as discussed in the previous chapter, and the new supply curve is the same as in Figure 14. After this upward shift, the resource rent (difference between supply curve and price) is reduced. Total production after the combined tax scheme is equal to the production with environmental taxation alone, as the behavioural response is unaffected by the resource rent tax. The production with environmental taxation (and with a combined tax scheme) was given in Table 11.

The reduction in resource rent in million NOK is illustrated in Table 13. In both the base and high-price scenarios, the resource rent is reduced by about 33% when the environmental tax is introduced. The reduction is partly related to the reduced total production, and partly related to reduced resource rent for the firms who are profitable after environmental taxation.

Table 13: Annual resource rent before and after introduction of environmental taxation [mill NOK].

Price scenario	B2030	H2030
Before environmental tax	170	513
After environmental tax	112	332
Change in resource rent	-58	-181

Despite the reduced annual resource rent and reduced tax income from the resource rent tax consequently, the total tax income is increased. Table 14 gives the total tax income over the lifetime of the power plants. The resource rent tax income is calculated as the NPV of all annual tax income, while the environmental tax is introduced as a one-time tax. The income from the environmental tax is equal to the case where the environmental tax was introduced alone, while the resource rent tax income is reduced by 33% from a case with only resource rent taxation. The total effect of the combined tax scheme is the result of two effects:

i) The resource rent tax is 37%, while the total tax rate with both tax schemes is higher (the same 37% plus environmental taxation) if production remains unchanged.

ii) Total production is reduced from introduction of a combined tax scheme resulting in lower tax income.

In both price scenarios, i) is more important than ii), and the total effect is increased tax income. This means that the effect from a higher total tax for the power plants exceeds the reduced production and loss of tax income from these projects.

Table 14: Total tax income over lifetime with combined tax scheme [mill NOK].

Price scenario	B2030	H2030
Environmental tax	439	1 608
Resource rent tax	648	1 921
Total tax income	1 087	3 529
Resource rent taxation alone	981	2 952
Difference in total tax income	106	577

5.3.1. Reduced resource rent tax

As discussed in chapter 4.4.1, it could be politically convenient to reduce the resource rent tax rate when this tax scheme is combined with environmental taxation. A case with equal total tax income with a combined tax scheme as for the resource rent taxation alone was discussed as a possible case for a lower tax rate in chapter 4.4.1. The tax rate required for this and the required resource rent tax income is given in Table 15. In the base scenario, the tax rate decreases some from the original rate at 37% to 31%, while in the high-price scenario the tax rate would need to be reduced further to 26%.

Table 15: Required resource rent tax rate and income to obtain equal total tax income.

Price scenario	B2030	H2030
Required resource rent tax rate	31%	26%
Environmental tax	439	1 608
Resource rent tax	542	1 344
Total tax income	981	2 952
Resource rent taxation alone	981	2 952

The difference in the required tax rate in the two scenarios is not a set conclusion, but rather related to these specific power plants and their costs and nature encroachment. In the high-price scenario, more projects will be profitable, even though the environmental tax could be high for some of them. As Table 15 illustrates, the environmental tax income in the high-price scenario is more than 50% of the tax income from the resource rent taxation alone, while in the base scenario, the environmental tax income is about 45% of the resource rent tax income. The required resource rent tax income in a combined tax scheme would need to be more than twice as high in the high-price scenario than in the base scenario, while the total tax income is more than three times higher. At the same time, the annual resource rent is almost three times higher in the high-price scenario than the base scenario, as given in Table 13. Less tax income requirements compared to the size of the resource rent results in a lower required tax rate in the high-price scenario than in the base scenario.

6. Sensitivity analysis

There are many uncertain factors in the analysis above. To evaluate the sensitivity towards different factors, multiple sensitivity analyses follow in this chapter. Some uncertainties related to future income for power plants are considered through evaluating different price scenarios in the analysis already. Other uncertain factors to be evaluated are uncertainty related to future costs and discount rate, and the huge uncertainties related to environmental impact and costs. One alternative environmental taxation with one uniform tax rate (instead of a stepwise tax) is also presented to illustrate what effect this would have. A uniform tax could be a relevant case if the categorization is viewed as too complicated or too uncertain.

6.1. Investment costs

Data from license applications and cost estimates used in this analysis contain uncertainty, especially when used to evaluate tax schemes relevant to future power plants. With technological development the costs of wind power production are expected to decrease, both investment costs and operating costs. Changes in either one or both costs will affect the number of profitable projects, and the size of the profit. With decreased costs, the profit and the resource rent will increase together with the tax income from a potential resource rent taxation. Table 16 illustrates how factors discussed earlier will be affected by changes in the investment costs related to wind power plants. Here, only the base scenario is evaluated, with the zonal base scenario prices. In this case, the 100% column has the same costs and results evaluated in the previous analysis, with an average investment cost at 13 million NOK/MW. The large differences in investment costs from a halving to a doubling, gives large variation in the average calculated LCOE. If the investment cost were doubled to 27 million NOK/MW, the average LCOE is above 80 øre/kWh, way above the price, and none of the projects would be profitable in the base scenario. At the opposite end, if the investment cost were halved to 7 million NOK/MW, almost all projects in the data set would be profitable with an average LCOE at 29.7 øre/kWh, and the annual production would be 19 816 GWh. This could generate a tax income of more than 23 billion NOK from a resource rent tax over the lifetime of the projects.

Table 16: Sensitivity in investment costs in base scenario.

Percentage of investment costs	50%	75%	90%	100%	120%	150%	200%
Average investment costs [mill NOK/MW]	7	10	12	13	16	20	27
Average LCOE [øre/kWh]	29.7	38.4	43.6	47.1	54.0	64.4	81.8
Production [GWh/y]	18 188	10 786	5 138	3 381	1 372	543	0
Resource rent [mill NOK/y]	1 820	572	273	170	73	1	0
Resource rent tax income [mill NOK]	18 275	7 799	4 378	982	422	5	0

Because of expectations of decreased future costs for wind power, the columns with decreased costs are most relevant to evaluate. The cost of investments and production has already decreased over the past years, making wind power the cheapest source of new power production (when the wind resources are good), and the costs are expected to keep decreasing from even more improved technology (Statnett, 2020). A decreased operating cost would follow the same trend as decreased investment cost. As the operating costs makes up about 25% of the total costs, and investment cost the rest, the sensitivity related to the operating cost is lower than for the investment cost and changes in the operating cost would have smaller impact than the results in Table 16.

Another outcome from the technological development is increased lifetime for wind turbines. Over the past 10 years, the assumed lifetime has increased from 20 to 25, and this is expected to increase further. This would also increase the profitability of investments and have similar effects as reduced costs in the table.

6.2. Discount rate

Changes in the discount rate used in the LCOE calculations would also affect the profitability of production. As discussed in chapter 3.1.1, there are arguments for using both a discount rate greater than 6% and less than 6%. A greater discount rate would decrease the calculated profitability of power plants and would have similar effects as increased investment costs discussed above. Differently from the change in investment costs, a change in the discount rate would not affect costs or production directly, but instead affect how each firm evaluates the costs. If the discount rate is evaluated from equation (3) given in chapter 3.1, the capital expenditure is affected by the discount rate in the LCOE calculation. With an increased discount rate, the denominator in the element with capital expenditure would decrease, making the value of the capital expenditure distributed throughout the production increase. This would increase the calculated LCOE. A decreased discount rate would do the opposite and decrease the calculated LCOE.

$$\mathrm{LCOE} = \frac{\text{Capital Expenditure}}{\sum_t \frac{Q_{i,t}}{(1+r)^t}} + \sum_t \frac{\mathrm{O\&M}}{Q_{i,t}} \tag{3}$$

To evaluate changes in the discount rate, a higher and a lower level will be evaluated, at 4% and 8% respectively. The 4% rate is related to the recommendation for public CBA (Ministry of Finance, 2014), while the 8% rate is related to a potential higher required rate of return or increased risk in the sector. The decreased discount rate will lower the weight of the capital expenditure in the LCOE calculation, thus reducing the calculated LCOE, while an increased discount rate will have an opposite effect. Table 17 gives some interesting measures to evaluate the sensitivity in the discount rate. As investment costs account for 75% of the LCOE with a 6% discount rate, most of the costs are affected by the change in the discount rate. This makes the LCOE sensitive to differences in the discount rate, as Table 17 illustrates. Since the choice of production and the resource rent is related to the profitability, this is also sensitive to changes in the discount rate, and the differences between a lower rate at 4% and a higher rate at 8% is large.

Table 17: Sensitivity in discount rate in B2030 scenario.

Discount rate	4%	6%	8%
Average LCOE [øre/kWh]	40.74	47.05	53.91
Production [GWh/y]	7 160	3 381	1 372
Resource rent [mill NOK/y]	402	170	74
Resource rent tax income [mill NOK]	2 322	982	426

Given the persistent low interest rate in Norway and other countries over the last decade, and expectations for the interest rate to remain low (Norges Bank, 2021b), firms' required rate of return could decrease. This would make more projects look profitable in a planning phase and increase the number of projects to apply for a license. Oppositely, if the interest rates increase sharply in the future or the risk related to wind power production increases, the discount rate could also increase. This would make less projects profitable and result in less power from wind power production.

Changes in the discount rate can affect the production and resource rent in the long term, but this will not result in rapid changes. It affects firms in the planning phase when the profitability of potential projects is evaluated, and decisions on whether to apply for future licenses. For projects already operating, the investment costs are sunk costs. The decision on whether to produce is related to each year's operating costs and potential income. This is not affected by the discount rate.

6.3. CO_2 taxation

There is a lot of uncertainty related to the environmental taxation in chapter 5, including the nature encroachment, CO_2 emissions, and the costs of emissions. To evaluate the sensitivity to these factors, the subsequent sections follow the same pattern as chapter 5.2, by first implementing only a CO_2 tax, and then expanding this to a total environmental taxation. To evaluate the sensitivity, an increased and a decreased rate will be used for both tax rates. The increased rate corresponds to a doubling, while the decreased rate corresponds to a reduction by 50%. For the CO_2 tax, this is equivalent to a tax on 4 000 and 1 000 NOK/ton CO_2e respectively.

In addition to uncertainty in the valuation, there is also uncertainty related to the actual emissions. The increased (decreased) tax will illustrate the effects if the emissions were higher (lower) than calculated. Table 18 gives the results from a sensitivity evaluation when the firms are faced with a CO_2 tax related to emissions from peatland. The “original” is the same production as presented in Table 10. An extended version of this table divided into each price zone is attached in Table A6.1 in Appendix 6.

Table 18: Sensitivity in total production with CO_2 tax [GWh/year].

	B2030	**H2030**
Decreased (50%)	3 355	8 212
Original	3 355	8 212
Increased (200%)	3 355	7 622
Before tax	3 355	8 212

As Table 18 illustrates, the changes in CO_2 price have almost no effect on the total production. If the price is halved, nothing happens to the production, and if the price is doubled, the production decreases slightly in the high-price scenario. The decrease in the high-price scenario is related to one single project in NO2. Figure 12 gave each firms’ costs related to the CO_2 tax, and for most of the power plants, this cost is very low. For a few, the CO_2 cost is high, but for most of them the increased or decreased cost does not change the choice of producing. From the figures in Appendix 5, one can see that most of the projects with high CO_2 tax also have a high LCOE and have cost above the price even before the tax is introduced. These projects would not produce without any taxes because of high costs and are in that respect not affected by the CO_2 tax.

6.4. Total environmental taxation

The encroachment tax is highly uncertain and also sensitive to changes, more than the CO_2 tax. The main reason for the larger sensitivity is that the tax is greater in the first place, compared to the CO_2 tax, and a doubling or halving of the tax will have greater impact. The huge uncertainty behind this tax is both related to the actual damages and the valuation of such damages as discussed in chapter 3.3 and 3.4. The differences in calculated average and marginal WTA from the CE study by Dugstad et al. (2020) as discussed in chapter 4.4.2 illustrates the large uncertainties related to valuation of damages. In Table 19, the firms face both the CO_2 tax and the encroachment tax, and the production level if the taxes was increased or decreased varies a lot. The decreased (increased) outcome is related to a reduction (increase) in both CO_2 tax and the encroachment tax simultaneous. Table 19 is extended to include price zones in Table A6.2 in Appendix 6.

Table 19: Sensitivity in total production with total environmental tax [GWh / year].

	B2030	H2030
Decreased (50%)	2 975	5 807
Original	2 202	5 027
Increased (200%)	1 955	3 399
Before tax	3 355	8 212

In the base scenario, a decreased total environmental tax will result in an increased production by 35%, while the increased tax will decrease the production by more than 10%. The trend is similar in the high-price scenario, but the effect is lower with the decreased tax and greater with the increased tax. In the high-price scenario the decreased tax will increase production by around 15%, while the increased tax reduces the production by almost 35%. Comparing this to the production without any tax in the bottom row, the production is 10% lower when the tax is introduced at a decreased rate in the base scenario compared to no tax. The production is almost halved if the tax is introduced at an increased rate. In the high-price scenario, the reduction in production from no tax to a decreased tax is almost 30%, while the production is reduced by almost 60% with an increased tax.

The large uncertainties discussed, and the sensitivity related to the environmental tax, especially related to the nature encroachment, make it difficult to decide on the best or optimal tax rate and tax base. These differences will have major impact on the production of wind power in Norway as Table 19 illustrates.

6.5. Uniform environmental taxation

The stepwise action-based environmental tax scheme designed in this analysis could be a challenge to implement in practice. Categorization into 5 different steps, instead of using actual damages from each power plant, is an attempt to reduce these challenges. The purpose of this chapter is not to suggest a uniform environmental tax scheme, but rather illustrate the difference between a stepwise and a uniform tax scheme.

The idea behind a uniform tax scheme is that the wind power industry would pay the external cost related to wind power plants. The burden would not be distributed dependent of each power plant's damages. Rather, it would apply the same yardstick to all power plants and only look at the damages from the production as a whole, not each project individually. A uniform tax scheme might be close to a "correct" compensation for some projects, but far away for others. This is also the case for the stepwise tax scheme, but by the categorization, the tax scheme is closer to an optimal one. When all power plants face the same tax, there are no incentives to choose a location with less damages or encroachment. More efficient spatial allocation is one of the goals of environmental taxation, but this effect would be avoided with a uniform tax. A uniform tax would make someone (here the industry as a whole) pay for the damages from wind power production. However, it would lose several of the goals from environmental taxation, such as making the polluter pay and give incentives to reduce the damages.

The uniform tax is set to the marginal WTA per turbine from Dugstad et al. (2020) as calculated in chapter 4.4 at 3.45 million NOK per turbine. In this case, the scale from the categorization by NINA is not used, and all projects face the same per turbine tax rate. Everything else is kept equal to the calculations done earlier.

Figure 17 illustrates all projects in ascending order of their LCOE before tax with the uniform environmental tax added on top. The figure also illustrates the difference between the LCOE with the uniform tax and the environmental tax used in chapter 5, with both a CO_2 tax an encroachment tax. For those projects in the figure where the dark green bar lies below the other ones, the difference is negative meaning that the total unit cost would be less for these firms with the stepwise tax than with the uniform tax. These power plants are in this analysis assumed to have less negative impact on the environment than what they would need to pay for with a uniform tax. The case is opposite for the projects with the dark green bar on top. These power plants would be better off with a uniform tax than the stepwise tax scheme.

The difference in the spatial allocation and the total production level is small between a uniform and a stepwise tax scheme. This is illustrated by the red and green outlines on the bars. The three green ones are related to the price in the base scenario, while the three red ones are related to the high-price scenario. The red ones are better off with a uniform tax scheme. These are non-profitable projects in the stepwise tax scheme, while they are profitable in the uniform one. The green ones are opposite and would be profitable in the stepwise tax scheme but not in the uniform one. Even though this has minor impact on the total production, it will affect each firms' profitability in either positive or negative direction, as the dark green bars illustrates.

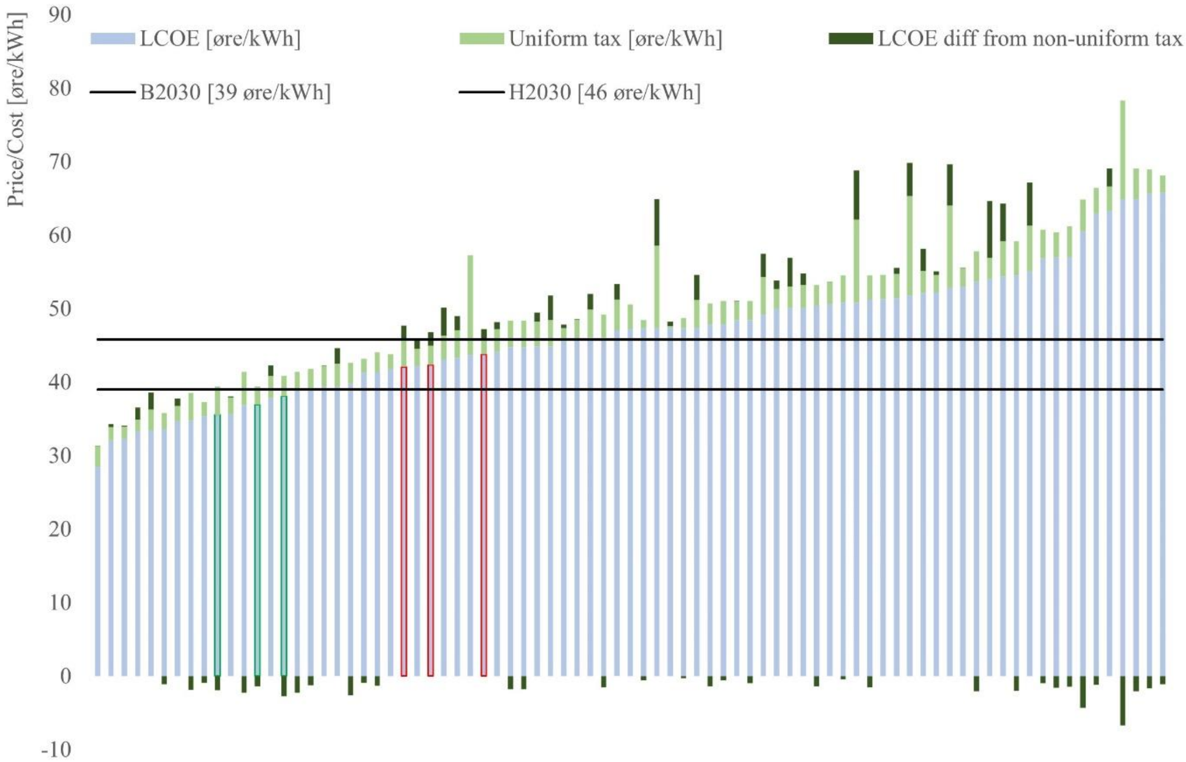

Figure 17: Difference between a uniform and action-based environmental tax scheme.

7. Concluding remarks and recommendations

The analysis presented potential effects on wind power production in Norway resulting from the introduction of different tax schemes with resource rent taxation and environmental taxation. I have analysed how wind power projects would respond to different tax schemes and what the effect of the tax schemes could be, using detailed information about projects holding a license with their respective costs and two scenarios for future electricity prices. Wind power production has increased over past decades and the associated discussions related to nature encroachment have also increased. The discussions are mainly related to the large encroachment from many wind power plants, and their effect on pristine nature and wildlife. It is important to evaluate whether one or several tax schemes should be implemented towards wind power. A resource rent tax would tax the extra profit from exclusive use of an area or a resource, while an environmental tax would tax the destruction and impact on pristine nature and wildlife. In this paper, I have looked at and evaluated potential effects of the two tax schemes separately and combined.

First, I evaluated a resource rent tax scheme in general, and the size of the potential taxable resource rent was calculated. This analysis used the resource rent tax scheme for hydro power as a base, with a tax rate at 37%. With the data set used in this analysis, a total annual resource rent of 170 million NOK would be generated in the base scenario, while it would increase to 513 million NOK with a price increased to the high-price scenario. Over a lifetime of 25 years, this would result in a total tax income of 804 million NOK and 2 425 million NOK in the base and high-price scenario, respectively. The resource rent and associated tax income is highly sensitive to changes in costs, and it could increase a lot with decreased costs from expected technological development. For example, a 50% decrease in investment costs would decrease the LCOE by more than 35%, resulting in more than 5 times higher production and more than 18 times higher resource rent tax income from the projects evaluated. To introduce a resource rent tax scheme for wind power, it would be necessary to create similar terms as the tax scheme on hydro power, with deductions, uplifts, and a possible negative tax, as discussed in chapter 2.3.1. This was not considered in the numerical analysis here, but the overall effect would be an unchanged size of the resource rent and reduced tax income.

Secondly, I evaluated environmental taxation, including optimal design of a tax scheme, the effect on the total power production, and the potential effect on development of wind power plants and their location. An optimal environmental tax is difficult to address, both related to uncertainties in impact and externalities from each power plant, and from the total power production with the difficulties of valuation. Compared to the resource rent tax, an environmental tax is designed to change the behaviour of at least some firms. The goal is for the polluter to pay for their pollution, in this case the encroachment, and to give incentives to reduce the impact or choose areas with less pristine nature or endangered species. Such a tax scheme will increase the costs for most power plants, and thus reduce the total wind power production. For the Norwegian power market, connected to Europe by transmission lines, this could have two possible outcomes. If power can be easily transported from other countries, the Norwegian electricity price will remain quite equal to the price in other countries, and the reduced wind power production will result in increased import (or reduced export). If, on the other hand, transmission capacity is constrained, the Norwegian power market would operate more like a separate market, and the reduced production of wind power would increase the electricity prices, increasing the production of power from other sources as substitutions. In the latter case, the production will decrease some, but less than the reduction in wind power production.

To evaluate potential effects from environmental taxation, a tax scheme with two simplified tax bases were designed, based on emissions and encroachment. I have calculated one CO_2 tax related to potential emissions from peatland in the area, and one stepwise encroachment tax related to 4 different criterions on nature encroachment and wildlife. For most projects, the potential emissions are small, and a CO_2 tax alone will not affect the total production or location of power plants. However, it imposes a cost for many firms, making them pay for their emissions. When the encroachment tax is introduced as well, the effect on production is greater, with a reduction of 1 153 GWh (35%) and 3 185 GWh (38%) each year in the base and high-price scenario, respectively. If the price increases to a level where the total production remains unchanged before and after the tax scheme, the location would change, switching from some projects with large encroachment to other projects with less, as Figure 15 and Figure 16 illustrated. As discussed, there are many uncertainties related the size and tax base for environmental taxation, and as the sensitivity analysis illustrated, the results are sensitive to changes in the tax rate. Different valuation of damages or method for choosing a tax base would change the outcome and potential effects, but environmental taxation will subtly reduce the production, and affect the choice of location.

Lastly, the two tax schemes were combined, taking both the theoretical aspect of optimal design, and using the data to evaluate potential effects. The main question was how an environmental tax affects the resource rent. In a combined tax scheme with both environmental and resource rent taxation, the environmental tax will increase firms' costs and thus, the resource rent will be reduced. Here, the resource rent is reduced by 58 (34%) and 181 million NOK (35%) every year in the two price scenarios. Since the resource rent does not affect firms' behaviour, the production is unchanged from a situation with only environmental taxation. The same goes for the environmental tax income, and even though the resource rent tax income is reduced, the total tax income is increased. A case with reduced resource rent tax rate from the original rate at 37% is also evaluated. This will only affect the tax income, not the size or location of production. If the tax rate were reduced to a level where the total tax income was equal to when the resource rent was introduced alone (at 37%), the resource rent tax rate would need to be 21% and 14% in the base and high-price scenario, respectively.

From this analysis, my recommendation is to introduce an environmental tax on wind power in Norway. Because of the strong sensitivity related to the encroachment tax, more research is needed on this topic to be able to create a best possible tax scheme. There is also uncertainty related to the potential emissions from power plants, but this uncertainty and the related sensitivity is smaller compared to the encroachment. Therefore, a CO_2 tax could be introduced on wind power as a first step towards full environmental taxation, as proposed for degradation of nature in general by Green Tax Commission (NOU 2015: 15, 2015).

Further, a resource rent tax is not relevant with today’s low profitability, but this could be very relevant if the resource rent increases. There are reasons to believe that this will happen because of decreased investment costs and increased electricity prices. My recommendation is to follow this subject closely, and to introduce a resource rent tax when it becomes more relevant. Then, the present resource rent tax scheme for hydro power will work as a good base for a similar tax scheme on wind power.

For further research there is a need for more valuation studies and studies related to damages. This research is essential for creating a good environmental tax scheme. First, the basis for a proper tax rate related to nature encroachment is still limited, and more valuation studies related to wind power in Norway are necessary for the tax rate. Today the number of CE and CV studies are increasing, giving indicators of peoples WTP, but there are still missing studies related to ecological destructions and the value of this. Secondly, a wider basis for the actual damages from encroachment related to wind power would be useful. There are large differences across locations, both related to wildlife, pristine nature, potential emissions, and more. Better data and knowledge on this area would be useful to create a differentiated tax scheme dependent on encroachment. Lastly, related to the resource rent, it is important to evaluate the potential resource rent from wind power regularly as the industry is in continuous development. Altogether, more research in these areas will be useful in further evaluations of potential tax schemes for wind power in Norway.

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Appendix 1: Behavioural response to a production tax

Here, equation (4) is extended to include a tax on production. The firm needs to pay a tax, t, on the level of production, and the new, after tax maximization problem is:

$$\max_{x_1,x_2} \pi = p * (1-t)f(x_1, x_2) - w_1 x_1 - w_2 x_2 \tag{A1.1}$$

The FOC gives:

$$\begin{aligned} \frac{\partial \pi}{\partial x_1} &= p(1-t)\frac{\partial f(x_1,x_2)}{\partial x_1} - w_1 = 0 \\ \frac{\partial \pi}{\partial x_2} &= p(1-t)\frac{\partial f(x_1,x_2)}{\partial x_2} - w_2 = 0 \end{aligned} \tag{A1.2}$$

Solving this gives the optimal solution:

$$\begin{aligned} p(1-t)MP_1 &= w_1 \\ p(1-t)MP_2 &= w_2 \end{aligned} \tag{A1.3}$$

This will have another optimal solution than the one in equation (5). In this case, the optimal solution is where the value of the marginal product, after tax, is equal to unit cost of the input. As this illustrates, a tax on production will affect the behaviour of firms, which was not the case for the resource rent tax. Therefore, a resource rent tax, as a tax on profit, is a better choice to obtain the optimal level of production and not affect firms' behaviour.

Appendix 2: Summary of data

Wind power plant	Region	Effect [MW]	Energy [GWh]	Invest. cost [kNOK/MW 2020]	Opper. cost [kNOK/GWh 2020]	Turbines	LCOE [øre/kWh]	Emission [ton CO2e]	Encroachment value (NINA)	LCOE w/ env. tax [øre/kWh]
WPP1	NO1	75	235	15288	119	27	50,1	23871	2	54,8
WPP2	NO1	145	390	13638	119	47	51,5	20368	2	55,5
WPP3	NO1	108	340	15350	119	37	50,1	116828	1	56,9
WPP4	NO1	46	111	13096	119	12	54,0	54559	2	64,6
WPP5	NO2	1	4	13754	115	2	43,7	0	2	57,2
WPP6	NO2	2	5	14885	120	2	50,8	332	3	68,8
WPP7	NO2	74	222	12199	114	27	43,0	30696	3	50,1
WPP8	NO2	4	12	16362	136	5	53,6	N/A	N/A	-
WPP9	NO2	71	220	15143	90	31	47,4	20800	3	54,6
WPP10	NO2	42	126	9995	120	13	38,1	243	0	38,1
WPP11	NO2	30	65	9807	117	10	47,1	196	3	53,4
WPP12	NO2	10	36	10508	119	3	35,7	324	2	38,1
WPP13	NO2	7	23	10542	143	2	39,1	155	0	39,2
WPP14	NO2	60	181	15007	117	20	50,6	664	2	53,6
WPP15	NO2	30	85	9557	129	9	39,3	555	2	42,3
WPP16	NO2	112	370	14855	132	35	48,5	7328	1	50,1
WPP17	NO2	39	85	11537	123	13	53,7	0	1	55,7
WPP18	NO2	139	543	9544	132	33	32,3	6879	2	34,1
WPP19	NO2	30	117	14371	106	13	39,5	4780	3	44,6
WPP20	NO2	2	6	16362	136	3	64,8	0	1	71,6
WPP21	NO2	95	363	9776	122	24	32,1	9718	2	34,3
WPP22	NO2	2	7	15636	120	3	52,8	0	3	69,7
WPP23	NO2	12	35	15364	174	5	56,9	2107	1	59,8
WPP24	NO2	155	558	14526	132	70	44,9	42268	2	49,4
WPP25	NO2	6	25	10824	119	2	33,6	0	1	34,7
WPP26	NO2	25	96	14225	146	8	43,8	449	3	47,2
WPP27	NO2	135	405	15108	127	45	52,1	160	4	58,1
WPP28	NO2	90	270	13754	115	3	47,3	12846	1	48,2
WPP29	NO2	76	230	12851	126	23	45,8	272	2	48,5
WPP30	NO2	208	670	12506	119	64	42,4	23741	3	46,8
WPP31	NO2	60	190	15637	122	26	50,8	17158	1	54,1
WPP32	NO2	36	95	16642	76	12	57,0	709	1	58,8
WPP33	NO2	160	550	15561	176	50	53,0	4050	2	55,6
WPP34	NO2	10	35	12676	157	4	44,1	2201	2	48,2
WPP35	NO2	7	26	13754	115	2	41,3	N/A	N/A	-
WPP36	NO2	150	434	9707	136	45	39,8	5302	0	40,0
WPP37	NO3	55	211	11749	115	15	35,4	687	1	36,4
WPP38	NO3	58	175	8867	127	25	35,5	4	1	37,5
WPP39	NO3	55	138	13754	115	24	54,5	3018	1	57,2
WPP40	NO3	12	35	12745	133	4	46,1	0	1	47,6
WPP41	NO3	4	10	13754	115	5	51,8	2903	2	69,8
WPP42	NO3	150	356	10381	149	68	49,2	71725	2	57,5

WPP43	NO3	4	12	13754	115	5	47,3	4872		2	64,9
WPP44	NO3	18	53	9930	109	6	37,9	4872		2	42,3
WPP45	NO3	70	238	17101	86	28	47,9	39429		0	50,5
WPP46	NO3	115	342	13319	134	32	48,4	913		2	51,0
WPP47	NO3	7	20	13050	167	4	51,9	N/A	N/A	-	
WPP48	NO3	122	368	19723	147	45	65,6	104		1	67,3
WPP49	NO3	90	300	14293	97	42	43,3	204		3	49,0
WPP50	NO3	256	900	21894	147	110	63,3	47182		3	69,1
WPP51	NO3	113	405	9258	82	42	28,5	1002		2	31,3
WPP52	NO3	151	457	15101	125	53	51,6	N/A	N/A	-	
WPP53	NO3	91	245	13754	115	30	51,3	0		2	54,6
WPP54	NO3	59	197	14117	119	26	44,9	19527		3	51,8
WPP55	NO3	130	370	13216	97	52	46,1	5602		3	52,0
WPP56	NO3	13	36	9657	71	5	34,8	0		1	36,7
WPP57	NO3	150	405	14013	122	96	52,8	N/A	N/A	-	
WPP58	NO3	288	973	13750	104	85	42,2	1926		3	45,8
WPP59	NO3	94	290	15841	122	26	52,2	8445		2	55,1
WPP60	NO3	8	24	13754	115	1	47,3	0		1	47,9
WPP61	NO3	66	225	11444	71	24	33,4	13351		3	38,6
WPP62	NO3	160	450	12028	144	47	47,9	0		1	49,3
WPP63	NO3	80	250	15336	120	26	50,4	0		1	51,8
WPP64	NO3	50	171	9770	122	13	34,7	0		3	37,8
WPP65	NO3	45	121	13349	182	19	57,0	4921		1	59,7
WPP66	NO3	7	13	10859	94	3	55,1	4872		2	67,2
WPP67	NO3	10	30	12608	171	3	50,0	4921		1	53,9
WPP68	NO3	21	65	12336	109	9	42,1	0		3	47,7
WPP69	NO3	179	537	13754	115	28	47,3	39429		0	48,5
WPP70	NO3	13	45	13754	115	3	41,3	0		1	42,2
WPP71	NO3	56	150	13754	115	18	51,3	687		1	53,0
WPP72	NO4	7	22	13754	115	3	44,8	0		1	46,6
WPP73	NO4	25	82	13754	115	11	44,8	0		1	46,6
WPP74	NO4	54	139	16698	122	18	62,9	4929		1	65,2
WPP75	NO4	160	453	15860	106	80	54,4	148427		2	64,3
WPP76	NO4	197	541	17844	149	47	65,8	1451		1	67,0
WPP77	NO4	5	16	14428	119	2	47,2	0		2	50,6
WPP78	NO4	100	300	14656	73	20	45,5	9631		2	47,8
WPP79	NO4	200	708	11590	136	67	39,2	0		1	40,5
WPP80	NO4	120	345	15955	215	53	64,9	0		1	67,0
WPP81	NO4	10	40	14972	125	3	41,8	0		2	43,8
WPP82	NO4	330	1100	12842	112	109	41,4	0		1	42,7
WPP83	NO4	50	154	9671	122	14	36,9	10397		0	38,0
WPP84	NO4	99	380	10349	122	23	33,3	0		4	36,5
WPP85	NO4	41	100	14607	143	16	60,5	0		0	60,5
WPP86	NO4	39	119	11382	76	20	36,9	0		1	39,2
WPP87	NO5	160	391	12780	168	39	57,7	N/A	N/A	-	
WPP88	NO5	10	30	14972	125	1	51,5	N/A	N/A	-	

Appendix 3: Calculation of emissions from peatland

Based on Nayak et al. (2010) calculations of both causes for emissions from peatland can be estimated. The loss of potential carbon fixing capacity, L_{fix} is calculated as:

$$L_{fix} = (A_{direct} + A_{indirect}) * G_{bog} * t_{restore} \tag{A3.1}$$

where A_{direct} is the area of direct impact by infrastructure, while $A_{indirect}$ is the area of indirect impact by drainage. G_{bog} is the carbon fixing capacity of undeveloped peatland measured in t CO_2 ha^{-1} y^{-1} and $t_{restore}$ is the time in years until the area is successfully restored. These calculations assumes that the area is fully restored after the production in closed. Restauration of peatland through rewetting can get the carbon sequestration back at the same level as before the wind power production started in the area (Joosten et al., 2015).

While the drainage and removal increase the CO_2 emissions, emissions from CH_4 is reduced (Nayak et al., 2010). To calculate the emissions from the destroyed peatland, L_{dest}, the emissions from flooded peatland, $L_{undrained}$, are subtracted from the emissions from the drained or removed area, $L_{drained/removed}$, as:

$$L_{dest} = L_{dr/rem} - L_{undrained} \tag{A3.2}$$

These two factors are calculated separately. The drained and removed area is calculated by the annual CO_2 emissions from destroyed areas, E_{CO2}, as:

$$L_{dr/rem} = E_{CO2} * A * t_{restore} \tag{A3.3}$$

Further, for undrained areas, it is calculated using the CH_4 emissions from flooded areas in the periods of flood, and the CO_2 emissions from drained soil in the period of no flood, as:

$$L_{undrained} = (E_{CO2} + E_{CH4}) * A * t_{restore} \tag{A3.4}$$

Where:

$$E_{CO2} = R_{CO2} * \frac{365-D_F}{365} \tag{A3.5}$$

$$E_{CH4} = R_{CH4} * \frac{D_F}{365} * C_{CH4 \to CO2} \tag{A3.6}$$

The R-factors are the annual rates of CO_2 and CH_4 emissions, D_F is the number of days in a year that the land is flooded, and $C_{CH4 \rightarrow CO2}$ converts CO_4 into CO_2 equivalents, equal to 30.67 (Nayak et al., 2010).

Area of direct impact would be the area for new infrastructure related to the wind power production. This is mainly related to the turbines and new roads. The indirectly affected areas could be areas around the directly impacted areas, which are drained. The maps over license areas provided by NVE shows the total area of the license, but not the exact location of each turbine and roads. In most cases, the production will not affect the whole license area, but in some cases it might, and it can be seen as a worst-case scenario. In the analysis, this license area will be used as a worst-case total area of both infrastructure and drainage (areas of direct and indirect impact). Each of the license areas are analysed using Kilden to estimate the area of peatland in each license area.

The carbon fixing capacity can be difficult to measure and depends on many factors. This can vary between and within countries, related to debt, type, temperature etc. de Wit et al. (2015) estimated a net carbon uptake by peatlands in Norway to be 19 $gCm^{-2}y^{-1}$ (±15). This estimate is within the range of other similar estimations for Norway ranging from 11 to 32 $gCm^{-2}y^{-1}$ (de Wit et al., 2015). Carbon can be converted into CO_2 equivalent by the molecular weight of CO_2, 44, divided by the atomic weight of C, 12, giving a factor at 3.667 (EPA, n.d.). Converting the estimate by de Wit et al. (2015) to the same unit of measurement as the equations from Nayak et al. (2010), gives 0.70 $tCO_2ha^{-1}y^{-1}$ for Norwegian peatland.

There are no good estimates for emission factors for dried or flooded peatlands in Norway, but IPCC (Intergovernmental Panel on Climate Change) has provided default values, specified to the climate in the area. For CO_2 emissions from drainage in boreal zones the default factor is 2.8 $tCO_2\text{-}Cha^{-1}y^{-1}$, equal to 10.267 $tCO_2ha^{-1}y^{-1}$ (IPCC, 2014, 2.14). CH_4 emissions for flooded land in boreal climate has a default factor at 0.086 $kgCH_4ha^{-1}day^{-1}$, equal to 0.0314 $tCH_4ha^{-1}y^{-1}$ (IPCC, 2006, Ap3.5). A factor at 25 is used to convert CH_4 into CO_2 equivalents. These default factors will be used in the calculations.

Number of flooded days, D_F, is an important factor in calculating the emissions. For pristine peatland, the CO_2 emissions will decrease when the area is flooded, while the CH_4 emissions will increase. IPCC's default value for acid bogs, which is widely spread in Norway, is 178 days in a year (IPCC, 2006), and will be used in these calculations.

Lastly, an estimate on the time it takes to restore the area is needed as $t_{restore}$. Here it is assumed that areas will be rewetted after the power plant is shut down. $t_{restore}$ is the total time from the peatland is destroyed, until it is back in the same conditions as before, i.e., the time of operation (25 years) plus the time it takes to restore the area afterwards. When rewetting is started, the methane emissions can increase some during the first years, and spike during the first ten years (Moxey & Moran, 2014). Thereafter it is reduced, back to a level similar to the untouched peatland after around 15 years. This gives a total of 40 years from the first intervention until the peat is somewhat restored.

All estimates used in calculating the emissions from peatland is given in Table A3.1.

Table A3.1: Estimates used to calculate emissions from peatland.

Symbol	Definition	Value	Units
$\boldsymbol{G_{bog}}$	Carbon accumulation rate	19	$gCm^{-2}y^{-1}$
$\boldsymbol{t_{restore}}$	Time of restoration	40	Years
$\boldsymbol{R_{CO2}}$	CO_2 emissions from dried peat	2.8	tCO_2-$Cha^{-1}y^{-1}$
$\boldsymbol{R_{CH4}}$	CH_4 emissions from flooded peat	0.086	$kgCH_4ha^{-1}day^{-1}$
$\boldsymbol{D_F}$	Days of flooded peatland each year	178	Days
$\boldsymbol{C \rightarrow CO_2}$	Convert C to CO_2	3.667	
$\boldsymbol{CH_4 \rightarrow CO_2}$	Convert CH_4 to CO_2	25	

Appendix 4: Resource rent taxation with omitted power plants

Table A4.1: Decreased version of Table 6: Production in each power zone [GWh per year].

	B2030	H2030
NO1	0	0
NO2	1 752	4 492
NO3	1 223	2 359
NO4	380	1 361
NO5	0	0
Total	3 355	8 212

Table A4.2: Decreased version of Table 8: Resource rent tax income [mill NOK].

Price scenario	B2030	H2030
Total annual tax income	63	189
Total tax income over lifetime	981	2 952

Appendix 5: LCOE with taxes divided into price zones

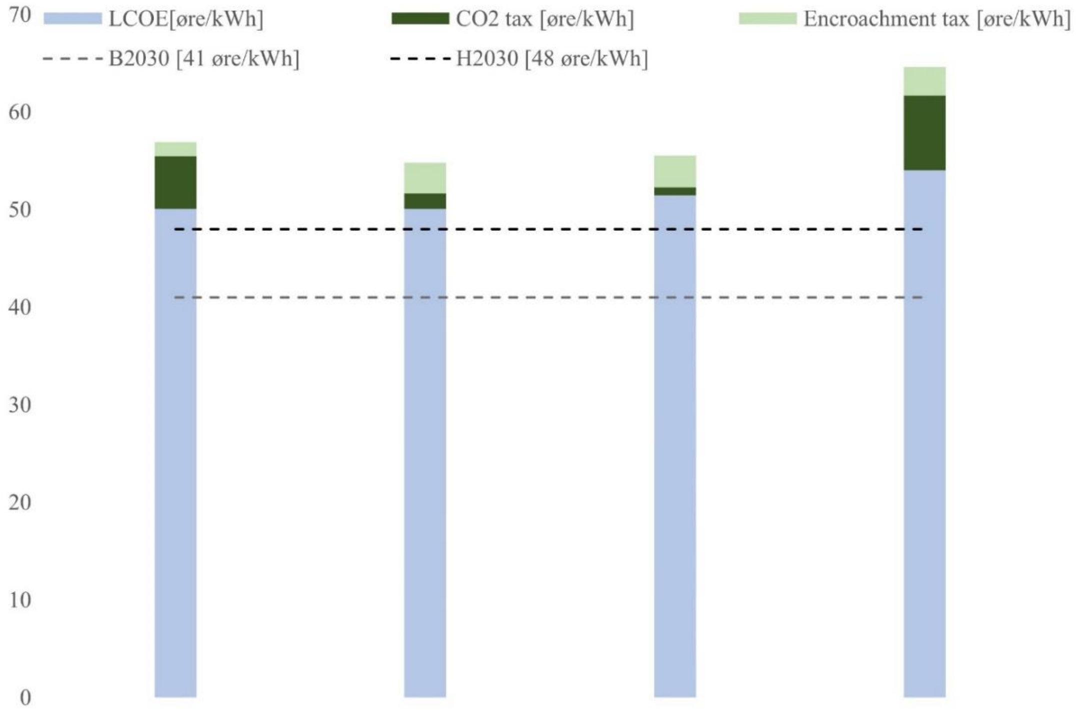

Figure A5.1: LCOE including CO2 tax and encroachment tax for power plants in NO1.

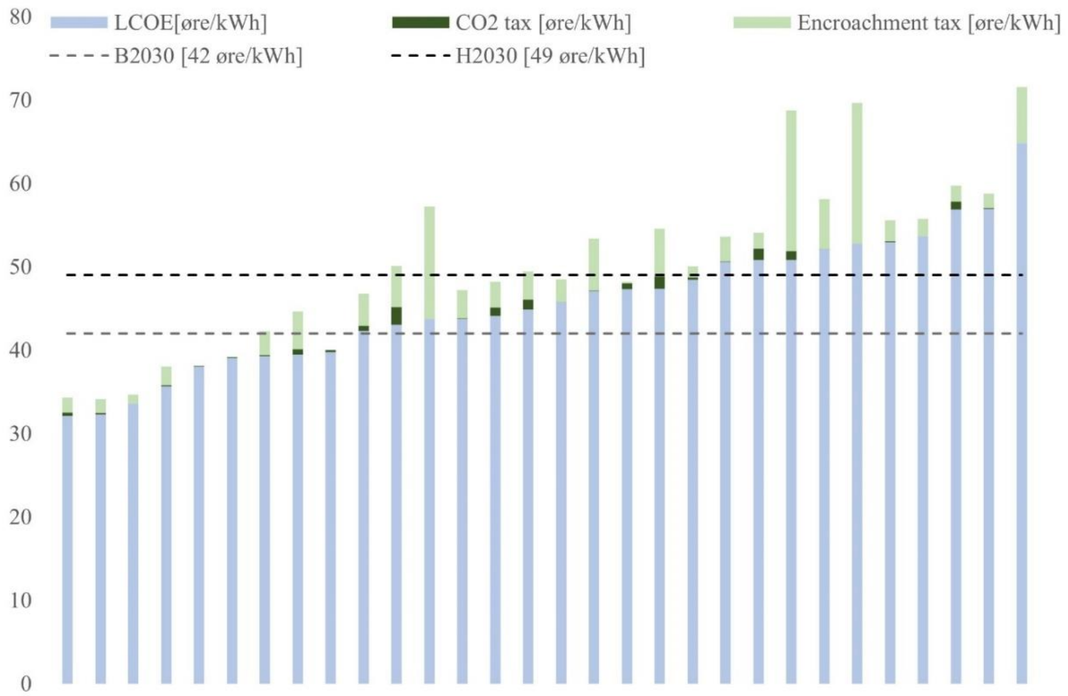

Figure A5.2: LCOE including CO2 tax and encroachment tax for power plants in NO2.

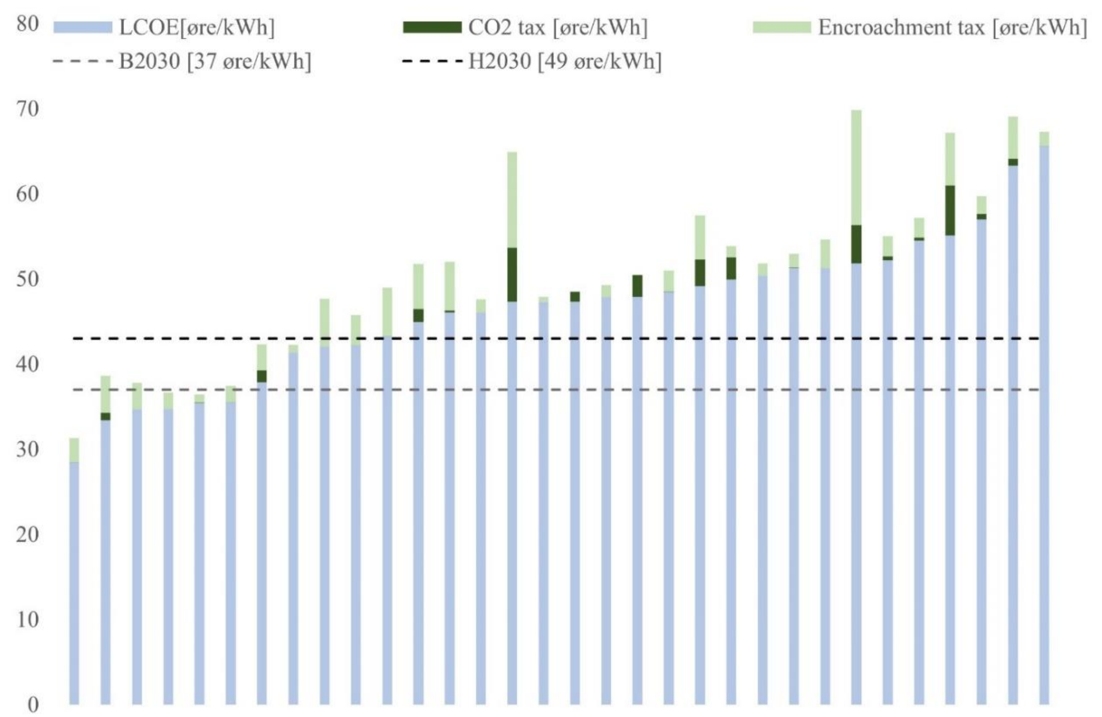

Figure A5.3: LCOE including CO2 tax and encroachment tax for power plants in NO3.

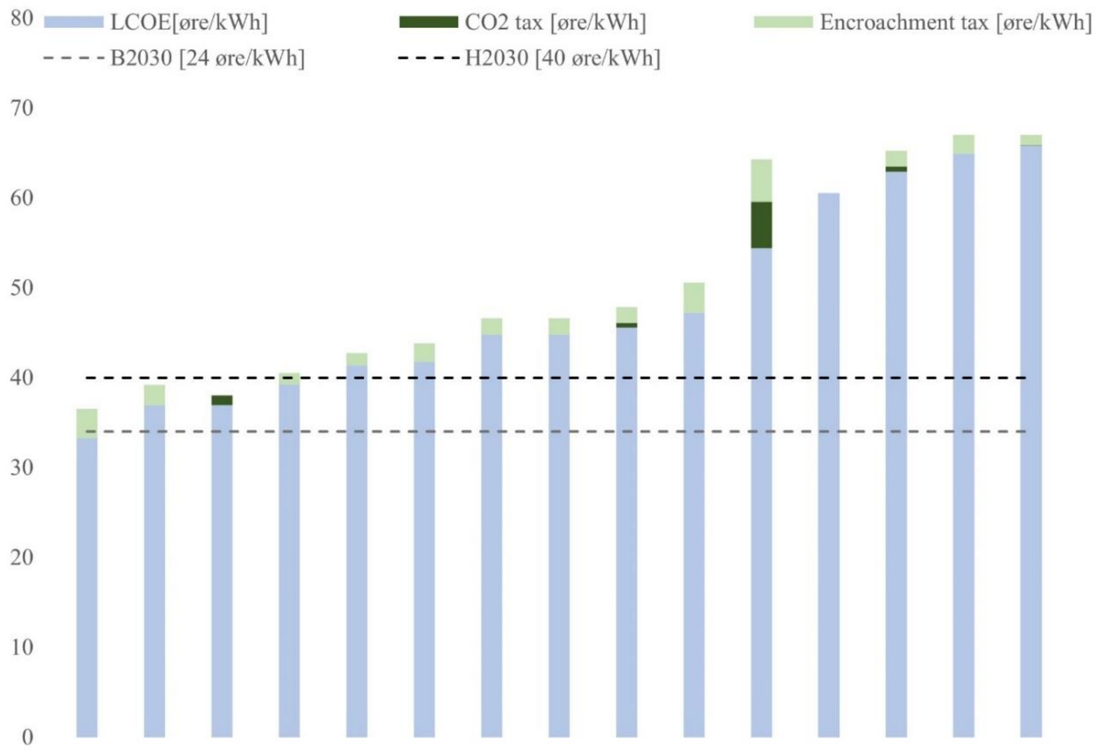

Figure A5.4: LCOE including CO2 tax and encroachment tax for power plants in NO4.

Appendix 6: Sensitivity analysis on environmental taxation

Table A6.1: Sensitivity in total production with CO_2 tax [GWh/year].

Price zone	Sensitivity	B2030	H2030
NO1	Decreased	0	0
	Original	0	0
	Increased	0	0
NO2	Decreased	1 752	4 492
	Original	1 752	4 492
	Increased	1 752	3 902
NO3	Decreased	1 223	2 359
	Original	1 223	2 359
	Increased	1 223	2 359
NO4	Decreased	380	1 361
	Original	380	1 361
	Increased	380	1 361
NO5	Decreased	0	0
	Original	0	0
	Increased	0	0
Total	**Decreased**	**3 355**	**8 212**
	Original	**3 355**	**8 212**
	Increased	**3 355**	**7 622**

Table A6.2: Sensitivity in total production with environmental taxation [GWh/year].

Price zone	Sensitivity	B2030	H2030
NO1	Decreased	0	0
	Original	0	0
	Increased	0	0
NO2	Decreased	1 752	3 833
	Original	1 550	3 053
	Increased	1 550	2 022
NO3	Decreased	1 223	1 321
	Original	652	1 321
	Increased	405	1 223
NO4	Decreased	0	653
	Original	0	653
	Increased	0	154
NO5	Decreased	0	0
	Original	0	0
	Increased	0	0
Total	**Decreased**	**2 975**	**5 807**
	Original	**2 202**	**5 027**
	Increased	**1 955**	**3 399**

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