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Guarantees of origin for electricity – an analysis of its potential to increase new renewable energy in the North European energy system

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Preface

This study is part of the project DIgitalisert Node-trading for fornybar energi med GO (DINGO), https://norsus.no/en/prosjekt/dingo/#. The project aims to improve the effectiveness of GO transactions and thus increase the income for renewable energy generators selling GO. Work package 2 aims to analyze the potential impact of increased income for the producers from selling GO. Thomas Martinsen was work package leader and is main author of the report. Marine Mouilleron did her master thesis on the subject "Impact of the Guarantees of Origin on investments in renewable energy in the Netherlands". Jon Gustav Kirkerud did the Balmorel model analysis.

Norsk sammendrag

Opprinnelsesgaranti-ordningen (OG) er kritisert for ubetydelig innvirkning på utbygging av ny fornybar energi og bidrag til reduksjon av CO_2-utslipp. Det begrunnes med at salg av OG fra gammel vannkraft, norsk vannkraft spesielt, gir kjøperne et miljøalibi uten noen reelle endringer i energisystemet fordi prisen på OG er for lav. Vannkraft utgjør omtrent halvparten av alle OG-sertifikater som kanselleres i Europa. OG fra vannkraft utstedes av Østerrike, Finland, Frankrike, Tyskland, Italia, Norge, Spania, Sverige og Sveits. OG-markedet har vokst jevnt det siste tiåret, og RECS International forventer en dobling av markedet frem mot 2025. Den forventede veksten i etterspørsel etter OG er vesentlig større enn det resterende tilbudet av gammel vannkraft i markedet. Gammel vannkraft vil dermed utgjøre en stadig mindre andel av OG markedet fremover. Det er også økende betalings-villighet for OG fra ny fornybar energi. Analyse av Levelized Cost of Energy (LCOE) indikerer at differansen mellom LCOE for ny fornybar energi og forventet markedspris er innenfor betalingsvillighet for OG. Analyseresultatene av LCOE har lav følsomhet for CO_2 kostnad opp til 30 € / tonn. For å vurdere påvirkning av en betalingsvillighet for OG analyserer vi to scenarier der inntektene fra OG blir allokert til ny fornybar energiproduksjon. Ved å bruke den nordeuropeiske markedsmodellen Balmorel anvender vi et systemperspektiv som også tar hensyn andre faktorer enn LCOE, e.g., etterspørsel etter elektrisitet og overføringskapasitet mellom regioner. Scenario 1 antar en inntekt fra OG på 4 € / MWh for ny fornybar energiproduksjon fra vind, sol-PV, og bioenergi. Scenario 2 antar 10 € / MWh i Nederland og 4 € / MWh i andre land. Resultatene viser økt fornybar energiproduksjon, spesielt vindkraft. Den ekstra vindkraften er ikke jevnt fordelt i det Nordeuropeiske kraftsystemet. Med 10 € / MWh i Nederland øker offshore vindkraft betydelig i Nederland og fortrenger delvis vindkraft og sol-PV i andre land. Basisscenarioet uten OG viser betydelig reduksjon i utslipp av CO_2. Med 4 € eller høyere betalingsvillighet indikerer analysene at OG vil bidra til ytterligere noe økt fornybar energiproduksjonen og redusert utslipp av CO_2. Samtidig viser analysene lavere strømpriser sammenlignet med et basisscenario. Nettokostnaden for kjøper av OG vil derfor reduseres.

Summary

The guarantee of origin scheme (GO) has been criticized for its insignificant impact on the development of new renewable energy and the contribution to reducing CO_2 emissions. The reason is that sales of GO from old hydropower, Norwegian hydropower in particular, give buyers an environmental alibi without any real changes in the energy system because the price of GO is too low. Hydropower accounts for about half of all GO certificates canceled in Europe. GO from hydropower is issued by Austria, Finland, France, Germany, Italy, Norway, Spain, Sweden and Switzerland. The GO market has grown steadily over the past decade, and RECS International expects a doubling of the market by 2025. The expected growth in demand for GO is significantly larger than the remaining supply of old hydropower GOs in the market. Old hydropower will thus constitute an increasingly smaller share of the GO market in the future. There is also an increasing willingness to pay for GO from new renewable energy. Analysis of Levelized Cost of Energy (LCOE) indicates that the difference between LCOE for new renewable energy and expected market price is within willingness to pay for GO. Furthermore, the LCOE-analysis exhibits low sensitivity to CO_2 cost up to 30 € / ton. To assess the impact of a willingness to pay for GO, we analyze two scenarios where the income from GO is allocated to new renewable energy production. Using the Northern European market model Balmorel, we apply a systems perspective that also considers factors other than LCOE, e.g., demand for electricity and transmission capacity between regions. Scenario 1 assumes an income from GO of 4 € / MWh for new renewable energy production from wind, solar PV, and bioenergy. Scenario 2 assumes 10 € / MWh in the Netherlands and 4 € / MWh in other countries. The results show increased renewable energy production, especially wind power. The extra wind power is not evenly distributed within the North European energy system. With 10 € / MWh in the Netherlands, offshore wind power increases significantly in the Netherlands and partially displaces wind power and solar PV in other countries. The baseline scenario without GO shows a significant reduction in CO_2 emissions up to the year 2035. With 4 € or higher willingness to pay, the analysis indicate that GO will induce a small increase in renewable energy production compared to the baseline and thus reduce CO_2 emissions. The scenario results also exhibit lower electricity prices compared to a base scenario. The net cost for the buyer of GO will therefore be reduced.

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1 Introduction

The prime purpose of the Guaranties of Origin (GO) scheme is to disclose information on the origin of electricity produced and thus to provide an opportunity for consumers to influence the development of the energy system (Jansen et al., 2016). The European Union introduced the GO concept in the EU directives on renewable energy (2009/28/EC) and the electricity market directive (2009/72/EC). The scheme facilitates the provision of information to the consumers on the origin of an energy carrier. That is, the power plant in the contract between the producer and the consumer has produced an equal amount of the energy carrier as the consumer has used. Until recently the energy carrier has been electricity. There is no direct electrical link between the producer and the consumer. The consumer may thus influence the choice of electricity generating technology in any of the participating countries. Participation in the scheme is voluntary and not connected to the renewable target. The impact of GOs on the transition of the energy system away from fossil fuel towards renewable energy sources is thus dependent on the consumers' willingness to pay the additional cost. Moreover, the scheme has been criticized for its limited contribution to the transition to renewable energy and is suggested to be merely useful in providing a green image for producers and consumers. However, awareness has increased, and some consumers are critical towards old Norwegian hydro GO and rather request GO from new renewable energy. In 2018 the wholesale market price for GO saw an unprecedented increase (Greenfact, 2019). The EU directive (2009/72/EC) with the rules for GO have been revised and the possibility for producers to claim the origin using other certificates than nationally certified GOs is removed. Any producer who wishes to guarantee the origin of its electricity must do so by GO. This may further increase the price of GO. We analyse the potential impact from an increase in income from sale of GOs on the deployment of renewable energy in the North European energy system.

The report is organised as follows. The critique of the GO scheme and relevant aspects of the energy market development described in the next section. In chapter 3 we outline the energy market analysis and provide the modelling results. A brief discussion and conclusion are given in chapter 4 and 5 respectively.

2 Energy market and Guarantees of origin

2.1 The critique

Two related problems with the market-based instruments to stimulate the renewable energy sector, emissions accounting and GO, have been identified. The first problem is that purchases of green electricity certificates fails to create new renewable energy capacity. Earlier the price of GO was deemed too low and the income uncertain for investors (Raadal et al., 2012). This argument has been supported by Mulder and Zomer (2016) who argue that the abundant number of GOs from Norwegian hydropower reduce the policy to a marketing instrument for retailers with little or no incentive for increased investment in renewable energy. Indeed, in many countries renewable energy generation is supported by subsidies or legacy investments, and the revenue from participating in a scheme like GO is negligible and uncertain when taking the decision to invest in renewable technologies (Brander et al., 2018). For business looking for a green image, low priced GOs may provide just that. Moreover, Brander et al. (2018) argued that the money used to purchase GOs would provide more environmental benefits if spent, e.g., on improving energy efficiency. Nordenstam et al. (2018) argue that using GO-certified electricity can counteract combined heat and power (CHP) production and its contribution to GHG emission reductions. The second problem is related to the use of contractual emission factors and their impact on the accuracy of greenhouse gas (GHG) emission inventories and relevance to emission reductions. A company buying GOs may use the emission factor of the origin of the electricity to calculate their GHG emissions. Thus, the term contractual emission factors. For example, companies that buy GOs may report a zero footprint while not reducing their emissions or changing their methods of production. There is no emissions reduction within production facility and still, the company has acquired a green profile. The contractual emission factors may be used for marketing purposes. On the other hand, companies implementing energy efficiency programs will appear to have a bigger footprint while they contribute to reduce electricity from fossil sources feeding the grid. Their profile will appear to be less green than the companies buying GOs despite the fact that their contribution to emission reductions is higher and actually occurs in a direct way (Brander et al., 2018). Contractual emissions factors may thus give the false impression that GHG are reduced. The common underlying cause is the abundance of, and preference for, low price GOs issued from existing renewable energy generation.

2.2 Implementation of the GO scheme

National implementation of the GO scheme is well established in many European countries with a national entity issuing and cancelling the GO. The ability to combine GOs with other policies promoting renewable energy generation varies. In Croatia, France, Germany, Ireland, Luxembourg, Portugal and Switzerland the entity cannot issue GO if the producer receives some form of support from the government. In the Netherlands sale of GO may be combined with other policies. In the revised EU-directive (2009/72/EC) any renewable energy producer who wish to guarantee the origin of its electricity must now do so by nationally certified GOs. However, this requirement only applies to the producer and not the consumers. A product manufacturer, e.g., aluminium production is a consumer of energy and may claim it is using only renewable hydropower without further documentation. In the end, customers may demand certified GOs and thus force the manufactures to use electricity with certified GOs.

Total GOs issued in 2018 were equivalent to 791 TWh. Currently more GOs are issued than are cancelled. In total were GOs representing 702 TWh cancelled in Europe in 2018. Thus, there is a surplus of GOs in the market. GOs issued by owners of hydro power plants constitute the largest share of GOs issued in 2018. They make up 58 % or 404 TWh of total volume. GOs from hydropower are in 2018 provided by Austria, Finland, France, Germany, Italy, Norway, Spain, Sweden and Switzerland. Norway is the largest issuer of hydro GOs with 134 TWh in 2018, but only 27 TWh of these was cancelled (RECS, 2018). About all the hydro GOs issued from the other countries were cancelled. Austria had in 2018 the largest number of hydro GOs cancelled, but a major part was national GO cancellation. The market development exhibits a continuous growth since 2009 in both the total number issued and cancelled. A forecast up to 2025 indicates an increase in both issued and cancellations of GOs. RECS (2018) assume the demand for GOs to increase more than the supply. Using the compound annual growth rate (CGAR) from the past decade they estimate the market will trade GOs representing 1323 TWh in 2025. This implies an average annual growth rate at 7.6 %.

2.3 Marginal cost pricing for electricity

The principle behind marginal cost pricing is that the price is fixed at the cost of producing one extra unit. There is a distinction between the Short Run Marginal Cost (SRMC) and the Long Run Marginal Cost (LRMC). The SRMC for energy generation from a certain technology is horizontal in a graph, as once in operation there is almost no extra cost to produce one more MWh. Moreover, the marginal cost of renewable electricity in the short term is low, because there is no cost for fuel. In the short run, we satisfy demand by increasing the energy input to the system using existing generation capacity. The most expensive generation technology determines the market price (see Figure 1). In the context of LRMC, there is time for investment in new production capacities. When the investment is made, only operation cost influences the merit order. For an investor, grid parity is reached when the levelized cost of electricity (LCOE) is equal or less than the average SRMC.

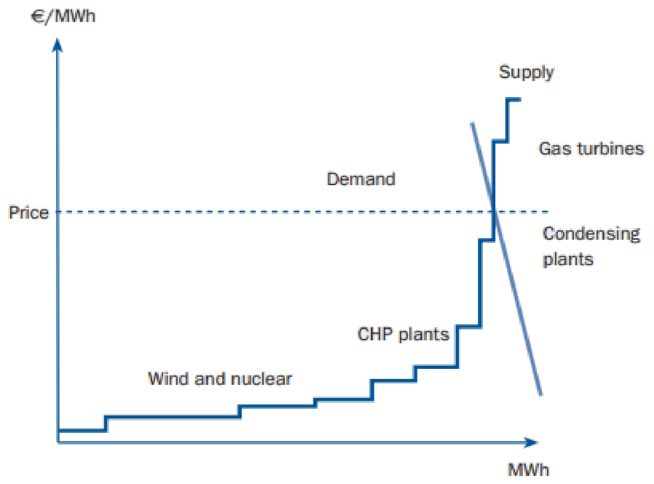

Figure 1 Illustration of short run marginal cost of electricity (merit order). The price balancing supply and demand indicates the SRMC.

2.4 Guaranties of origin contributing to learning investment

Renewable energy conversion technologies still cannot compete in most markets without policy support. Policies include the CO_2 emission trading scheme and feed-in tariffs. GO, like feed-in tariff, generate an income based on the amount of energy produced. This income helps pay the difference between the energy generation cost and the marginal technology setting the SRMC. The cost difference is called “learning investments” because the producers learn how to be more efficient and thus cost is reduced as accumulated deployment of the renewable technology increases (Martinsen, 2011). Thus, if deployment is increased because of the GO scheme the investment cost will decline faster. The consumer buying the GO provide the learning investment.

2.5 Changes in energy sale value over the lifetime of a technology

The annual average electricity price is expected to increase in the future. The demand for electricity is at times equal or smaller than the generation by wind power. The low SRMC for wind power then set the electricity price in the market. Kirkerud et al. (2017) found that increased use of power-to-heat in district heating systems may increase the value factor and thus the average electricity price (see Figure 2). Perez-Linkenheil (2017) analysed the EU electricity system and concludes that there will be more low or negative electricity prices in the future, but also periods with very high prices. They found that the benefit during periods with high prices for wind power outweighs the periods with low prices. Their conclusion is therefore that the wind power annual average sale value will increase up to 2040 (see Figure 3). Assuming constant electricity price over the lifetime of a technology may not be appropriate when evaluating grid parity.

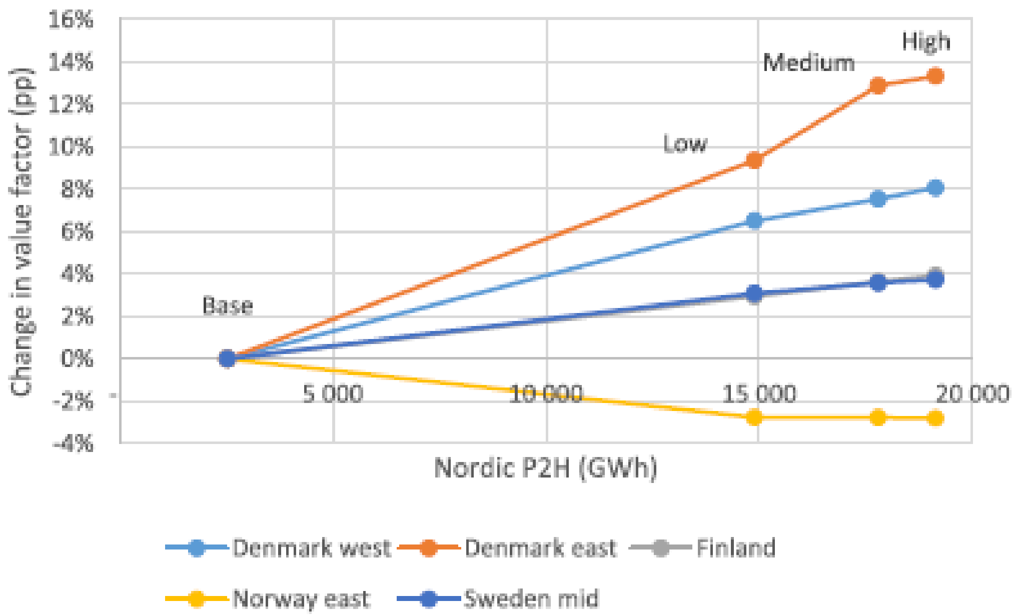

Figure 2 Percentage point change in onshore wind value factor when introducing more power-to-heat (P2H) in a wet hydro year source: Kirkerud et al (2017).

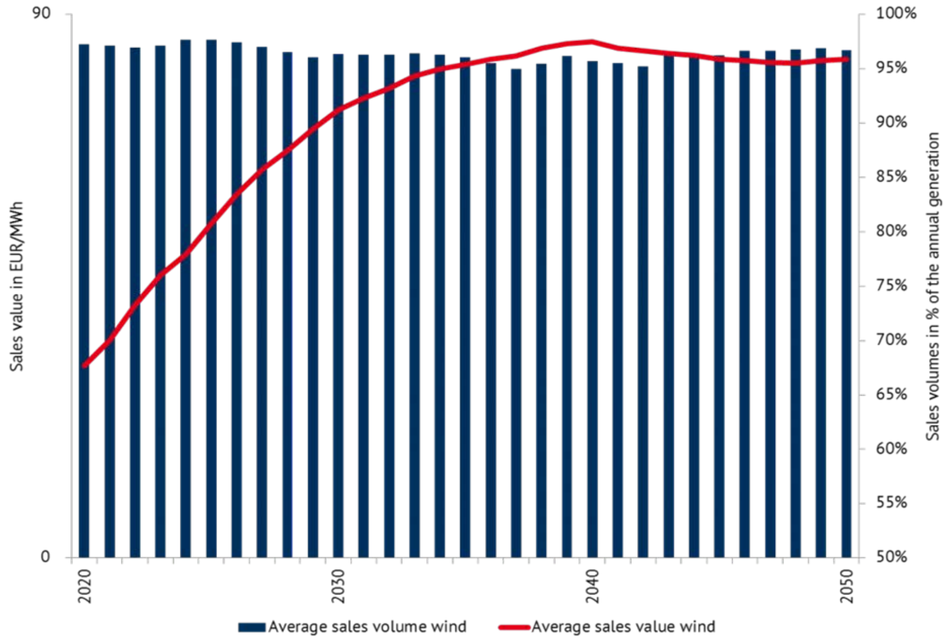

Figure 3 Change in wind power average sale value and variation in average sale volume in percentage of total annual generation. Source: (Perez-Linkenheil, 2017).

2.6 Levelized cost of electricity

The Levelized cost of electricity (LCOE) is a common indicator when comparing different technological options. Given a set of investment and operation costs, and energy generation potential the LCOE is the required energy price to have zero net present value (NPV) (see Equation 1).

Equation 1 $NPV = \sum_{n=0}^{N} \left(\frac{Cn}{(1+r)^n} - \frac{LCOE \cdot En}{(1+r)^n}\right) = 0$

Where C_n is sum of all the costs in period n and E_n is the energy generation in period n. Assuming LCOE is constant over time Equation 1 may be rearranged (see Equation 2).

Equation 2 $LCOE = \frac{\sum_{n=0}^{N} \frac{Cn}{(1+r)^n}}{\frac{En}{(1+r)^n}}$

The assumption that LCOE is constant may be an oversimplification, in the absence of a choice between alternative investments but if an in investment will be economically sustainable. Both electricity price in the market, the SRMC, and energy generation may vary within the lifetime of the technology. Hernández-Moro and Martínez-Duart (2013) suggests a model for the LCOE for solar PV including a number of factors to correct the energy generation over the lifetime. Nissen and Harfst (2019) argue that assuming a constant electricity price is a shortcoming when evaluating grid parity and provide an adjusted LCOE calculation method. Including the influence of deteriorating efficiency (d) and energy price rise (epr) on the LCOE, deduced an adjusted LCOE $_{ad}$ (see Equation 3).

Equation 3 $$LCOE\ ad = \frac{\Sigma_{n=0}^{N} \frac{C_n}{(1+r)^n}}{\Sigma_{n=0}^{N} \frac{E_n (1-d)^{n-1} \cdot (1+epr)^n}{(1+r)^n}}$$

Both the factors *d* and *epr* are a fraction representing average annual change.

2.7 Projection of GO market for countries included in the Balmorel model

In 2018, 474 TWh GOs was cancelled in the countries included in the Balmorel model (RECS, 2018). Based on market information from Association of Issuing Bodies (AIB), RECS (2019) have calculated a compound annual growth rate for GOs issued from 2009 to 2018 at 7.6 %. Applying this growth rate to project GO cancellation for the countries in Balmorel we get 793 TWh in 2025. Projecting it further to 2035 we get GO cancellation amounting to 1653 TWh.

3 Potential impact of GO on renewable energy deployment

Sale of GO represent an income for the renewable energy project decreasing the LCOE. New projects, close to but not reaching grid parity, represent a deployment potential that may be released by GO. However, economically viable with GO within the GO price range does not imply that the project is included in the optimal solution from a North European energy system perspective.

Potential impact of consumers purchase of GOs in a North European energy system perspective is analysed with the energy system model Balmorel. Two cases have been analysed corresponding to the critics of the GO scheme. First, a flat rate GO income per MWh electricity generated is applied to renewable energy conversion technologies. Second, a higher willingness to pay is applied for GOs in the Netherlands while the flat rate is applied to all other countries. The Netherlands is also analysed using a LCOE comparison.

3.1 Common assumptions

A 6 % interest rate is applied in all calculations and simulations. The CO_2 emission trading cost thus was also assumed to increase with this rate during the coming years starting at 15 €/ton in 2020 and increasing to 36 €/ton in 3035 (see Table 1).

Table 1 The assumed CO_2 price (€/ton) in from 2020 - 2035.

2020	2021	2023	2025	2027	2029	2031	2033	2035
15	16	18	20	23	25	28	32	36

Three categories of wind power are included in the model, onshore, nearshore and far offshore. For solar PV there is also three categories; small, medium and large. The small PV category is individual houses, while the medium is larger industrial sites and large is power plants. The cost components specified are constant for the periods 2020-29 and 2030-35. Both the investment cost, and operation and maintenance cost are reduced in 2030 to account for technology learning effects. Moreover, the lifetime for wind power is assumed to increase from 27 years for investments made in 2020-29 to 30 years from 2030. Various grid and energy charges are country specific. The option to use biomass for power generation is included for several countries. There is no new hydropower potential in the model. The heat market and installed electrical capacity per country and technology is further described in Kirkerud et al. (2017). Energy demand is exogenous and about constant in the period modelled.

3.2 Technologies within the GO price range

Evaluation of technologies within the GO price range is only evaluated for new Norwegian hydro power and wind power in the Netherlands. Norwegian hydro power in a GO context are mostly known for low priced GOs from old power plants. There is, however, several potential projects to increase generation from Norwegian hydro power within a LCOE value that become economically viable within a GO price range (see Figure 4). The LCOE values are calculated using Equation 1. Assumptions used in the calculation are described in Isachsen (2017).

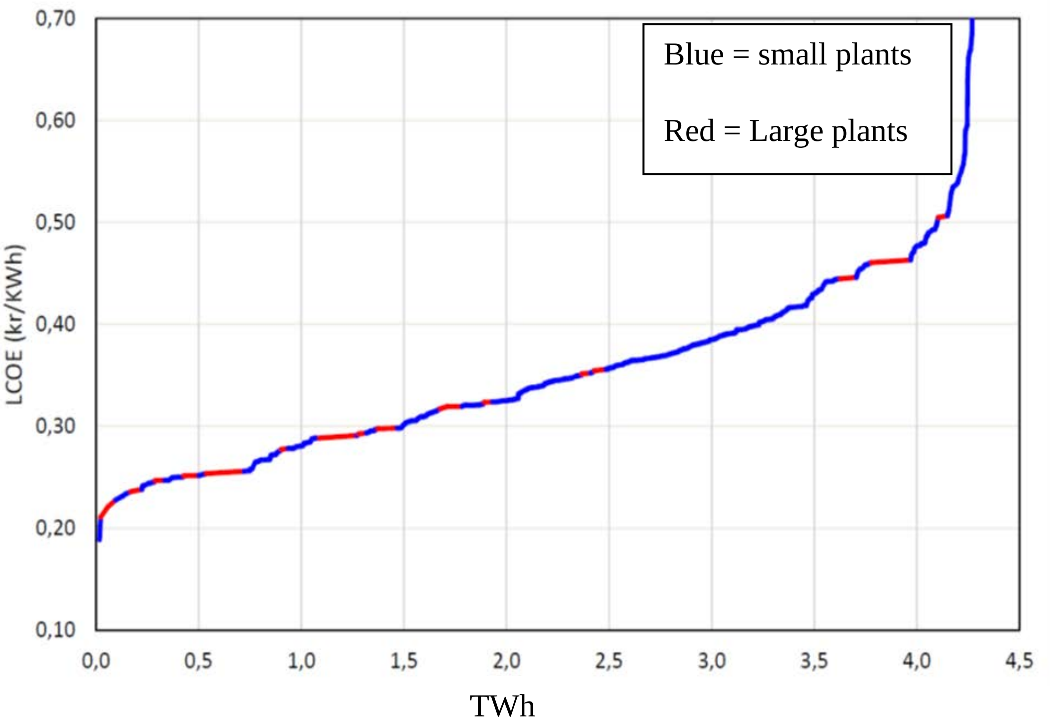

Figure 4 LCOE for hydro power projects in Norway calculated using Equation 2. The graph shows the energy generation potential of the projects versus LCOE value in Norwegian kroner (Nkr). With the Euro valued just above 10 Nkr GO could make projects representing between 1 and 2 TWh electricity generation economically attractive. The blue and red part of the curve is small and large projects respectively (Isachsen, 2017).

Mouilleron (2018) calculated LCOE values using Equation 2 for energy conversion technologies. A 6 % interest rate is applied in all calculations (Finansdepartementet, 2005). For electricity from fossil fuel conversion technologies we assume no new investment. Only fuel and operation cost affect the price that is assumed to increase somewhat up to 2030 (see Table 2). For renewable energy conversion technologies reduced future investment cost is assumed because of technology learning. Complete input data for LCOE calculations are given in Mouilleron (2018).

Table 2 Price of electricity from fossil fuels and nuclear conversion technologies. Source (Mouilleron, 2018).

€/MWh	2020	2025	2030
Natural gas	18,2	21,85	25,5
Coal	8,9	10,05	11,2
Nuclear	7,5	7,5	7,5

The results indicate that wind onshore and offshore, and biomass are within a 10-euro price range by 2030 (see Table 3). With the additional cost of CO_2 for the fossil technologies the difference in LCOE cost is reduced.

Table 3 LCOE values for electricity conversion technologies included. The CO_2 cost is not included in the costs listed (see Table 1) (Mouilleron, 2018).

	Year		
El. conversion tech.	**2020**	**2025**	**2030**
Natural gas	23,5	27	31
Coal	15	16	17
Wind onshore	31,5	29,5	27,5
Wind offshore	42,5	38,5	34,5
Biomass	28	25	23
Solar PV	70	60	51

3.3 LCOE analysis for the Netherlands

The Netherlands is used as a case study for the LCOE analysis. The LCOE values are calculated using Equation 2. Complete input data for LCOE calculations are given in Mouilleron (2018). For electricity from fossil fuel conversion technologies we assume no new investment. Only fuel and operation cost affect the price. Moreover, biomass for power generation is assumed to use fuel-converted coal plants. The price of the emission permits in the European emission trading system is added to the technology costs. Specific emissions for coal and natural gas power plants is set to 0.37-ton CO_2 /MWh and 0.2-ton CO_2 /MWh respectively. The LCOE analysis only focus on the Netherlands and assume zero export of electricity.

Wind-generated electricity in the Netherlands in 2016 only constitute 7 % of total electricity generation. It increased 30 % in 2017 to 10,9 TWh and further increase is expected in the near term (Ras, 2018). In 2016 the electricity demand in the Netherlands was approximately 113 TWh. The majority of the electricity produced came from gas (46%) and coal (35%) (NEAA, 2017). The Dutch government has set targets for renewable energy and is stimulating the deployment. The SDE+ (Stimulering Duurzame Energieproductie) is a premium feed-in scheme. The producers receive this operating grant to compensate for the unprofitable component for a fixed number of years (up to 15 years). Investment support for renewable energy technologies occurs through several incentives like loans and various tax benefits. Together with the cost of CO_2 emissions through the European trading system, there are strong incentives to increase the renewable share in the Netherlands. The income from sale of GOs is in addition to policy support measures.

The results indicate most impact in the short term up to 2025. Moreover, the impact is larger when other national measures and policies are excluded. The share of renewable electricity is smaller with government involvement as restrictions on biomass are imposed. However, the coal used in the without policy case is totally replaced by natural gas. Thus, the total emission intensity from the electricity sector is smaller than with policy.

3.4 National policies implemented in Balmorel

Nuclear power in Germany is scheduled to shut down by 2022 and in Belgium by 2025. In the Netherlands 0.63 GW coal power will be shut down in 2020. Further 0.6 GW coal power will close in by 2025 and the remaining in 2030. Coal power plants operating beyond their estimated life span of 40 years are in the model assumed to become closed between 2020 and 2030 on a random schedule.

3.5 Cases analyzed with the Balmorel model

- *Case 1, flat GO rate* income for the power producer at 4 € / MWh applied to all power generation with wind power, solar PV and biomass in all model countries.
- *Case 2, high GO rate for the Netherlands* at 10 € / MWh and 4 € / MWh applied to all power generation with wind power, solar PV and biomass in other model countries.

3.6 Results from the Balmorel model

3.6.1 Emission trading and closing of coal plants – the baseline

The impact of the European emission trading scheme and policy decision to close coal power plants form a baseline for the evaluation of the GO scheme. Demand for energy is exogenous and assumed constant. Total delivered energy from the conversion technologies up to 2035 only increase slightly from 2072 TWh in 2021 to 2102 TWh in 2035. The increase in the renewable energy generation replaces generation from coal and lignite in particular, but also some reduction in gas power and nuclear. There is no new hydropower available in the model and thus hydropower generation would remain about constant. Wind-power generated electricity is projected to more than double from 291 TWh in 2021 to 668 TWh in 2035 (see Figure 5). Solar PV energy generation appears to almost triple by 2035 while use of biofuel is projected to increase 40 %. Total electricity from wind power, solar PV and hydropower exhibit a continuous increase from 2021 to 2035 and is projected to reach 1220 TWh.

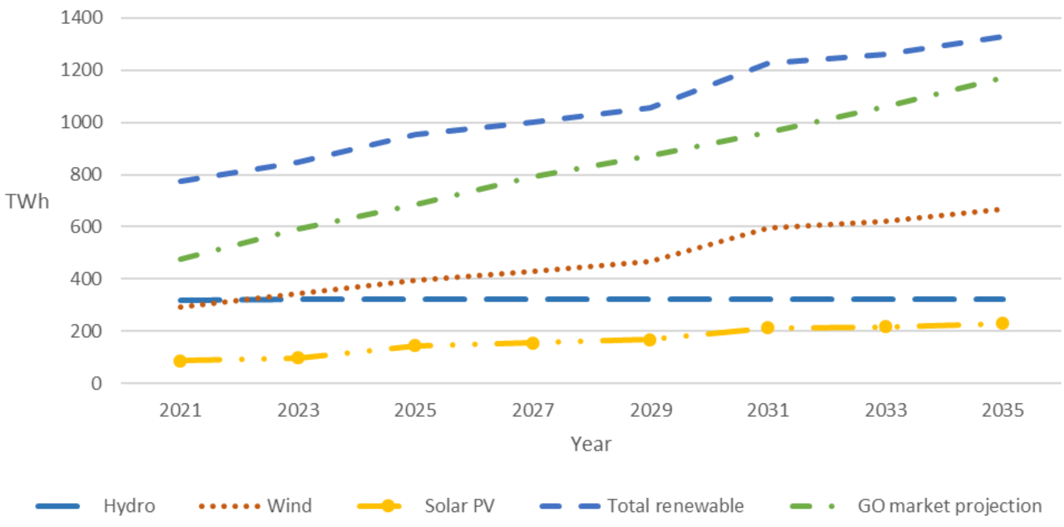

Figure 5 Renewable energy generation in the baseline, i.e., without support from OG. While total energy demand is about constant, we project a substantial shift from coal effectively increasing renewable power up to 2035. The GO market is projected to follow the increasing renewable energy generation.

Consistent with the shift in generation technology, CO_2 emissions are also reduced substantially from 2021 to 2035 (see Figure 6). The model simulations indicate 37 % reduction in CO_2 emission without GOs. Germany contributes most to the CO_2 emission reduction before 2030 and Poland contributes most after 2030.

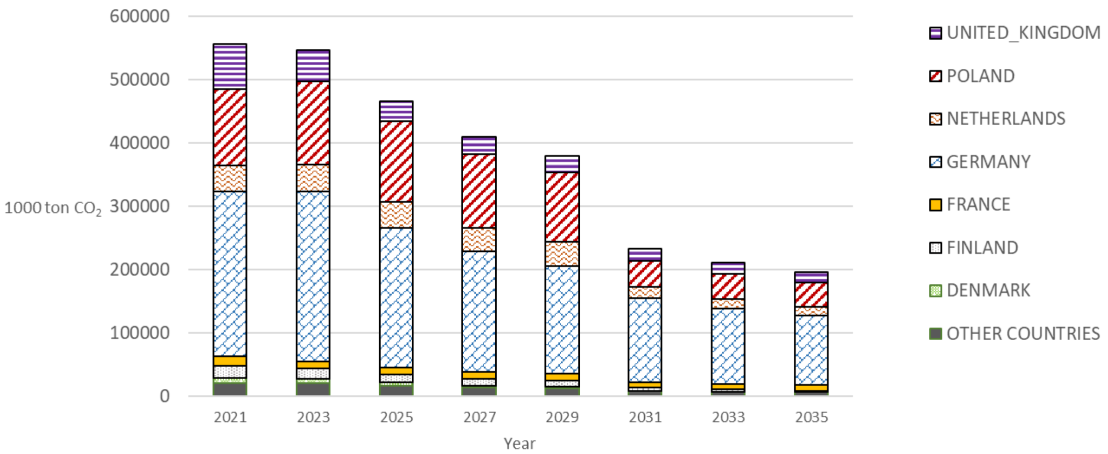

Figure 6 CO_2 emissions from power generation in the baseline projection. Germany exhibit largest reduction before 2030 and we expect Poland to reduce most after 2030.

The projected electricity prices exhibit two distinct patterns. Those influenced by wind power, e.g., western Denmark, Netherlands and Germany show increasing prices except for a reduction around 2030. The electricity profile for Norway has the same shape but exhibit less increase and slightly larger decrease around 2030 leaving the average electricity price about unchanged. In Poland and Eastern Europe, a smaller continuous increase is projected (see

Figure 7). The difference between the countries is mainly caused by the influence from wind power where investment cost is reduced, and performance improved in the input data in 2030 because of technology learning.

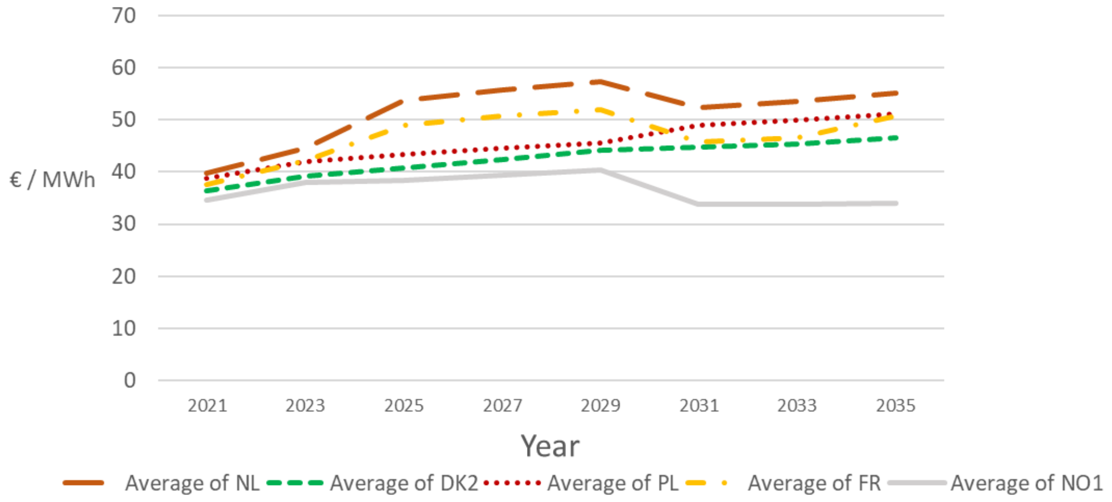

Figure 7 Annual average electricity prices in selected regions. Regions most affected by wind power, e.g. Denmark (DK2), Netherlands (NL) and Germany exhibit the highest prices, Poland (PL) and eastern Europe is in the middle while the lowest prices are found in southern Norway (NO1). The sudden reduction in price from 2029 to 2031 is influenced by reduced investment cost in input data.

3.6.2 A high GO price increase deployment

The flat rate GO income at 4 € / MWh awarded to renewable electricity conversion by wind power, bio and solar PV increases renewable energy generation in the model area. The increase peaks at 72 TWh in 2023 and drops gradually to 49 TWh in 2035. The increase is about 13 % in 2023 and 5 % in 2035 compared to the baseline without GOs (see Figure 8). With 4 € / MWh GO income in all other countries and 10 / MWh GO income in the Netherlands no additional generation is projected in the near term, but a slight increase from 3031-2035 as technology cost is reduced and coal power plants are shut down.

The GOs are disproportionately affecting the deployment of renewable energy technologies. The influence on electricity from biofuel is negligible. Wind power exhibit the largest increase over the period. Only in 2023 is the additional generation of wind energy and solar PV equal.

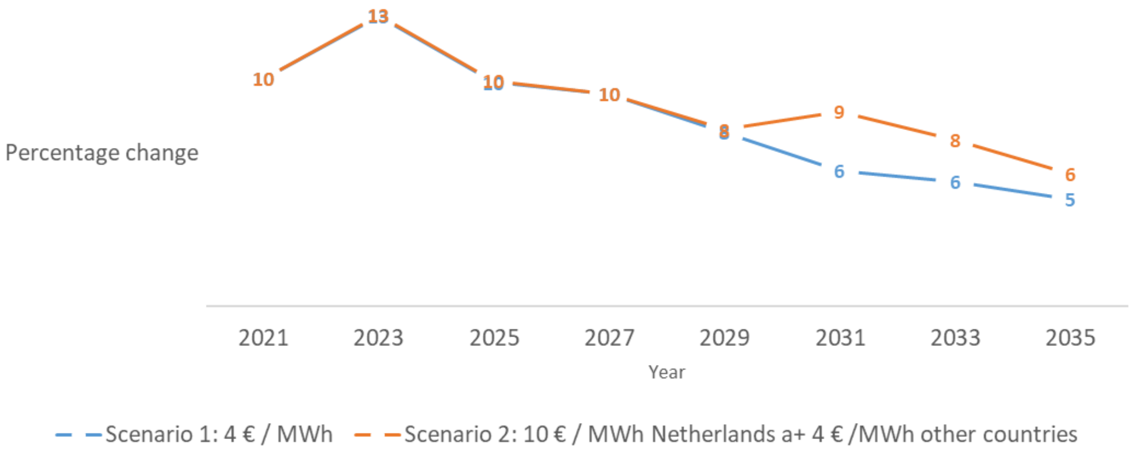

Figure 8. Increase in renewable energy generation compared to baseline in the North European energy system with a 4 € / MWh GO income for all (scenario 1), and 4 € / MWh GO for all countries except the Netherlands with 10 € / MWh (scenario 2).

After 2029 when technology costs are reduced, wind energy totally dominates the additional energy generation caused by the GOs (see Figure 9). With high GO price in the Netherlands (10 € / MWh) wind power generation increase further, partly at the expense of solar PV.

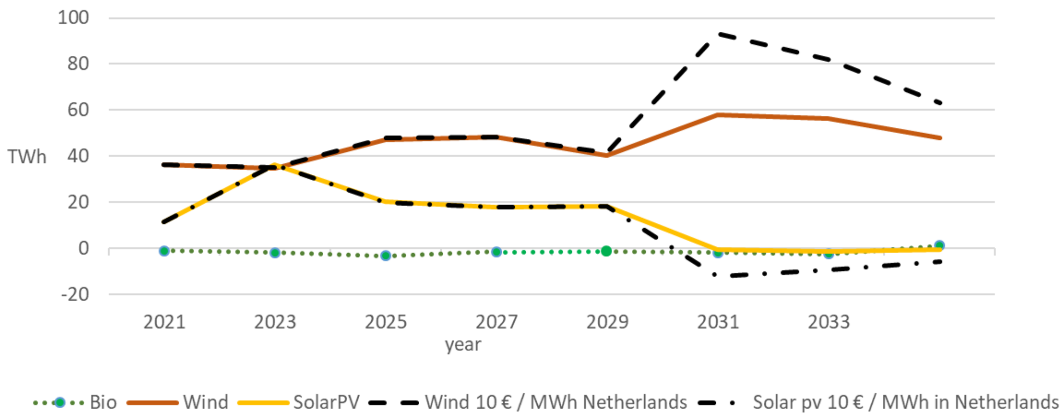

Figure 9 Change in electricity generation in the North European energy system with a 4 € / MWh flat rate support (scenario 1) and with 10 € support in the Netherlands (scenario 2) awarded to generation from wind, solar PV and biofuel. After 2030 wind power increase partly displacing an increase in solar PV.

The imbalanced distribution is also present in the allocation between the countries. In order to better reflect the time series, we examine the annual average change in energy generation. Moreover, the additional energy generation in each country is calculated separately for the two periods 2021 – 2029 and 2031 – 2035. Recall, the added income from GOs are equal per MWh for all renewable energy generation across the countries included in the model. The additional generation, however, are mostly in Germany, United Kingdom, Netherlands, Norway and Finland. In the first period 51 % of the additional wind power is in the Nordic countries and the 24 % is in the United Kingdom. In Germany wind power increase 10 % while in the Netherlands the accumulated additional wind power from 2021 to 2029 is only 4 %. In the second period from 2031 – 2035 wind power increase 28 % in the Netherlands and 34 % in the UK with the GO scheme. Several countries have in the latter period less wind power generation than without the GO scheme. The largest reduction is in France at minus 11 %. Solar PV increase mostly in Germany and the United Kingdom in the first period. In Germany solar PV continue to increase in the second period while it decreases in the Netherlands and the United Kingdom (see Figure 10).

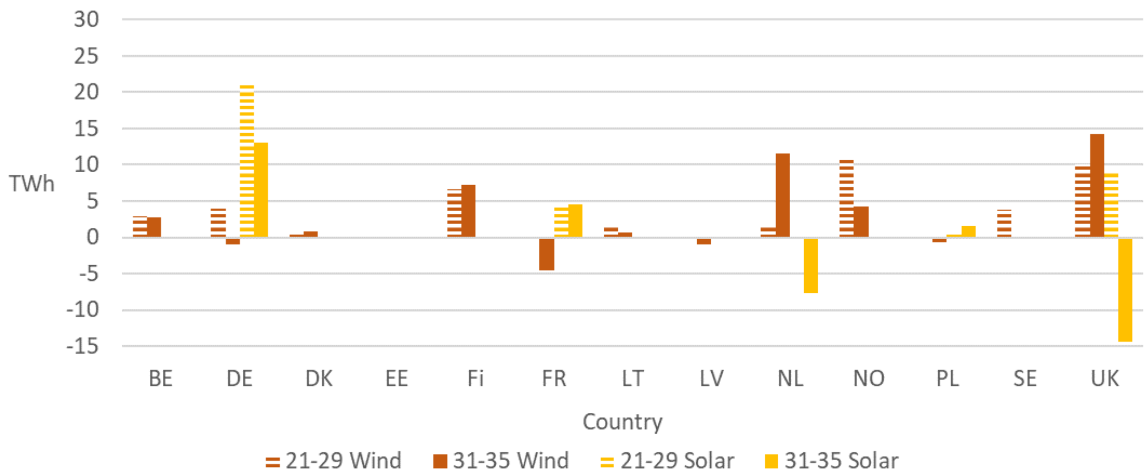

Figure 10 Average annual change in energy generation by renewable technologies allocated to each country in the model with 4 € / MWh (scenario 1). The change is calculated separately for the two periods 2021 – 2029 and 2031 – 2035. BE=Belgium, DE=Germany, DK=Denmark, EE=Estonia, Fi=Finland, FR=France, LT=Lithuania, LV=Latvia, NL=Netherlands, NO=Norway, PL=Poland, SE=Sweden and UK=United Kingdom.

Increasing the GO-income to 10 € / MWh in the Netherlands while retaining 4 € / MWh in other countries shifts most of the additional renewable energy generation from the other countries to the Netherlands. In this scenario the wind power generation in the Netherlands is projected to more than triple in 2031 compared to the baseline scenario or double compared to the 4 € / MWh scenario (see Figure 11). In this scenario there is also substantial export of electricity from the Netherlands.

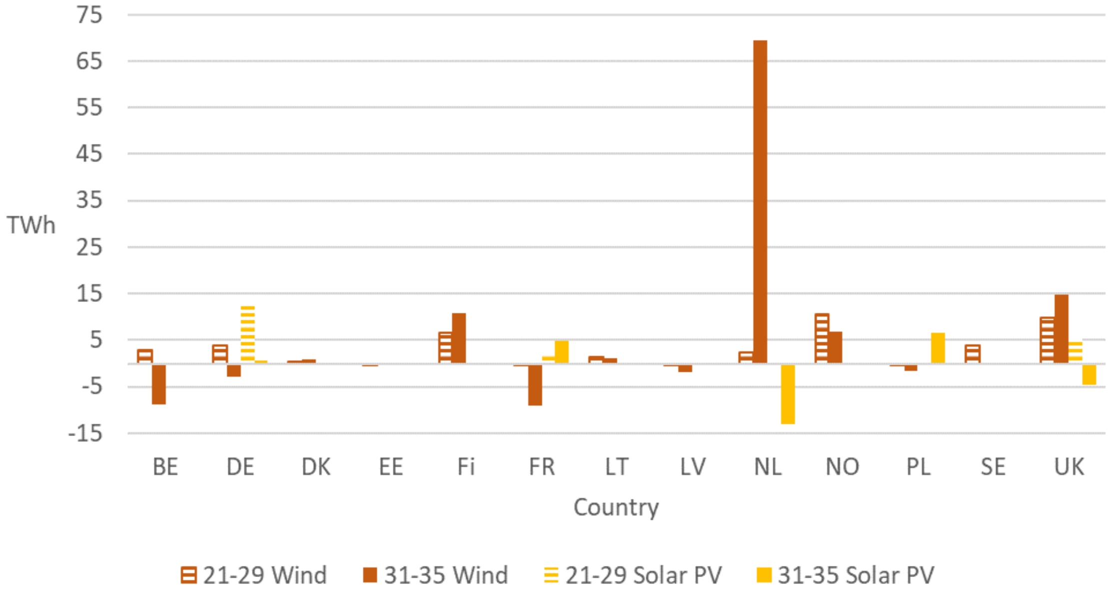

Figure 11 Annual average change in electricity generation between base scenario and with 4 € / MWh in all countries except the Netherlands where there is 10 € / MWh (scenario 2). BE=Belgium, DE=Germany, DK=Denmark, EE=Estonia, Fi=Finland, FR=France, LT=Lithuania, LV=Latvia, NL=Netherlands, NO=Norway, PL=Poland, SE=Sweden and UK=United Kingdom

3.6.3 The price effect

Our model outcomes suggest that the increased generation from wind power causes a reduced annual average electricity price. The reduced market price for electricity likely benefits the consumer and offsets some of the additional cost incurred by the purchase of GOs. The effect is most pronounced after 2030. With the high GO price in the Netherlands, about half the GO price is offset (see Figure 12). Increasing the share of wind power in the system also decreases the average electricity market price for wind power. The power producers get a lower price for the electricity generated, and thus owners/investors income is reduced. The additional income from sale of GOs likely more than compensates for the lower market price.

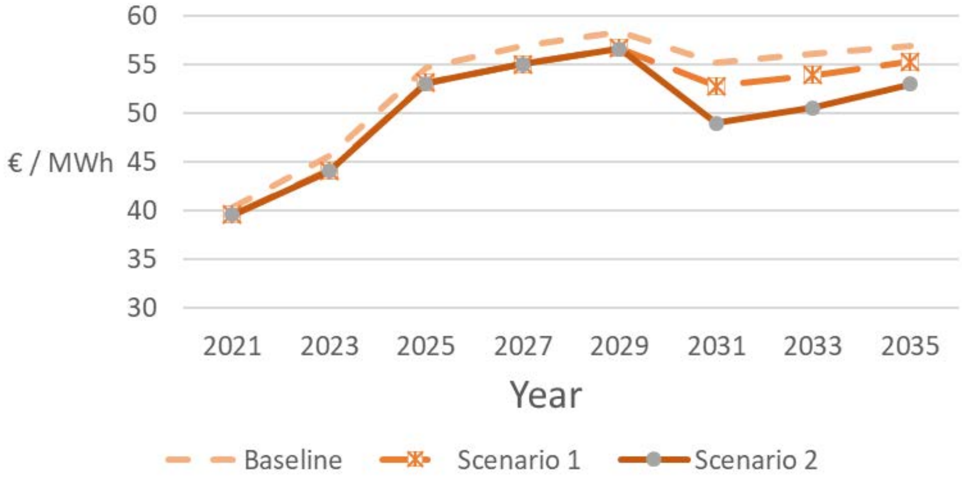

Figure 12 Electricity price in the Netherlands for scenario 1 and 2. Scenario 1 has 4 € / MWh GO income for wind power, solar PV and biopower in all countries. Scenario 2 increase the 4 € / MWh GO income in the Netherlands to 10 € / MWh.

There is an increase in power to heat generation with the GO income. The generation of heat using electricity follows the increase in total intermittent renewable energy generation. Increasing power to heat in periods with abundant renewable energy in the system reduce periods with very low prices and thus increase the average income, particularly for wind power generation (Kirkerud et al., 2017).

3.6.4 Reduced CO_2 emission

The additional renewable energy generated because of GO-income provides a net CO_2 reduction in the model area. The percentage average annual CO_2 reduction compared to baseline is evenly distributed among the model countries. The net CO_2 reduction mainly takes place in the large emitter countries Germany and Poland (see Figure 13).

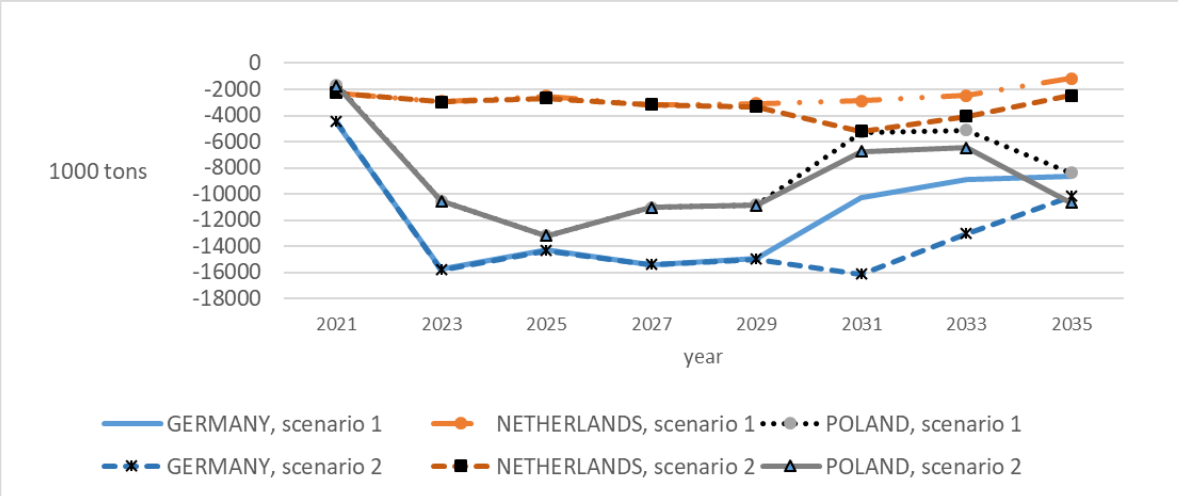

Figure 13 Selected emission reduction profiles for the two scenarios. Scenario 1 with 4 € / MWh, and scenario 2 with 4 € / MWh in all countries except the Netherlands where there is 10 € / MWh.

4 Discussion

As a voluntary policy the GO scheme is dependent on several factors for success. The GO market development must be adequate to create a demand for the additional GOs issued. Moreover, the number of old hydropower GOs available for cancellation should not be enough to amend the results of our analysis. Will a high GO price in the Netherlands help meet their national wind power target? Finally, the Balmorel model assumes a perfect market, but the actors may not behave accordingly. We elaborate on each of these issues below.

The GO market development exhibit strong growth (see section 2.7). We compare the GO-market potential to the renewable energy generation in the model results. They indicate a total of 606 TWh wind and solar PV energy generation in 2025 with the 4 € / MWh GO income. After 2029, wind and solar PV energy generation peaks in 2033 at 894 TWh with equal GO income at 4 € /MWh in all countries (scenario 1). In scenario 2, the combination of lower technology cost after 2029 and 10 € / MWh in the Netherlands cause offshore wind power in the Netherlands to become viable. The total renewable energy generation then increase to 911 TWh. Both in 2025 and in 2035, this is well within the projected GO market development in the Balmorel countries.

The number of old hydropower GOs available for cancellation are not sufficient to amend the results of our analysis. Norway is the largest issuer of old hydropower GOs in 2018 at 134 000, equivalent to 134 TWh. Only 27 000 of these were cancelled leaving an equivalent of 107 TWh surplus in the market. However, the projected growth in the GO market is several times larger than the available surplus of old Norwegian hydro GOs. Thus, the low-cost Norwegian hydropower is not enough to amend the results of the analysis. Moreover, as the GO market grows the market share of old hydropower GOs will decrease.

The Netherlands is interesting because of its long experience with a voluntary support scheme and lately a higher willingness to pay. Dutch consumers have recently used their market power, requested GOs generated from national wind power and denied the low-cost Norwegian hydropower GOs (Davids et al., 2015). The Dutch national Energy Agreement from 2013 included targets for increased share of renewable energy in the national system by 14 % in 2020 and 16 % by 2023. For the year 2023, wind generation onshore and offshore should not be lower than 18.6 TWh and 19.5 TWh respectively. Together the target is 38.1 TWh wind power. In the baseline scenario the Netherlands only generate about half of this in 2023. Analysing the Netherlands in a north European energy system perspective, the results indicate that a GO price at 4 € / MWh or 10 € / MWh does not make very much difference in reaching the national wind power targets.

The analysis exhibit large amount of offshore wind power in the Netherlands with 10 € / MWh GO income after closing coal power in 2030. However, several factors indicate it may happened earlier. The projected increase in the electricity price helps renewable energy technologies reach grid parity. This increase has limited effect on the Balmorel results because the foresight is restricted to one year. Investment decisions are often supported by evaluations of LCOE. The LCOE analysis indicate that in the Netherlands there is a renewable energy potential becoming economically viable within the GO price range. Moreover, the difference between the standard LCOE and the adjusted $LCOE_{ad}$ for nearshore wind power imply about 20 % reduction in the LCOE for wind power in the Netherlands[1]. Capital investment cost in the Balmorel model is reduced between 2029 and 2031. Assuming the cost of wind power in 2021 and 2031 are points on a learning curve, the LCOE would be reduced by about 1 % per year. The CO_2 price as of March 2020 is about 23,5 € (Market_Insider, 2020) and thus much higher than the 15 € / ton CO_2 assumed in the analysis. This influences coal power before 2029 and mostly gas power after 2029 (see section 3.4). Increasing the CO_2 cost from 15 to 23.5 € / ton increase the LCOE-value 3 € / MWh for coal power in 2020. Together, the electricity price increase, reduced cost because of technology learning and increased cost of coal power, together with 10 € / MWh, indicate that the

[1] 3 % electricity price increase per year consistent with Figure 12 and 0.5 % less energy generation per year because of age.

renewable energy investment in the Netherlands could happen earlier than the Balmorel model results. However, the number of GOs cancelled in the Netherlands in 2018 was more than three times the number issued. Moreover, the price effect is limited before 2030 (see section 3.6.3). In scenario 2 the wind power generation in the Netherlands is more than its total electricity use and more than two times the number of GOs cancelled in 2018. The willingness to pay 10 € / MWh must thus extend beyond the Netherlands. In Germany about 4,5 times the issued GOs were cancelled, but almost all the GOs cancelled was low price hydro GOs. On the other hand, willingness to pay could increase because a major part of the CO_2 reduction is in Germany.

5 Conclusions

The GO policy scheme may contribute to increase the share of renewable energy and reduce CO_2 emissions in the north European energy system if there is higher willingness to pay than today. Even though there is a surplus of old Norwegian hydro power GOs it is not nearly enough to meet future market demand for GO at the recent market growth rate. Consumers in the Netherlands have exhibited high willingness to pay for GOs from Dutch wind power. At 10 € / MWh net GO income to electricity producers, substantial new offshore wind power is economically viable in the Netherlands after 2030. LCOE evaluations for wind power in the Netherlands indicate that grid parity may occur slightly earlier than the model analysis.

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