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Impact of the Guarantees of Origin on investments in renewable energy in the Netherlands

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ABSTRACT

The shift of energy production from fossil fuel to renewable energy is a central point to reduce the greenhouse gases emissions and reach the 2°C target under the COP21 Paris Agreement. The development of renewable energy is hampered by the low generation price of electricity from fossil fuel. To counter this lack of competitive price of renewable energy, the European Union has implemented measures to bolster renewable energy production and use. Measures have rather been focusing on dynamizing renewable electricity production than dynamizing electricity consumption. Guarantees of Origin, defined in European Directive 2009/28/EC, is an instrument allowing renewable electricity producers to certify to their customers that their electricity comes from renewable sources. This paper examines the impact of these Guarantees of Origin in the future investment in renewable electricity technologies. I constructed a model based on linear programming, applied to the electricity production in the Netherlands. The objective function is minimizing the cost of national electricity supply (including import), under the electricity demand constraint and maximum generation capacity constraint. This model is tested in different scenarios. A scenario with no involvement of the Dutch government in the minimum or maximum electricity generation from sources, and a scenario with limits imposed by the government on the minimum or maximum electricity generation from some sources. These scenarios are also tested with and without the presence of Guarantees of Origin. We will consider that the price of Guarantees of Origin is 10€/MWh.

The results show that with or without a government involvement, Guarantees of Origin allow a shift in the electricity production to renewable electricity faster than without. In the short term, the impact of Guarantees of Origin on renewable is higher than in the long term. Indeed, in the long term, the electricity generation price from renewable sources is expected to decrease by itself due to gain in efficiency and learning effect. Simultaneously, the electricity generation price from non-renewable sources will likely increase due to an increase in the fuel price. Thus, the impact of Guarantees of Origin attenuated as the price of renewable technologies become competitive. In the short term, Guarantees of Origin allow the production of electricity from some renewable sources that would not have been profitable without the financial benefit generated by the Guarantees of Origin.

The results also show that Guarantees of Origin have more impact on the share of renewable electricity generation when there is no government involvement than when the government imposes limits on some electricity sources. The share of renewable electricity is smaller in the case of government involvement as restrictions on biomass are imposed. However, the coal used in the case of no government involvement is totally replaced by natural gas. Thus, the total emission intensity from the electricity sector is smaller in the case of a government involvement.

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1. Introduction

In the context of raising awareness about environmental challenges, efforts to mitigate global warming are made worldwide. The Paris agreement of the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 is the fruit of the international community's willingness to fight against climate change. The aim of the Paris agreement is to keep the global increase in temperature below 2 degrees Celsius by achieving a balance between greenhouse gas emissions and capture and storage (Paris Agreement, 2015). The European Union (EU) is taking part in this global action, and aims to reduce its anthropogenic emissions by 40% of the amount recorded in 1990 by 2030 (The European Commission, 2016). However, scientists agree that we are now off track to achieve these targets and that unprecedented changes are required if we are to limit global warming. In particular, there must be rapid and significant changes in the energy system (IPCC, 2018).

Renewable energies are promising, as they provide sustainable solutions for a low-carbon society and energy supply independency. The global demand for energy is constantly increasing. To meet this demand without depleting the world of its natural resources, renewable energy appears to be the best alternative. Renewable energy policies are implemented to ensure the transition to a more secure, sustainable and low-carbon energy sector. In the recent years, the EU, has been moving closer to its goal of reducing the use of carbon-intensive fossil fuels and achieving a leading position in renewable energies. Indeed, the share of energy consumption generated by renewable resources in the EU almost doubled between 2004 and 2016, going from 8.5% to 17% (Eurostat, 2018). However, renewable energy production and use still lag behind the production and use of fossil fuels. Currently, renewable technologies are more expensive. Although policies are implemented to bring economic support to renewable energy, the unclear future of these measures often discourages investments.

1. Guarantees of Origin

Although electricity in itself is a homogeneous product, producers and retailers can differentiate themselves by the way their electricity is generated. The Guarantee of Origin (GO) is a market-based instrument to document and report that for 1 megawatt hour (MWh) of energy consumed, 1 MWh of renewable energy has been generated (Renewable Energy Directive, 2009).

The purpose of a GO is to make electricity production more transparent for customers. Thus, they have the opportunity to choose between purchasing renewable or non-renewable energy (Renewable Energy Directive, 2009). In Europe, GOs facilitate accounting and disclosure of information on renewable energy production and consumption. Indeed, all the electricity produced certified by GO is registered in a standardized system, the European Energy Certificate System (Association of Issuing Body). The GO system has been implemented to create incentives for investing in renewable energy generation, with renewable energy producers receiving a financial reward.

A GO can be traded separately from actual electricity generation. In this case, electricity producers sell the GO to other consumers than their electricity consumers (EKOENERGY). This is referred to as unbundled sale of a GO. In the wholesale market, GO transactions are mainly done through brokers between energy producers and energy suppliers. GO transactions also go through trading houses or directly between energy producers and energy retailers. Most of the private consumers buy GOs from their energy supplier, while some large businesses and companies buy GOs in the wholesale market (Oslo Economics, 2017).

The GO system is rather unpopular in academic literature and has largely been criticized for its lack of creating additional renewable energy production. However, since its creation in 2001, the GO market has grown to reach a value of €120 million per year in 2016, including €100 million going to renewable energy producers (Jansen, 2018).

2. Objective of the study

The contribution of this thesis is to analyse the impact of the GO system on investments in renewable energy. The analysis will focus on the Netherlands at a national level. The energy sector is sensitive to changes in policies, and during the last years this context has been redefined by keystone events like the Paris Agreement and the EU Renewable Energy Directive. For this reason, in this study we will look at the energy market moving forward.

I chose the Netherlands as my reference case because it has a good potential for renewable energy development from all kind of energy sources, but they are still under-exploited. Currently, the country is ranked low when it comes to the proportion of renewables in its overall energy consumption (DutchNews, 2018). However, there is a strong demand for renewable energy that is reflected in the high price of GOs from Netherlands. A central point that had to be taken in account when choosing a country was the national renewable energy policy. In this sense, the Netherlands is an interesting country for analysis, as its energy policy is suitable for the GO system. This is contrary to some other European countries, like Germany where no GO can be issued to producers benefiting from the German support scheme (Jansen, 2018). In the case of the Netherlands, renewable energy producers do not have to make a choice between certifying their production or receiving financial support from the government. Thus, there is no conflict between the reward from the GO system and the national support scheme. So, GOs in the Netherlands cover a large part of the renewable energy production. Moreover, the price of GOs from the Netherlands is expected to grow in the near future, becoming the highest priced GOs in all of Europe. It will then be possible to compare the results from my model to the real impact of a substantial increase in price of GOs on the production of renewable energy.

The research question of this thesis is the following:

With the Netherlands as a reference case, how will the GOs system impact investments in renewable energy production in the country?

To answer this question, I will build a model with three different scenarios for the GO price and two different scenarios for minimum and maximum generation capacity. Indeed, the Dutch government plans to reduce electricity generation from non-renewable sources in the future and to impose minimum generation limits for electricity from renewable sources. The different scenarios should show the changes of electricity production from renewable and non-renewable sources following a change in the GO price.

Energy can be used in the areas of transportation, heating and electricity. In my analysis, I will only focus on the use of energy for electricity. To simplify the interaction on the electricity market, the models will not consider middlemen (traders, brokers…). Thus, the totality of the GO price goes to the electricity producer.

2. Background

2.1 Renewable energy in Europe

Renewable energy can be generated from a large variety of natural sources that are particular in that they are constantly being replaced. Increasing the share of renewable energy in total energy consumption allows us to secure energy production in the long term and to reduce the footprint related to fossil fuel combustion. Countries worldwide are shifting to more sustainable energy sources (International Energy Agency, 2018).

In Europe, the share of renewable energy in the final stages of consumption and production has increased in the last decades. Europe is an indisputable leader in renewable energy capacity per capita and per GDP unit. It has the largest solar and wind power generation globally. From 2005 to 2016, the renewable electricity capacity installed in the EU per GDP unit has grown at an annual rate of 7% on average. This growth has been particularly noticeable since 2009, the year of the adoption of the EU climate and energy package (European Environment Agency, 2017).

In 2015, the share of electricity from renewable energy sources in the EU amounted to 28.8%. Figure 1 show the production of renewable electricity by source in the EU from 1990 to 2015.

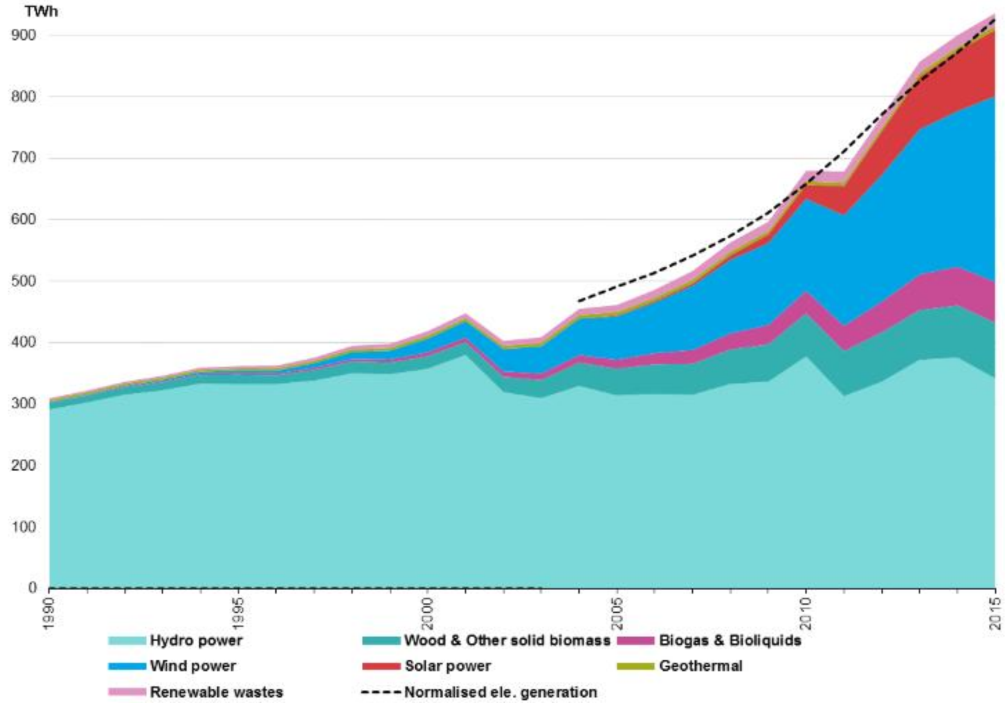


Figure 1 Electricity production from renewable energy sources in the EU-28

Source: Gross electricity generation from renewable sources (EU-28, 1990-2015), Eurostat

In 2015, around 900 terawatt hours (TWh) have been produced by renewable technologies, and hydro power has always been the largest renewable source of electricity. During the last decade, electricity generation from wind has achieved strong growth, especially due to a large increase in onshore wind electricity generation. Other renewable sources still account for a small share of the total renewable electricity production, but they are promising and expected to grow fast in the future.

The consumption of renewable electricity in Europe follows renewable energy production. In 2015, the gross final energy consumption of renewable energy was 927 TWh. The largest contributions came from hydro (38%) and wind onshore (26%).

European renewable energy policy

To meet the ambition of shifting its economy to a more sustainable and low-carbon economy, the European Union has set targets and objectives for 2020 and 2030. The EU aims to reduce its greenhouse gas (GHG) emissions, to improve its energy efficiency and to increase the share of energy consumption coming from renewable sources.

The overall EU goal for 2020 is to have 20% of energy coming from renewable sources. This level can vary by country. It is adapted to each country's characteristics and circumstances, ranging from 10% of renewable energy in Malta to 49% in Sweden.

"*The Renewable Energy Directive (RED; 2009/28/EC) sets out options for cooperation to help countries achieve their targets cost-effectively. To assess the progress towards countries' binding target, two interim trajectories are of particular interest:*

- *The minimum indicative Renewable Energy Directive for each country. These trajectories concern only the total renewable energy source share. They run until 2018, ending in 2020 with the binding national renewable energy source share targets. They are provided in the Renewable Energy Directive to ensure that the national renewable energy source targets will be met.*
- *The expected trajectories, adopted by Member States in their National Renewable Energy Action Plans (NREAPs) under the Renewable Energy Directive. These NREAP trajectories concern not only the overall renewable energy source share but also the shares of renewables in the electricity, heating and cooling, and transport sectors up to 2020."*

The EU's binding target for 2030 is a share of at least 27% of energy from renewable sources in gross final energy consumption. The European Commission's winter package (2016) includes measures to encourage renewable electricity into the electricity market. It also updates the measures for bioenergy (European Energy Agency, 2017). The political agreement reached by the European Commission, the European Parliament and the European Council in June 2018, increased the target for the EU to 32% by 2030. Moreover, the Regulation on the Governance of the Energy Union aims to make sure that the 2030 target can be met. Their task is to ensure that the national objectives and policies of each member country are coherent with EU goals and guarantee a long-term certainty and predictability for investors

(European Commission, 2016). According to the Regulation Governance, all member states shall report their national contributions to the EU target through national climate and energy plans.

In June 2018, revision of the EU Renewable Energy Directive was approved. The renewable energy target is now 32% of renewable energy by 2030. In this revision of the directive, the status of the participation in the GO system has been redefined. The GO still has no function in term of compliance to the member states' targets. Previously, taking part in the GO system was voluntary. Thus, energy suppliers could use a wider range of alternative certificates or measures to guarantee the origin of their electricity. However, after the revision was implemented, participation in the GO system has become obligatory to certify renewable energy source claims. "Where an electricity supplier is required to prove the share or quantity of energy from renewable sources in its energy mix for the purposes of Article 3 of Directive 2009/72/EC, it shall do so by using its guarantees of origin" (European Parliament). This modification significantly strengthens the GO system, as users and suppliers will be obliged to use GOs to document the source of their energy and emission reductions.

Guarantees of Origin

A GO is proof that for one unit of electricity consumed, one unit of electricity has been generated by renewable energy. The electricity producers that receive GOs can sell them to different suppliers or other actors in the electricity market. When an energy supplier acquires a GO, he is allowed to sell electricity as renewable electricity. When a GO is used, it is "cancelled". If a GO is not used within a year, it expires.

The market for GOs is composed of different actors. GOs are mainly traded through brokers and traders. Usually, suppliers buy GOs from their energy suppliers and businesses buy GOs from the wholesale market. Figure 2 represents all the actors of the GO market and their interaction. For each intermediary between the producer and consumer, a part of the price paid for the GOs by the consumer does not reach the producer.

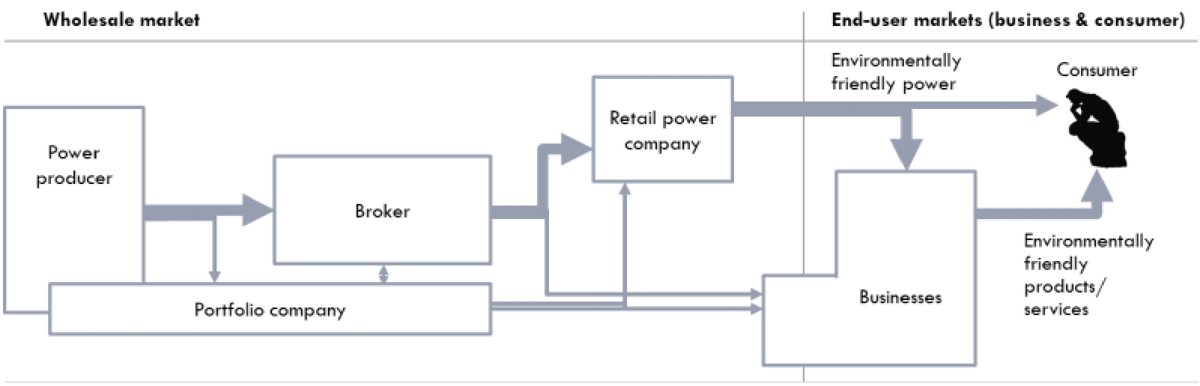


Figure 2 Actors of the GO market

Source: Oslo Economics, 2017

In Europe, 40% of renewable energy consumption is certified with GOs. In 2017, the EU reached a record in renewable energy consumption certified with GOs, which amounted to 470 TWh consumed. It represents an increase of 103 TWh between 2016 and 2017, meaning a growth rate of 28%. As shown on Figure 3, the production of renewable energy with GOs has decreased between 2016 and 2017, partly due to low hydro power production across Europe. In 2018, production is expected to continue to drop while consumption should still increase, leading to a level of consumption higher than the level of production.

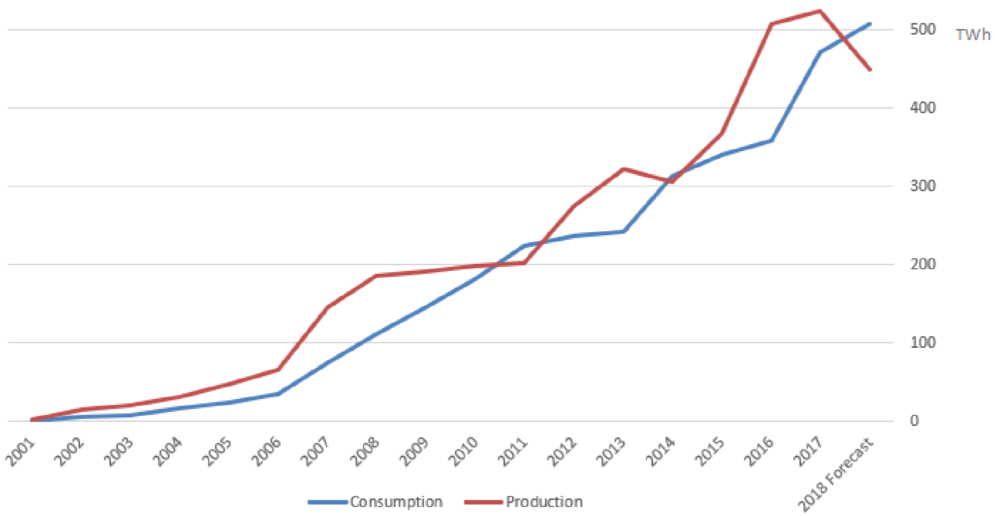


Figure 3 Consumption and production of renewable energy with GO in Europe

Figure 3 shows that, since its creation, production of renewable energy with GOs has generally been higher than consumption. Only twice in history has consumption exceeded production; however, this will certainly be the case for the year 2018. In 2011, consumption surpassed the demand due to the explosion of the nuclear power plant in Fukushima, and the following promise of the German government to shut down all of the national nuclear power plants. Again in 2014, consumption surpassed demand due to a temporary market opening in England.

Figure 4 shows the production and consumption of renewable energy with GOs in Europe in 2017 by country. Norway is the largest producer by far, due to its high hydro power production. The country also holds the first position in term of export of GOs. Germany is the country with the highest renewable energy consumption with GO and it has a big imbalance between its production and consumption, meaning that the country is a large importer of GOs. It is the same case for the Netherlands, which has a much higher rate of GO consumption than GO production.

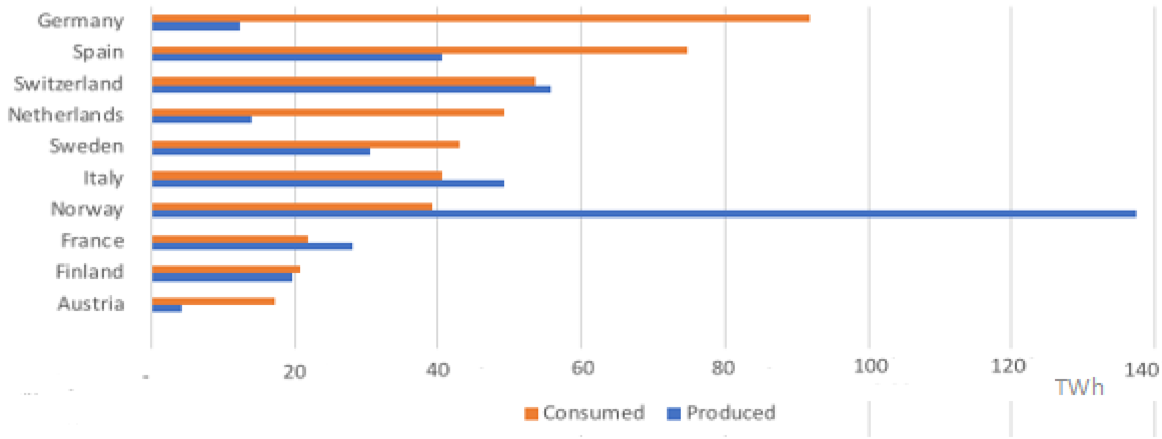


Figure 4 Consumption and production of electricity with GO in 2017 by country

Price of the Guarantees of Origin

GOs are traded in the wholesale market and then sold to energy consumers in the retail market as energy certified from renewable sources. The price of GOs in the wholesale market is transparent; however, this is not so for the retail market. Price history for the retail market is not available.

Figure 5 shows the evolution of the GO price in the wholesale market, since 2008

Figure 5 Spot Price for GO in the wholesale market since 2008 (€/MWh)

The price of GOs in the wholesale market has been low, since 2008, around 0.20€/MWh. However, since the last month this price has seen an unprecedented increase, rising to 1.84€/MWh at the end of August 2018. The main reason behind the price increase is an increasing demand from European electricity retailers and businesses for renewable energy. It is also due to low hydro power production (which is the primary source of renewable energy in Europe) across Europe in 2017 and the beginning of 2018.

The price of GOs in the wholesale market has experienced two peaks during the last years. In both cases, it has happened when the consumption of renewable energy with GOs surpassed production. The first time, in 2011, corresponds to the year of the Fukushima nuclear power plant incident. The second peak, in 2016, was due to a temporary market opening in England.

2.2 Renewable energy in the Netherlands

Despite its reputation of windmills, the Netherlands is ranked low when it comes to renewable energy use. Energy generation from gas amounts to almost half of Dutch energy production while wind represents only 7%. However, natural gas is becoming harder to extract due to earthquakes, and energy consumption is constantly increasing. To face those trends, the Netherlands is taking actions to shift toward more sustainable energy solutions. Over the last decade, electricity generation from renewable sources has constantly increased, mainly driven by an increase in power generation from wind and biomass (Frontier Economics, 2015).

In 2017, the Netherlands produced 114.9 TWh of electricity. Dutch energy production can cover 97% of the country's own usage (WorldData, 2017). In 2016 the electricity demand in the Netherlands was approximately 113 TWh (Netherlands Environmental Assessment Agency, 2017). The majority of the electricity produced came from gas (46%) and coal (35%). The total share of electricity generated by renewable energy sources was 15%; whereas, the average of the International Energy Agency's members was 24%.

Historically, the Netherlands has always been a big exporter of natural gas. Between 2000 and 2013, its exports were at least twice as large as its imports. However, 2017 was the first year in which the Netherlands imported more natural gas than they extracted in the country due to earthquakes that hampered gas extraction. Most of the imported gas came from Norway (Statistics Netherlands, 2017).

Figure 6 shows the evolution of electricity generation in the Netherlands from 2000 to 2016.

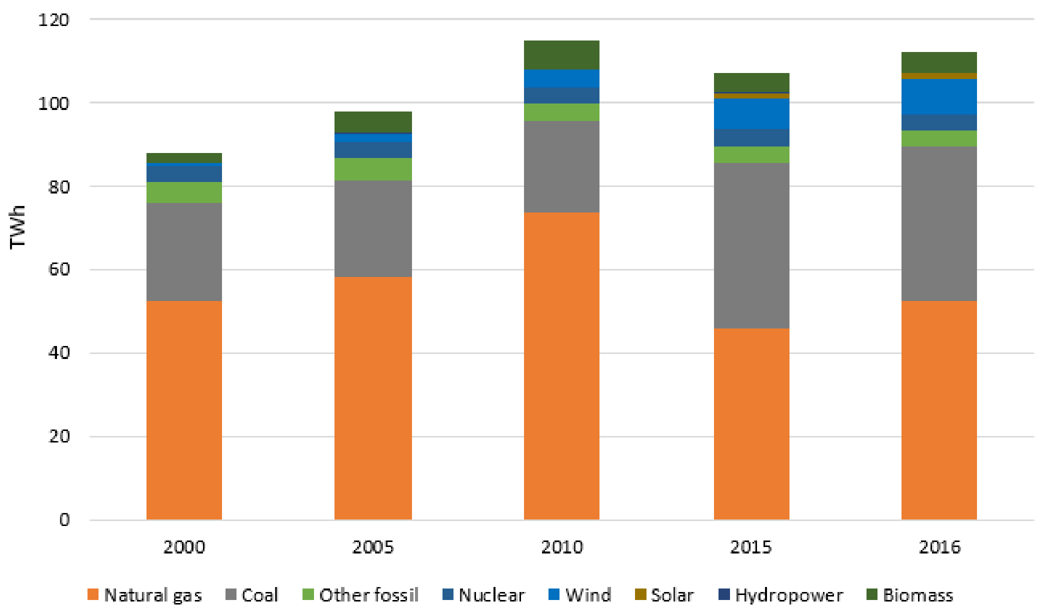


Figure 6 Electricity supply by source in the Netherlands from 2000 to 2016

Source: Netherlands – Energy System Overview, International Energy Agency

Coal production in the Netherlands has increased from 23.4 TWh in 2000 to 37.1 TWh in 2016. Natural gas production increased in 2010, before decreasing to reach a level of 52.3 TWh in 2016. The share of renewable energy in overall electricity production is expected to grow in the coming years. The Netherlands are working to create more offshore wind farms, and aims to reach a capacity of 6,000 megawatts by 2020. In the coming years, the development of low-carbon technologies will be highly dependent on environmental policy, energy demand and the availability of new energy solutions and their costs.

Dutch renewable energy policies

The Netherlands joined the global effort to develop a low carbon energy economy that is safe, reliable and affordable by implementing environmental goals and objectives. The society-wide Energy Agreement for Sustainable Growth that was concluded in September 2013 with industries, non-governmental organisations and governments was a major first step. The Energy Agreement included targets for energy efficiency savings of up to 1.5% of final energy consumption and for an increased share of renewable energy (14% by 2020 and 16% by 2023). According to forecasts, the 2023 target will be met, but despite a strong growth in renewable energy consumption, the 2020 target will probably not be reached (Reuters, 2017). In 2016, the share of renewable energy in gross final energy consumption was only 6%.

In the Netherlands, the government is stimulating the production of renewable energy through a support instrument called SDE+ (Stimulering Duurzame Energieproductie). The SDE+ is a premium feed-in scheme on top of the wholesale price. The cost price of renewable energy might be higher than the market price, so the producers receive this operating grant to compensate for the unprofitable component for a fixed number of years (up to 15 years). The SDE+ is applicable to renewable electricity, renewable gas and combined heat and power (CHP). The price of the SDE+ depends on the energy price: the higher the energy price, the lower the SDE+ price. The SDE+ also allows for the possibility of banking.

Investment in renewable energy technologies is also supported through several incentives like loans and various tax benefits. For example, consumers that invest or put their savings in green funds receive tax benefits. Moreover, “in the Netherlands, the consumption of electricity and natural gas is subject to the Act on the Environmental Protection Tax” (RES Legal Europe); however, consumers who generate their own renewable energy are exempted from this tax. Businesses and private individuals can also apply for a grant from the Sustainable Energy Investment Grants (ISDE) to offset the costs of energy saving equipment.

Guarantees of Origin in the Netherlands

In the Netherlands, the CertiQ is the organization in charge of issuing GOs. The CertiQ issues GOs for renewable electricity, electricity from highly-efficient cogeneration and renewable heat. The CertiQ also issues GOs for non-renewable electricity. "The CertiQ stated the objectives for 2023 to provide reliable, secure and user-friendly certification of electricity and heat, facilitate Full Disclosure in the broadest sense (supply and production, centralized and decentralized, renewable and non-renewable), to include plant-specific CO_2 emissions and a fuel's country of origin on GOs and to provide real-time information on the production and use of sustainable electricity and heat" (Association of Issuing Bodies, 2017).

In 2017, the Netherlands was the eighth country to issue GOs from renewable production, representing 3% of the total amount of GOs. 15.8 million certificates have been delivered, corresponding to 15.8 TWh – 1.4 TWh more than in 2016. This increase is generally due to a growing number of large photovoltaic power plants. The Netherlands is a net importer of GOs, and last year its import of GOs rose to a record level of 40,1 TWh. The number of GOs sold by electricity suppliers (cancelled GOs) also rose from 2016 to 2017 to reach 49.4 TWh — an increase of 2.8%.

Figure 7 shows the production of renewable energy by source, that has been certified since July 2015.

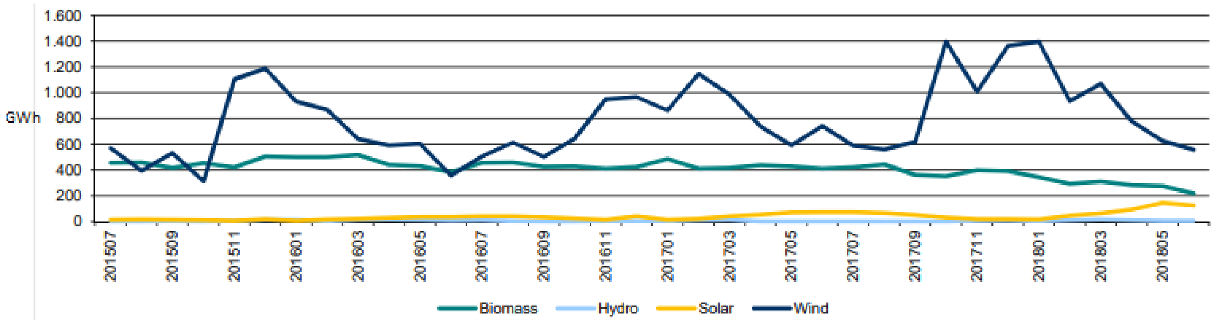


Figure 7 Certified production of renewable electricity in the Netherlands

Source: Statistical overview 2018, CertiQ

We can see that the majority of renewable electricity production in the Netherlands comes from wind. The electricity generated by biomass has been quite stable the last 3 years, but has seen a slight decrease of 200 GWh since the beginning of 2018 mainly due to some large biomass plants shifting from electricity to heat generation. The opposite trend can be observed for solar power, which has seen an increase of almost 200 GWh for the same period. This represents a growth of 70% for this renewable source compared to 2016.In 2018, the Netherlands exported 3.26 TWH and imported almost 40 TWh. Figure 8 and Figure 9 show details of the destination and origin countries in Europe for Dutch GO exports and imports

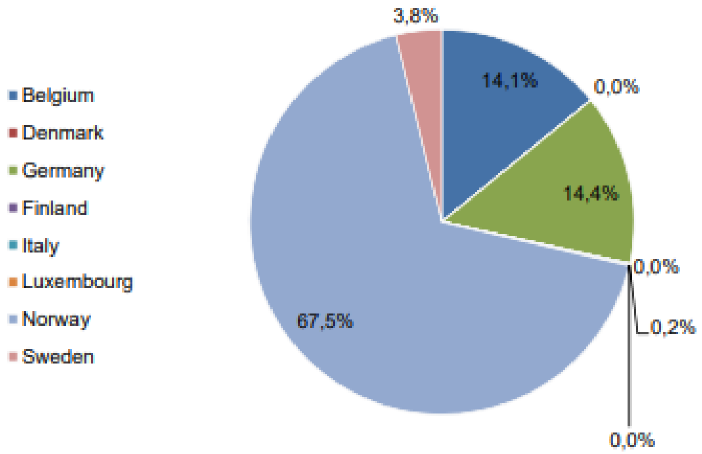


Figure 8 Destination countries of Dutch GO exports during 2018

Source: Statistical overview 2018, CertiQ

The Netherlands primarily exports GOs to four countries: Norway, Germany, Belgium and Sweden. More than two-thirds of the export goes to Norway, with 67,5% of the total GOs exported. The Netherlands interacts with many different countries for the import of GO, as we can see in Figure 9.

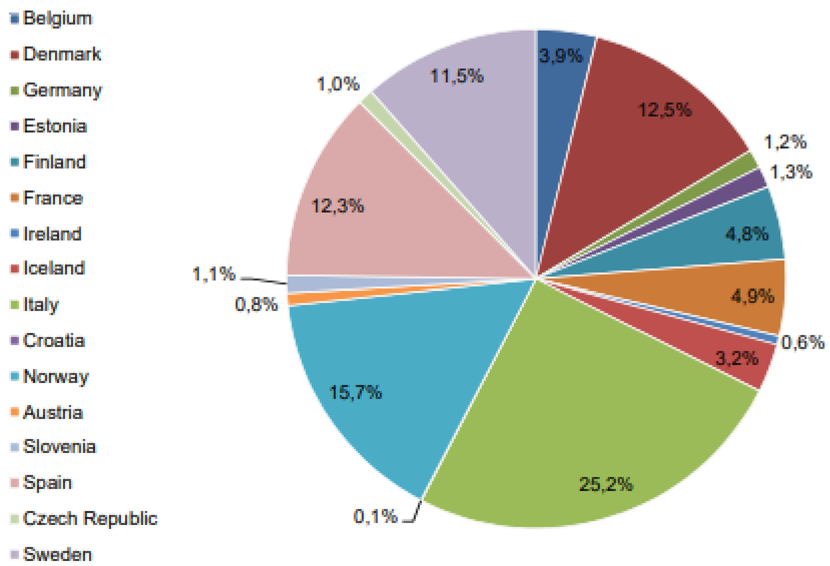


Figure 9 Originating countries of GO imports to the Netherlands during the last 12 months

Source: Statistical overview 2018, CertiQ

Almost a quarter of the exported GOs produced in the Netherlands goes to Norway. Norway is also a major exporter of GOs to the Netherlands. However, it has lost almost 10 percentage points of its share over the last year, due to a drop in the popularity of Norwegian renewable energy power in the Netherlands. Critics say that this big, cheap "green" stream does not have any impact in helping to improve the sustainability of Dutch energy production and do nothing to add to national renewable production.

Price of the Guarantees of Origin in the Netherlands

In recent years, the unpopularity of renewable energy with GOs imported from other European countries has led to a sharp increase in the price of energy with GOs coming from the Netherlands. Moreover, a large number of Dutch municipalities and companies have announced that they want to make their energy consumption completely renewable, and that it will be done by replacing existing fossil fuel contracts with clean energy contracts from the Netherlands. All these factors have made the demand for Dutch GOs jump.

The price of GOs has recently increased all over Europe. For example, a GO for European wind was valued at 0.30€/MWh in October 2016, and by September 2016 the cost had risen to 1.85€/MWh. Now that Dutch certificates are specifically wanted, their prices have risen even more. Exact prices are difficult to find due to a lack of transparency in the market; however, according to information coming from various traders and buyers, it appears that the price for a Dutch wind GO is equal to 8€/MWh as of mid-November 2018. This makes Dutch wind the most expensive renewable GO in Europe. Historically, the price for renewable electricity was only a slightly more than the price for non-renewable electricity, but this is not the case any longer. It now costs 10% more to buy electricity from Dutch wind. As seen before, this strong increase in price reflects the fact that the production of renewable energy in the Netherlands is by far smaller than the demand.

3. Literature Review

Governments and institutions can use several policy instruments, subsidies or quotas in order to support the development of renewable energy production. To leverage the low carbon energy sector, two approaches can be considered: demand-side policies and supply-side policies. Demand-side policies correspond to policies looking to increase the demand for renewable energy, like quotas on the share of total energy consumption originating from renewable resources. They aim to make renewable energy more attractive to consumers as opposed to non-renewable energy consumption. Supply-side policies correspond to policies looking to increase energy production from renewable sources. This can be achieved by allocating subsidies or feed-in tariffs to green energy producers. Environmental policies, like emission trading systems, can also be an indirect way of stimulating renewable energy. Over the last few years, countries have often implemented overlapping regulation through different instruments in their efforts to reduce GHG emissions and limit global warning. However, in European countries policies to stimulate the demand for renewable energy from households or businesses have not been the priority. The focus has rather been on supply-side policies or on policies that indirectly support renewable energy generation like the European Emissions Trading System (EU ETS).

Strategies to stimulate the renewable energy sector implemented by governments can be short-term or long-term. A short-term strategy will stop having an effect after the strategy investment runs out, while a long-term strategy investment continues having an effect after the policy has been implemented (Aquila, 2017). Among the most popular short-term policy instruments are subsidies, tax exemption or tax reduction for consumers of renewable energy and extra taxes on CO_2 emitters. Generally, governments mix short and long-term policies. However, long-term strategies are more effective as they are fundamental in creating a new model for renewable energy consumption and production. The most important long-term strategy instruments can be divided into three categories: feed-in tariffs, auctions and the quota system. A feed-in tariff is a payment made to renewable energy producers. Feed-in tariffs are seen as highly effective in promoting renewable energy as they offer stability and ensure financial security for producers. A strategy based on a quota-approach will necessitate an amount determined by the government of renewable energy generated. Unlike feed-in tariffs and auctions, in the quota-approach the producer does not have a guarantee that the government will purchase the energy. By using the auctioning approach, the government encourages renewable energy producers to join auctions. The producer with the cheapest price is then granted a contract and offered a subsidy. Auctioning creates an incentive for renewable energy producers to reduce their costs, making it more attractive for consumers.

Market-based instruments to stimulate the renewable energy sector include emissions accounting and reporting purchases of green electricity, like GOs. Two interrelated problems with those two market-based approaches have been identified (Brandera, Gillenwater and Ascui, 2018). The first problem is that reporting purchases of green electricity fails to create new renewable energy capacity. Indeed, in many countries renewable energy generation is largely supported by subsidies or legacy investments, and the revenue from participating in a system like GO is negligible and uncertain when taking the decision to invest in renewable technologies. The second problem is related to contractual emission factors and their impact on the accuracy and relevance of GHG inventories. For example, companies that buy contractual emission factors can report a zero footprint while in reality not reducing their emissions or changing their methods of production. In this case, no improvement has been made from emissions reduction in production and yet, the company has acquired a green profile. Thus, contractual emission factors have been used only for marketing purposes. On the other hand, companies implementing energy efficiency programs will appear to have a bigger footprint but will actually contribute to reducing electricity from fossil sources from the grid. Their profile will appear to be less green than the companies allocating money in contractual emissions factors despite the fact that they are contributing to emission reductions in a higher and more direct manner (Matthew Brandera, Michael Gillenwaterb & Francisco Ascuia, 2018).

The efficiency of implementing the GO system to enliven the green electricity market has been subject to debate and analysis. The GO system has largely been criticized for its double-counting of renewable energy and its relatively small impact on new renewable energy generation. Indeed, GO prices have always been quite low, so they have not represented a substantial incentive to invest in renewable energy. In 2016, the average price of a GO in Europe was estimated to be approximately €0.30 per MWh. However, two main drivers could increase the financial value of GOs and thus expand the cash flow delivered to renewable energy generators. The first driver is an augmentation in demand that comes from the consumers and businesses who are willing to decrease their level of GHG emission, especially after the Paris Climate Agreement. The second driver is the reduction in the cost of low carbon technologies that reduces the price differences between renewable and non-renewable sources, so GOs become more likely to fill the cost gap between the two (Jaap Jansen, 2017).

An argument against GOs is that their inefficiency is not only due to low prices, but also to a lack of transparency for the consumer and that it undermines fair competition when GOs cover all European renewable energy production (Jaap Jansen, 2018). For this reason, when a consumer purchases GOs from a country where renewable energy producers benefit from a support scheme or legacy investments, he is not contributing to new renewable energy production capacity. Consumers can then be misled by thinking that the cost they have paid for the GO has an impact on the electricity sector. For Jaap Jansen, renewable energy producers should not receive both GOs and national support, because consumers that wish to provide an extra voluntary support to green electricity generation will not be able to see the distinction between whether the development of renewable power generation facilities is due to the support scheme or solely to additional consumer demand (Jaap Jansen, 2018).

Until recently, the Netherlands was a big importer of hydroelectricity GOs from Norway, with most Dutch GO consumption taking the form of Norwegian GOs. This particular relationship for GO trading between the Netherlands and Norway has been discussed and analysed by Mulder and Zomer (2016). They share the common thinking that the premium price that is paid through GOs for green electricity by the Dutch consumers appears to amount for a really small percentage of the retail price. Hence, the GO system as it is now is used more like a marketing instrument than a policy instrument in order to increase the share of renewable energy production. Their main criticism is that, while taking the contribution to the GO system into account, the Netherlands seems to be close to the EU target of renewable energy in final energy consumption; but actually, only a small share of this energy is generated in the country. In 2014, 34% of the electricity used in the Netherlands came from renewable sources, but only 10% of the total electricity supplied was produced in the country. During 2018, the consumption of green electricity in the Netherlands increased; however, Dutch production has not followed this trend and is growing slowly. So, the green image of the country is mainly based on GO trading and does not represent the real performance of the country in terms of renewable energy generation. Moreover, Mulder and Zomer also discuss the willingness to pay (WTP) of the consumer that is derived from the difference between the price of renewable and non-renewable electricity. According to a study of the OECD, the WTP of Dutch consumers for renewable energy is the smallest of the sample of 11 OECD countries, accounting for 7.5% (Machiel Mulder and Sigourney P.E Zomer, 2016).

The effectiveness of the different instruments for stimulating renewable energy and their simultaneous use, has been the subject of much debate and discussion in the academic literature. In the EU in 2005, a CO_2 emission trading scheme (EU ETS) was created in order to decrease CO_2 emissions, and therefore reduce black power production. This trading scheme is now working alongside new instruments, aiming to increase the EU's share of energy from renewable energy sources. The GO system helps countries to meet this objective, and it can be combined with existing support mechanisms such as feed-in-tariffs and tradable green certificates. All these instruments aim to combat climate change. However, the simultaneous use of tradable black (CO_2) and green (renewables) quotas can actually increase energy production from the dirtiest technologies (Böhringer and Rosendahl, 2010). This is because green quotas reduce the cost of CO_2 emission, and thus mainly benefit the most emission-intensive technologies.

According to Lehmann and Gawel, criticism about the inefficiency of EU ETS and support schemes for electricity generation from renewable energy sources is based on "quite narrow and unrealistic assumptions". The unrealistic assumptions are that choices in technologies are only distorted by the negative externality from CO_2 emissions and climate change mitigation is the only policy objective. For Lehmann and Gawel, those instruments are complementary, as they have been created to tackle two different problems. Economic theory suggests that in presence of negative externalities and technology market failure, the EU ETS need to be supplemented by some support to renewable electricity generation. While EU ETS focuses on CO_2 emission reductions, support schemes focus on a wider range of actions to enliven renewable electricity production and consumption. Increasing renewable electricity production may be hampered by restrictions on technological development and adoption caused by market failures or policies and more generally by path dependency in socio-technical systems. In addition, support schemes for renewable energy may address more problems than just climate change.

However, Raadal, Dotzauer, Hanssen and Kildal found evidence that the interaction between Electricity Disclosure and Tradable Green Certificates when working in tandem has a positive impact on renewable energy development. They found that Electricity Disclosure may create customer-driven demand for renewable electricity which can supplement Tradable Green Certificates. In the long-term, GOs may thus influence the decisions made by investors in renewable energy. “Based on the assumption that the increased income from GOs does not reduce the incomes from the sale of certificates and power, the GO income opens up possibilities for investment in projects with higher long-term marginal costs, e.g. off shore wind power.” There are two important conditions for this: significant increase in GO prices and including GO income in investment calculations. One of the ways to achieve the second condition is to make a long-term commitment to customers to purchase GOs. This may lead to an increase in electricity production and thus a surplus of certificates. Governments can rectify this by increasing the quota level for Tradable Green Certificates, which in the short-term will reduce the surplus and create incentive to augment renewable energy production (Raadal, Dotzauer, Hanssen and Kildal, 2012).

4. Theoretical Analysis

Before presenting the methodology and data used in this analysis, in this section I will introduce the relevant economic theory behind the model.

4.1 Equilibrium Theory

The research model in this analysis is partly based on market equilibrium theory, as applied to the electricity market. In equilibrium theory, the supply of, and demand for, commodities depend on the market price. As the price of the commodity rises, the supply increases and the demand falls. Market balance is determined by the supply-demand equilibrium. This fundamental economic theory was introduced by Alfred Marshall (1842-1924). In a Marshallian supply-demand cross, the market balance is represented by the point where the supply equals the demand. This point is an equilibrium and it determines the ‘equilibrium price’ and ‘equilibrium quantity’. Thus, any change in supply and/or demand has a direct impact on the price equilibrium and quantity equilibrium.

Figure 10 Impact of GO on the energy market equilibrium

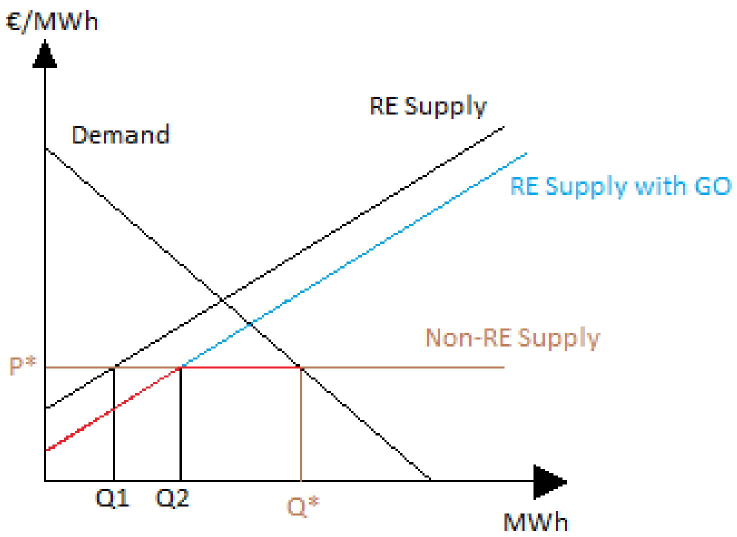


Figure 10 represents a simplified demand-supply cross for electricity in the long run with a fixed price of GO. In the long term, we consider the price of non-renewable energy supply flat, as power plants are operational and the costs of running them to increase production are negligible. However, renewable energy supply is increasing in order to generate more, and the cost of generating electricity varies according to technologies used, location, and weather conditions.

Mathematically, the functions can be defined as functions of the price. The demand function (D) can be written as:

$$D = f(p) \; with \; f'(p) < 0$$

The supply function for renewable energy and renewable energy with GO are:

$$S_{RE} = g(p)\ with\ g'(p) > 0$$

The supply function for non-renewable energy is:

$$S_{non-RE} = l(p)\ with\ l'(p) \geq 0$$

In our case, we assume that the derivative of the non-RE supply function is equal to zero.

The initial market equilibrium, with only non-renewable energy production, is represented by the point where the non-renewable energy supply curve and the total demand for energy intersect (Figure 10). The equilibrium price is P* and the equilibrium quantity is Q*. The equilibrium price and quantity are actually the same when we introduce the supply function for renewable energy supply. However, the total supply function will change. The supply function for the total energy supply corresponds to the lowest supply function between renewable and non-renewable sources. In other words, before the implementation of the GO system, from 0 to Q1, the total supply is equal to the RE Supply function, and from Q1 it is equal to the Non-Re Supply function. The production quantity from non-renewable energy will be reduced from Q* to Q*-Q1. Without renewable energy production, the producer's surplus is null as the price equals the marginal cost function. However, with renewable energy production the surplus of the renewable energy producer increases and is equal to the area between the price line and the RE Supply function. The surplus of Non-RE producers is null.

By introducing the GO system, the European Union increases the profitability of producing renewable energy by increasing the revenue of renewable energy producers. Thus, the supply curve of renewable energy is shifted downwards. The magnitude of the shift is equal to the price of GO that is fixed in Figure 10. The new total energy supply curve, in red, corresponds to the lowest supply function between renewable with GO and non-renewable sources. From 0 to Q2, the total supply function is equal to the RE Supply function with GO, and from Q2 it is equal to the Non-Re Supply function. In this case too, the equilibrium price and equilibrium quantity will be the same. However, the share of renewable energy in total energy production will increase from Q1 to Q2. Thus, non-renewable energy production will decrease from Q*-Q1 to Q*-Q2. Moreover, the surplus of the producer increases.

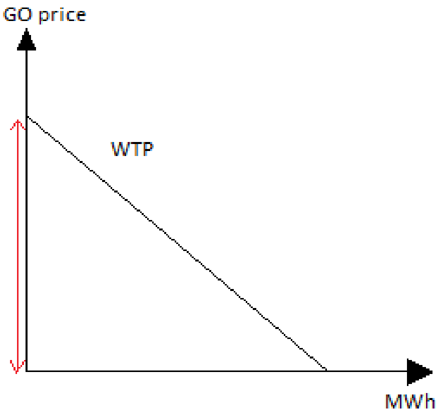
In the case of an increase in the price of GOs, the renewable energy supply function will shift further down, increasing the share of renewable energy in total energy production.

4.2 Willingness to pay

In Figure 10, the GO price was assumed to be constant and independent of the quantity (MWh). Thus, when the GO system is implemented the new renewable energy supply function is parallel to the former renewable energy supply function. However, the price of GOs is determined on the market, and it is changing over time, among other things due to consumer willingness to pay (WTP).

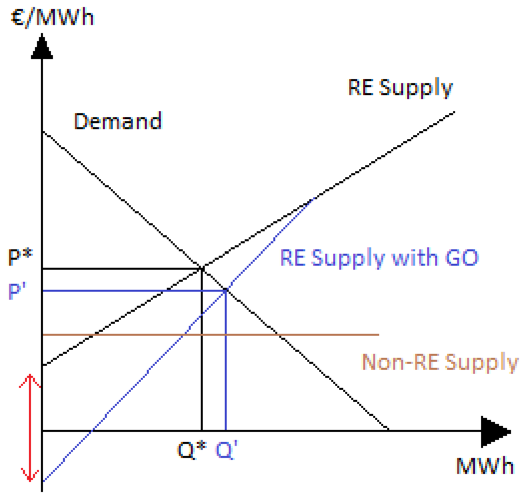
The willingness to pay is the maximum price that consumers are willing to pay to purchase one extra unit of a product. Typically, the WTP is a decreasing function as the marginal utility for one extra unit of a product decreases. We consider that the WTP for GOs is also decreasing, as it is represented in Figure 11. Indeed, some energy consumers are concerned about the environment and are ready to pay a higher price for consuming energy that does not have a negative impact on the planet. The quantity of energy consumed is different but quite stable for each consumer. Thus, once the concerned consumers have bought the amount of energy with GOs that they need to cover their electricity consumption, the WTP drops. Consumers that are not concerned about consuming renewable energy do not appear in the WTP function because their WTP for GO is equal to zero.

Figure 11 Willingness to pay for GO



Below we have a representation of the supply function of renewable energy with GO when taking account of the changes in GO price related to the WTP. Knowing that the WTP for the first MWh is high, the price of GO will reduce the marginal cost. It is possible that the WTP is so high that the cost of supplying the first quantity of renewable energy with GO is negative.

Figure 12 Supply function of renewable energy with GO and WTP

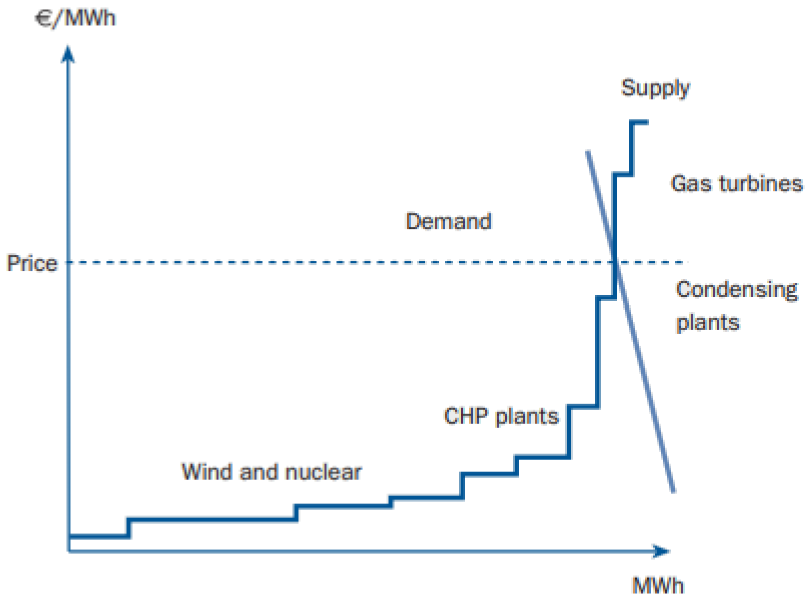


The difference between the RE Supply function and the RE Supply function with GO corresponds to the WTP for GO price represented in the Figure 11.

4.3 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, in our case, one extra MWh. There is a distinction between the Short Run Marginal Cost (SRMC) and the Long Run Marginal Cost (LRMC). In the context of LRMC, there is time for investment in new production capacities (Figure 10 and 12). In the SRMC, the increase in production is reached by increasing the input but not in investing in new generation capacity. The SRMC for electricity can be illustrated as below.

Figure 13 Short run marginal cost of Electricity



Usually the SRMC for energy generation from a certain power plant is flat, as once the power system is operational and running there is almost no extra cost to produce one more MWh, for an amount of electricity inferior or equal to the maximum power capacity generation. The marginal cost of renewable electricity in the short term is low, because there is no cost for fuel, unlike for non-renewable sources. With such a function, depending on the demand, only energy systems from the sources with the lowest marginal cost will generate electricity. Note that the demand on the graph is very steep. Indeed, in the short term, the demand for energy is quite inelastic as it takes time and investments in order to adjust the energy consumption regarding changes in price. In the long-term, demand is more elastic so the demand function is flatter (Figure 10 and 12).

4.4 Levelized Cost of Electricity

The Levelized Cost of Electricity (LCOE) is often use to measure and compare the overall competitiveness of different technologies for electricity generation. It is an important factor when it comes to deciding to build a new power plant. The LCOE represents the average cost of building and operating a power plant, divided by the production per MWh and for its expected operational lifetime. The key parameters of the LCOE are the investment expenditures, the operation and maintenance expenditures (fixed and variable), the fuel expenditures and the electricity generated by the power plant. The importance of these parameters differs among technologies. For renewable energy technologies, the fuel cost is nonexistent. There is uncertainty for these parameters and they can vary among region and countries.

The LCOE is defined mathematically as:

$$LCOE = \frac{\sum of\ the\ costs\ over\ lifetime}{\sum of\ electricity\ produced\ over\ lifetime} = \frac{\frac{\sum_{t=1}^{n} I_t + M_t + F_t}{(1+r)^t}}{\frac{\sum_{t=1}^{n} E_t}{(1+r)^t}}$$

With I_t representing the investment expenditures, M_t the operation maintenance expenditures, F_t the fuel expenditures, E_t the electricity generated, r the discount rate and n the expected lifetime of the power plant.

An alternative interpretation of this equation is that the LCOE corresponds to a constant price that makes the entire profit over lifetime production equal to zero.

4.5 Price elasticity of demand and supply

The concept of elasticity is useful when analyzing how actors react to a change in price. The change in consumption and production of renewable energy due to a change in its price is an important factor that can help to determine the effect of implementing GOs on the totality of renewable energy production. For example, if producers are responsive to a change in price, then a small GO price will lead to a big increase in renewable energy production. Price elasticities represent the slope of the demand and supply function. Thus, they are decisive parameters in determining the equilibrium price and quantity.

Demand elasticity

Demand elasticity is the measurement of the change in the demand for a good in response to a change in the price of this good. Typically, the demand for a good will decline as its price increase. The demand elasticity is the percentage of change in quantity as a result of a relative change in price. Mathematically, it can be written as:

$$\varepsilon_d = \frac{\%\ change\ in\ the\ quantity\ of\ demanded\ good}{\%\ change\ in\ the\ price\ of\ the\ good} = \frac{\Delta Q_D/Q_D}{\Delta P/P}$$

Where Q_D is the quantity of the demanded good and P the price of the good.

For example, if ε_d=-0.5 it means that if the price increases by 1%, the demand will decrease by 0.5%. Typically, in the short run the elasticity of the demand for energy is less elastic or almost inelastic (Figure 13).

Supply elasticity

Supply elasticity measures how the supply for a good reacts to a change in its price. Usually, the elasticity is positive, meaning that when the price increases the production increases. It is the percentage change in quantity supplied corresponding to a percentage of change in the price. Mathematically, the supply elasticity is defined as:

$$\varepsilon_s = \frac{\%\ change\ in\ the\ quantity\ of\ supplied\ good}{\%\ change\ in\ the\ price\ of\ the\ good} = \frac{\Delta Q_s/Q_s}{\Delta P/P}$$

For the supply of energy, the time scale has a significant influence on elasticity. In the short term, if the price goes up the increase in production is limited to the installed capacities. Usually it takes several years to open a new power plant, depending on the technology employed. Thus, in the short term, elasticity of the supply is quite inelastic and is probably smaller than the longer-term elasticity. A more elastic function means that the function is flatter. The more the supply function is flat, the more a shift in the function changes the equilibrium quantity. As we saw before, the implementation of GOs shifts the supply function downwards so the impact on the quantity of renewable energy produced is higher in the long term (Figure 10).

5 Numerical Analysis

The objective of this research is to determine the economic impact of the implementation of GO as a tool to stimulate and to develop renewable energy production in the Netherlands.

5.1 Model Description

The analysis presented here is based on a linear programming (LP) model applied to the electricity sector in the Netherlands. LP is used in maximization or minimization of a linear function that is subject to linear constraints. To solve the model, I will use the Solver tool in Excel. The objective function is minimizing the cost of electricity supply in the Netherlands under some constraints. The proposed LP formulation consists of several elements: the maximum capacity production from the different sources, the demand for electricity, the costs of production, the CO_2 price and the GO price. The constraints are the following:

- Electricity supply and demand must be balanced for each year
- Electricity generation from a technology must be lower or equal to the maximum generation capacity of this technology

The horizon of the model is 2030. The model will run for the short-term, medium-term and long-term, corresponding to the years 2020, 2025 and 2030.

To find the objectives function we will use the electricity sources present in the Netherlands. The sources that will be use in the model are:

Table 1 Electricity sources used in the model

Source	Index
Natural gas	x_1
Coal	x_2
Nuclear	x_3
Wind onshore	x_4
Wind offshore	x_5
Solar (small and medium panel)	x_6
Biomass	x_7
Import	x_8

The electricity balance constraint can then be written as:

$$\sum x_{it} = D_t$$

Where x_{it} is the electricity generated from the source i during the year t, and D_t is the demand for electricity for the year t.

There are two scenarios for the maximum and minimum capacity constraints.

- Scenario 1

For the first scenario, the maximum generation capacity corresponds to the maximum generation capacity installed. In this scenario, there is no minimum generation capacity constraint. The constraints can be written mathematically as:

$$x_{it} \leq MAX_{xit}$$

Where MAX_{xit} is the maximum electricity generation capacity from renewable or non-renewable source i in year t.

- Scenario 2

For the second scenario, the maximum capacity constraints correspond to the limits sets by the government in terms of electricity generation from non-renewable sources. Thus, the electricity production from non-renewable sources cannot exceed the government restriction. Indeed, in the Energy Agreement the government plans to phase out natural gas from the energy mix by 2050 and to ban the use of coal for electricity generation by 2030 (Energy Agreement, 2013). No concrete objective has been set for natural gas before 2050, so this technology will not be subject to any limit from the government in the model. As part of this measure, they announced that the two oldest coal power plants must be closed by 2024. In the Energy Agreement, the government also set targets regarding renewable energy sources. They aim to reach a certain amount of electricity generation from wind onshore and wind offshore. Thus, the electricity generation from these sources should not be lower than the amount set by the government. For the sources that are not concerned by any restrictions from the government we use the maximum generation capacity installed as constraint. Mathematically, these constraints can be written as:

$$x_{it} \leq MAX_{xit}$$

$$x_{it} \leq MAX.G_{xit}$$

$$x_{it} \geq MIN.G_{xit}$$

Where MAX_{xit} is the maximum electricity generation capacity from renewable or non-renewable source i in year t , $MAX.G_{xit}$ is the maximum electricity generation capacity limit set by the government from the non-renewable source i in year t and $MIN.G_{xit}$ is the minimum electricity generation capacity limit set by the government from the renewable source i in year t.

Under those constraints, we will use the Solver in Excel to minimize the sum of the costs (including parameters like CO_2 price or GO) of each technology used to meet the electricity demand. We will use the LCOE of each technology to represent the cost of generating 1 MWh. Indeed, LCOE is a good toll when it comes to comparing different methods of electricity generation, as it represents the average cost of the different technologies on a consistent basis. In the case of technologies that are already installed (typically non-renewable power plants), we will disregard the investment costs in the LCOE. For new installed technologies, we will include the investment costs. Some policy parameters which have a considerable effect on the electricity producer's cost of supply are typically not included in the LCOE, such as the CO_2 price and GOs. In the model, we add these parameters to the LCOE. These parameters are considered exogenous to our model. The CO_2 price will be multiplied by the emission factor of a technology and added to its LCOE. For renewable technologies, the emission factor is null, thus the CO_2 price does not appear in the final generation cost. GOs will be deducted from the LCOE of each renewable technology.

By solving this model with LP, we will determine the amount of electricity produced from each source that meets the demand constraint at the lowest cost. As mentioned before, generation from a technology will have to respect the constraint of maximum generation capacity from this technology and in some cases a minimum generation constraint. We will have two scenarios regarding these constraints. The first scenario does not take into account the target imposed by the government and considers that the maximum generation capacity for non-renewables follows the lifetime of the currently installed power plants. The second scenario includes the governments objective to phase out coal by 2030, with plans to shut down a number of coal power plants in 2023. Scenario 2 also includes the restrictions set by the government on biomass production and their target of increasing wind generation to a certain level by 2023.

We will then implement GOs in the model and look at the impact on the supply function. There will be three different GO prices. According to the current market price for GOs, the prices in the model will correspond to a low price, a medium price and high price of GOs.

5.2 Model Assumptions and Data

CO_2 Price

The CO_2 price has an indirect impact on the production of renewable energy by increasing the cost of energy generation from alternative sources. Non-renewable technologies have an emission factor that corresponds to the amount of CO_2 emitted for 1 MWh generated. The higher the emission factor, the higher the cost of CO_2 emission will be. Typically, coal has a higher emission factor then gas.

In Europe, the level of emission certificates is fixed by the emission cap. In the past years, emission certificates have been oversupplied due to the drop in demand following the economic crisis and the increase of renewable energy. It has resulted in a low CO_2 price. Nevertheless, the price is expected to increase in the next years as the EU will implement measures to increase the CO_2 price (Frontiers Economics, 2015). In my analysis, the CO_2 price is an exogenous variable as the price is determined at a European level and the Netherlands does not have a considerable influence on this price.

The average CO_2 price for the year 2018 is around 15 €/t CO_2 (Markets Insider, 2018). I use this price for my short-term analysis, which corresponds to the year 2020. I increase the CO_2 price each year by an interest rate of 6%. The same interest rate is used for the calculation of the LCOE. Using the formula:

$$P_t = P_{2020} + P_{2020} * ((1 + i)^n - 1)$$

Where P_n is the CO_2 price in year t, i is the interest rate and n is the number of compounding periods.

By starting at 15 €/t CO_2 in 2020, I get 20,07 €/t CO_2 in 2025 and 26,86 €/t CO_2 in 2030.

Demand

In my model, the demand for electricity will be fixed for the years 2020, 2025 and 2030. As mentioned before, electricity demand is decreasing with respect to price and it is particularly inelastic in the short term. It means that a change in the electricity price in year t will not impact the electricity demand for the same year and onwards. My assumption for the evolution of electricity consumption is based on the National Energy Outlook, published by the Netherlands Environmental Assessment Agency in 2017. According to the National Energy Outlook, electricity consumption should drop slowly in the next years, going from 113 TWh in 2016 to 110 TWh in 2035. This decline in consumption reflects increases in energy efficiency. This projection of electricity consumption is based on established and proposed policy measures. It includes grid losses and private electricity generation.

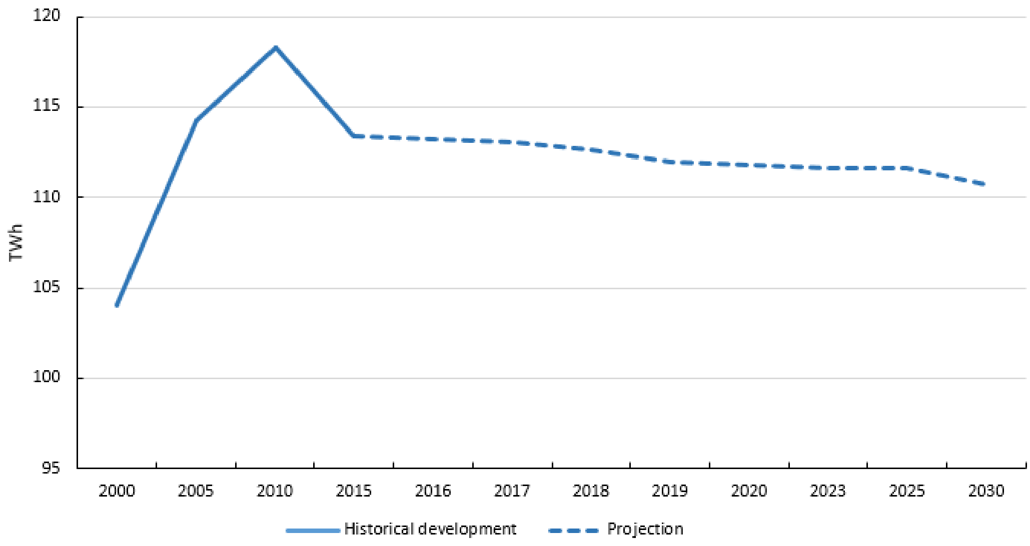


Figure 14 Assumed development of electricity consumption

Fuel price

The fossil fuel price is an important component in the future of the electricity market. Indeed, the price of fossil fuel affects the variable cost of electricity generation. The final price and the profitability of electricity generation is impacted by fluctuation in fossil fuel price.

To calculate the LCOE for electricity generation from natural gas, coal, and nuclear, I need to make assumptions about their prices. For natural gas and coal, I based my assumptions on the "Research on the effects of the minimum CO_2 price" (Frontier Economics, 2018). For nuclear I based my assumptions on "Levelized cost of Electricity" (VGT PowerTech, 2015). As the uranium price has been quite constant over the last years, we assume that the price will be constant in the coming years. The prices are in €/MWh (the price of natural gas, coal or uranium needed to produce 1 MWh). The price depends on both the fuel price and the conversion rate from fuel to power output. The conversion rate can vary, so the prices presented in the table below are average prices.

Table 2 Forecast of fuel prices

€/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

Levelized cost of electricity

The LCOE depends on multiple parameters, such as the nominal investments cost, the operation and maintenance costs, the technical lifetime of the power plant and the technical improvements (e.g. due to the learning curve). The development of these parameters, and thus the development of the LCOE, is characterized by a high level of uncertainty. In this section, I will first summarize the LCOE for each technology and each year in a table. I then will present the process used to determine the LCOE for each technology. Data and equations vary among technologies.

The LCOE for each technology and each year are summarized in the table below:

Table 3 LCOE for each technology

In €/MWh	2020	2025	2030
Natural gas	23.45	27.1	30.75
Coal	14.81	15.96	17.11
Nuclear	12.3	12.3	12.3
Wind onshore	31.47	29.62	27.77
Wind offshore	42.38	38.46	34.55

Solar	69.9	60.58	51.3
Biomass	27.9	24.93	23.33
Import	29	37	41

We can see that the LCOE for natural gas and coal increase as the fuel price increases in the coming years.

- LCOE for natural gas, coal and nuclear

As mentioned before, we disregard the investment costs for technologies that are already installed. Natural gas, coal and nuclear power plants are already in place in the Netherlands. As the Netherlands is trying to increase the share of renewable energy in its total energy production, there are no plans for building new natural gas, coal or nuclear power plants. Thus, the LCOE for those technologies is simply the fixed and variable operation & maintenance (O&M) costs plus the fuel costs. For the fixed and variable O&M costs, I used the data from "Levelized Cost of Electricity" (VGB PowerTech, 2015). The fuel costs are described in the previous section.

The LCOE for natural gas and coal can mathematically be written as:

$$LCOE = \frac{fixed\ and\ variable\ O\&M\ cost}{full\ load\ hours} + fuel\ price_t$$

Where the fixed and variable O&M is in €/MW/year and the fuel price is in €/MWh for the year t.

- LCOE for wind

To determine the LCOE for wind and solar technologies, I used data from the Danish Energy Agency. The Danish Energy Agency provides detailed technology data for energy plants in Denmark for the years 2015, 2020, 2030 and 2050. Such detailed data are not available for the Netherlands. As Denmark and the Netherlands share quite similar geographical and economical attributes, I will assume that the LCOE is the same for both countries. Information and cost data are different among the technologies, thus calculation of the LCOE is slightly different for each technology. The calculation of the LCOE for each technology is described below. Data are provided for wind offshore and near shore. As both offshore turbines and near shore turbines are present in the Netherlands, we use the average of these two technologies as the LCOE for all the turbines installed offshore.

Table 4 Cost data for wind onshore

Wind turbines on land		
Year of final investment decision	2020	2030
Average annual full-load hours	3 150	3 200

Technical lifetime (years)	27	30
Nominal investment (M€/MW) including grid connection	0.99	0.91
Fixed O&M (€/MW/year)	23 900	22 300
Variable O&M (€/MWh)	2.5	2.3
Discount rate	0.06	0.06

Table 5 Cost data for wind offshore

Wind turbines near shore		
Year of final investment decision	2020	2030
Average annual full-load hours	4 500	4 650
Technical lifetime (years)	27	30
Nominal investment (M€/MW) excluding grid connection	1.728	1.5
Nominal investment (M€/MW) grid connection	0.27	0.25
Fixed O&M (€/MW/year)	39 870	34 020
Variable O&M (€/MWh)	2.97	2.43
Discount rate	0.06	0.06

To calculate the LCOE for wind technologies, I used the equations:

$$Total\ cost = I + \sum_{i=0}^{t-1} \frac{F}{(1+r)^t} + \sum_{i=0}^{t-1} \frac{V * H_0}{(1+r)^t}$$

$$H_t = \frac{H_0}{(1+r)^t}$$

$$LCOE = \frac{Total\ cost}{\sum_{i=0}^{t-1} H_t}$$

Where I is the investment including the nominal investment for grid connection, F is the fixed O&M, V is the variable O&M and H_t is the average annual full load-hours in year t.

- LCOE for solar

In the data set from the Danish Energy Agency, small and medium solar panels do not have any grid losses. Thus, it is a reasonable assumption that these solar panels are private panels and that their electricity production is for private purposes. Small and medium solar panels are typically installed on roofs of residential, office or public buildings. We consider both technologies as one by using the average between LCOE for small and medium solar panels.

Table 6 Cost data for small solar panel

Small solar panel		
Year of final investment decision	2020	2030
Full load hours (kWh/kW)	1 042.50	1 077.13
Technical lifetime (years)	35	40
Investment, total system (M€/MW)	1.13	0.87
Fixed O&M (€/MWh/year)	13 440	10 815
Discount rate	0.06	0.06

Table 7 Cost data for medium solar panel

Medium solar panel		
Year of final investment decision	2020	2030
Full load hours (kWh/kW)	1 129.38	1 166.04
Technical lifetime (years)	35	40
Specific investment, total system (M€/MW)	0.80	0.63
Fixed O&M (€/MWh/year)	11 440	9 240
Discount rate	0.06	0.06

To calculate the LCOE for both small and medium solar panels, I used the equations:

$$Total\ cost = S + \sum_{i=0}^{t-1} \frac{F}{(1+r)^t}$$

$$H_t = \frac{H_0}{(1+r)^t}$$

$$LCOE = \frac{Total\ cost}{\sum_{i=0}^{t-1} H_t}$$

Where S is the specific investment, F is the fixed O&M and H_t is the average annual full load-hours in year t.

- Biomass

Currently, five biomass power plants are installed in the Netherlands. The government plans to stop the use of coal in the country by converting the existing coal power plants into biomass power plants. Thus, we will assume that there is no investment cost in the calculation of the LCOE for biomass. Indeed, no new biomass power plant will be built, but the capacity generation may increase by converting old coal power plants into biomass power plants. We consider that the Netherlands and Germany share enough characteristics to have approximately the same LCOE for biomass. So, the data used are German data from "The reference forecast of the German energy transition" (Knaut, A., Tode, C, 2016).

- Import

As the largest part of electricity import in the Netherlands comes from Germany, we will consider that the cost of the electricity imported is the market price of electricity in Germany (TenneT, 2018). We will also assume that the import capacity is fixed. Moreover, in this model, the German electricity price is exogenous. The market price is based on the "Price Forecast for the German Power Market" (THEMA Consulting Group, 2016).

Generation capacity

The maximum and minimum production per year for each source for Scenario 1 and Scenario 2 is summarized in the next two tables. The details of each number are provided after the tables. The details for coal, natural gas, nuclear and biomass generation units can be found in Appendix A.

Table 8 Generation capacity for Scenario 1

Scenario 1 (in TWh)	2020	2025	2030
Natural gas	85.644	85.644	85.644
Coal	21.58	18.28	18.26
Nuclear	4 .096	4.096	4.096
Wind onshore	20	20	20
Wind offshore	119	121	123
Solar panel (small+medium)	50	50	50
Biomass	21.58	21.58	21.58
Import	30.8	30.8	30.8

Table 9 Generation capacity for Scenario 2

Scenario 2 (in TWh)	2020		2025		2030	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Natural gas	0	85.644	0	85.644	0	85.644
Coal	0	21.58	0	**14**	0	**0**
Nuclear	0	4.096	0	4.096	0	4.096
Wind onshore	0	20	**18.6**	20	**18.6**	20
Wind offshore	0	119	**19.58**	121	**19.58**	123
Solar panel (small+medium)	0	50	0	50	0	50
Biomass	0	**6.944**	0	**6.944**	0	**6.944**

Import	0	30.8	0	30.8	0	30.8

The numbers in red bold are the targets implemented by the government. When no target is specified, the minimum generation capacity is 0 and the maximum is the same as for scenario 1.

Natural gas

The gas capacity currently installed is around 1000 MW. The government stated that they aim to phase out gas by 2050. However, no concrete plans have been made to reach this target. We assume that there will be no new capacity for natural gas. Thus, we consider that the maximum capacity for electricity generation from natural gas is the currently installed capacity multiplied by the maximum full load hour in a year (8000 hours).

Coal

Two scenarios are considered for the maximum generation capacity of the technologies. In both scenarios, we assume that there will not be any new capacity for coal. The first scenario does not include any target from the government. The only constraint that affects the capacity for coal is the natural lifetime of coal power plants. Between 2020 and 2030, one coal power plant will reach the end of its lifetime. The maximum generation capacity for coal is thus obtained by multiplying the electricity output (MW) of all the installed coal power plant in activity by the maximum full load hour in a year (8000 hours).

The second scenario includes the objective of the government to phase out coal by 2030. Currently, five coal-fired power plants are in activity, of which two are planned to be shut down by 2024.

Nuclear

Currently, only one nuclear power plant, Borssele, is generating electricity. The government has not communicated any intention to close the power plant, and the power plant will not reach the end of its lifetime before 2030. The maximum capacity for nuclear electricity generation is thus the generation capacity of this power plant. The capacity is obtained by multiplying the electricity output (MW) by the maximum number of hours that a power plant can run in a year (8000 hours).

Hydropower

The Netherlands has a flat topography. For this reason, it has little to no potential for hydropower production. In this model, we will consider that the maximum capacity for hydroelectricity to be zero. Thus, this technology will not appear in the model.

Wind

According to the report “Towards a clean economy in 2050”, the maximum generation capacity for wind onshore is planned to be 20 TWh for the year 2050 (Netherlands Environmental Assessment Agency, 2011), and the government aims to reach a wind onshore production production of 18.6 TWh by 2023

(National Energy Agreement, 2013). We will then assume that the maximum capacity is 20 TWh for the years 2020, 2025 and 2030.

In 2017, the yearly capacity of wind turbines offshore was 4.2 TWh (CBS, 2018). In the report "Towards a clean economy in 2050", the maximum generation capacity for wind offshore is planned to reach 130 TWh by 2050. To find the maximum generation capacity for the years 2020, 2025 and 2030, we assume a linear development from 4.2 TWh today to 130 TWh in 2050. Those previous data are used for Scenario 1, where there is no target from the government, and in Scenario 2 as maximum generation capacity.

For Scenario 2, we introduce new constraints that correspond to the targets sets by the government in the National Energy Agreement (2013). Targets for wind onshore and offshore are defined for the year 2023. Electricity generation from onshore wind should not be lower than 18.6 TWh and 19.5 TWh for offshore wind (Government of the Netherlands, 2013). This constraint is implemented for the years 2025 and 2030.

Solar

According to the Ministry of Economic Affairs of the Netherlands, if solar panels were to be installed on all suitable rooftops, they would produce 50 TWh (Ministry of Economic Affairs of the Netherlands, 2016). In 2017, electricity generated from solar panels represented 2.1 TWh (CBS, 2018). To find the maximum generation capacity for the years 2020, 2025 and 2030, we assume a linear development from 2.1 TWh today to 50 TWh in 2030. Solar panels are typically installed on roofs of residences, offices or buildings and are not connected to the grid.

The small surface area of the country reduces the possibility to install solar power plants. Currently, the entire electricity production generated by solar sources comes from solar panels installed on roof tops. Therefore, we will consider that the maximum capacity of large solar panels that are typically used in solar power plants is zero.

Biomass

In the Energy Agreement of 2013, the Dutch government set an upper limit for biomass co-firing in coal combustion plants of 7 TWH. "Biomass should only be deployed for energy production if there are no or only very limited alternatives available, preferably where the biomass solution can substitute the most fossil energy carriers per energy unit" (Ministry of Economic Affairs of the Netherlands, 2016). Currently, the maximum generation capacity installed is 21.58 TWh. This number represents the sum of all the biomass power plants installed in the Netherlands. In Scenario 1, this number is used as the maximum generation capacity for each year since none of these power plants will reach the end of its lifetime before 2030. In Scenario 2, the maximum generation constraint is equal to the target of the government for the years 2020, 2025 and 2030.

Import

The maximum capacity for import is based on the assumed development of interconnection capacity to the Netherlands in the "Scenarios for the Dutch electricity supply system" (Frontier Economics, 2015).

6 Results and Discussion

As mentioned previously, the implementation of a system that allows for higher remuneration for renewable energy producers has an impact on the decision to invest in renewable energy technology. This decision directly impacts the share of renewable and non-renewable energy in total energy production.

In this section, I will present and discuss the results of my model that aims to find the impact of GOs on renewable electricity production. I will first compare the results of the two scenarios described previously without including any GOs. In both scenarios, the CO_2 price is included. I will run the model for the years 2020, 2025 and 2030. I will then include the GOs in Scenario 1 and compare the results from Scenarios 1 and 2 that do not include GOs. In the second part, I will use Scenario 1 as my study case scenario and look at the impact of changes in different parameters in the model, such as the GO price and the CO_2 price. Scenario 1 will be used as the study case scenario as it will enable us to compare the efficiency of the GO system with the governmental measures.

6.1 Scenario 1 and Scenario 2, with and without GO

The Dutch government has committed to reduce its share of non-renewable electricity generation. To accomplish this end, it has set targets regarding the maximum amount of electricity generated from non-renewable energy and minimum amount of electricity generated from renewable energy sources. We compare Scenario 1, where there is no governmental involvement in the maximum or minimum amount of electricity production from different sources, with Scenario 2 to see the impact on the electricity sector when the government respects its commitments. Then, we will analyze the impact of the implementation of the GO system applied to Scenario 1.

For the three years studied and the different scenarios analyzed, not all the technologies are used to meet electricity demand. As the model is a linear model, the cheapest technology is used at its maximum capacity, then the next one is used at its maximum capacity, until the electricity supply meets the demand. In the case where minimum generation limits are imposed by the government, if the technology is not among the cheapest, its amount of production will equal the target of the government but not run at its maximum capacity. Typically, the most expensive technology in use does not reach its maximum capacity, as it is the marginal technology. The marginal cost of the marginal technology is equal to the market price. It means that for each year, n technologies are used, and n-1 are used at their maximum capacity. There can be an exception to this rule in the case where government imposes a minimum limit generation on a technology that is not among the cheapest technologies. Then, we can have more than one technology that is not running at its maximum capacity. The n^{th} technology is used at a capacity that correspond to:

$$DM_t - \sum_{m=1}^{n-1} x_{tm} = x_{tn}$$

Where DM_t is the electricity demand in year t, x_{tm} is the electricity generated in year t by the technology that is the cheapest and reaches the maximum capacity, and x_{tn} is the electricity generated by the most expensive technology and does not reach its maximum capacity.

The results of the model for Scenario 1 and 2, with and without GOs are represented below. The detail of the numerical results can be found in the Appendix B.

Marginal technology for Scenario 1 and Scenario 2 without GO

Table 10 represents the marginal technology and the price of this technology for Scenario 1 and 2 in the year 2020, 2025 and 2030. The price of the technology is the LCOE including the CO_2 price.

Table 10 Scenario 1 & 2 without GO - Marginal technologies

	2020		2025		2030	
€/MWh	**Technology**	**Price**	**Technology**	**Price**	**Technology**	**Price**
Scenario 1	Biomass	27.94	Natural gas	31.9	Wind offshore	34.56
Scenario 2	Biomass	27.94	Natural gas	31.9	Natural gas	37.19

Scenario 1 without GO

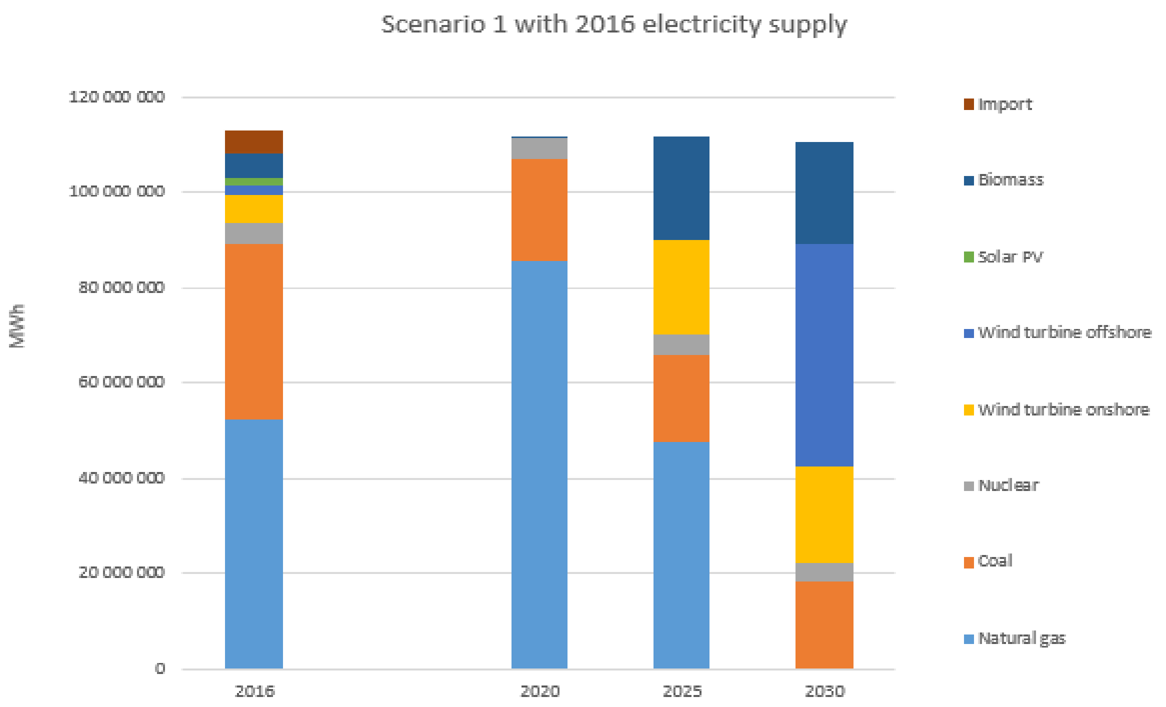


Figure 15 Scenario 1 - Evolution of electricity generation by source, historic electricity supply

The figure above represents the development of electricity generation by source for Scenario 1 and the historical electricity supply for the year 2016. In the graph, we can see that with no governmental action regarding the amount of electricity generated from renewable and non-renewable sources and no financial help for renewable energy producers, in 2020 almost no electricity generation will come from renewable sources with the exception of a small share from biomass. Compared to the electricity supply for the year 2016, in 2020 both the share of electricity from coal and renewable sources will decrease, whereas natural gas share will increase. Biomass is the marginal technology for the year 2020. The biggest part of electricity generation will come from natural gas. The increase in the CO_2 price and the decrease in LCOE for renewable technologies between 2020 and 2030 will lead to a decrease in the share of natural gas for the benefit of biomass and wind onshore. In 2025, natural gas will be the marginal technology, meaning that it is the most expensive technology used to meet the electricity demand. Coal production will slightly decrease between 2020 and 2025 as some power plants will reach the end of their technical lifetime. However, this technology will still run at its maximum capacity until 2030 due to a very advantageous LCOE and a CO_2 price that is too low to make coal technology disadvantageous compared to some renewable energy sources. Nuclear production will stay constant as the only nuclear power plant in the country will not reach the end of its technical lifetime before 2030, and its generation price will still be competitive. Wind onshore will start to be competitive from the year 2025 and run at full capacity for the years 2025 and 2030. Wind offshore will start to appear in the national electricity production only from 2030. In 2030, wind offshore will be the marginal technology. The reduction of its LCOE over the years will lead to an increase in its share of total electricity production, and it will phase out natural gas. Natural gas will also be phased out due to an increase in fuel cost. The LCOE for wind offshore is higher than for wind onshore, because wind turbines at sea are more costly to connect to the grid. However, the maximum generation capacity is higher at sea than on land due to larger turbines offshore and more available space. Thus, electricity generation from wind offshore will surpass the electricity generation from wind onshore. Solar technology will still be too expensive in the long term, in 2030, to compete with the other technologies.

Scenario 2 without GO

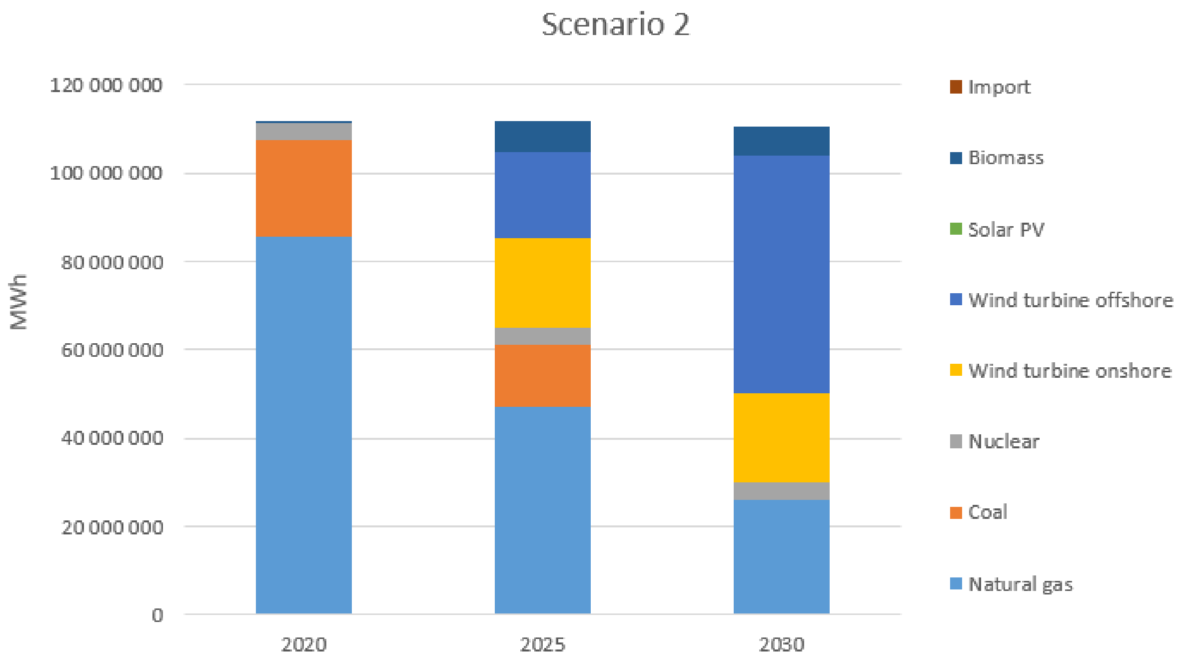


Figure 16 Scenario 2 - Evolution of electricity generation by source

We can see that the involvement of the government has no impact on energy production for the year 2020 compared to Scenario 1. In 2020, only an upper limit is imposed on biomass by the government. As mentioned in section 5.2, the government wants to limit the electricity generation from biomass to stimulate electricity generation from alternative renewable energy sources that are considered to be more environmentally friendly. As biomass is the marginal technology, meaning that it is used at a lower level than the limit imposed by the government, this measure does not affect the electricity share of biomass. However, the governmental measure that forces the closure of the oldest coal power plants by 2023 will lead to a smaller amount of electricity generation from coal in 2025 compared to Scenario 1. Following the government's plans in 2030 all coal power plants will be shut down, so production from coal will be equal to zero. For the year 2025, production from wind offshore is higher in Scenario 2 than in Scenario 1. Indeed, there is a minimum generation limit for wind onshore and wind offshore imposed by the government from 2023. As the LCOE of wind offshore is still not competitive compared to other technologies, the amount of electricity generated by wind equals the target. With the ambition of the government to shut down all the coal power plants by 2030, coal production in Scenario 1 shifts to natural gas production in Scenario 2. For the years 2025 and 2030, natural gas is the marginal technology. In 2030, the overall fossil fuel electricity generation is higher in Scenario 2 than in Scenario 1 due to the restriction on biomass generation that reduced its share in total electricity production in Scenario 2. However, the CO_2 emission intensity from non-renewable energy technologies in Scenario 2 is 6.6% lower than in Scenario 1. Indeed, the coal production in Scenario 1 is replaced by natural gas production in Scenario 2. Nuclear technology is the only technology that is not impacted by the evolution of the years or government measures. Import and solar are the two most expensive electricity supply alternatives. Although the LCOE of solar panels decreases during the period 2020-2030, it is still the most expensive technology in 2030. For a number of technologies that are sufficient to generate electricity to cover the national demand, the import price is higher than the domestic price. Thus, there is no import in Scenario 1 and Scenario 2.

I will now use the same scenarios presented above and include a GO system. During 2018, the price of GOs has drastically increased in Europe. Currently, the price of a GO for wind from the Netherlands is 8€/MWh and is constantly increasing. This price is the highest for a GO in Europe. In the scenarios including the GO system, the GO price is set at 10€/MWh. I will assume that the GO price is the same for all renewable energy technologies. As explained in section 5.2, solar panels will not receive a GO as they are private installations, and the electricity generated is not sold but directly used by the households or companies that own them.

Marginal technology for Scenario 1 and Scenario 2 with GO

Table 11 represents the marginal technology and the price of this technology for Scenario 1 and 2 in the year 2020, 2025 and 2030. The technology price is the LCOE including the CO2 price, net of the GO price.

Table 11 Scenario 1 & 2 with GO - Marginal technologies

	2020		2025		2030	
€/MWh	**Technology**	**Price**	**Technology**	**Price**	**Technology**	**Price**
Scenario 1	Natural gas	27.1	Natural gas	31.9	Coal	26.87
Scenario 2	Natural gas	27.1	Natural gas	31.9	Natural gas	37.19

Scenario 1 with GO

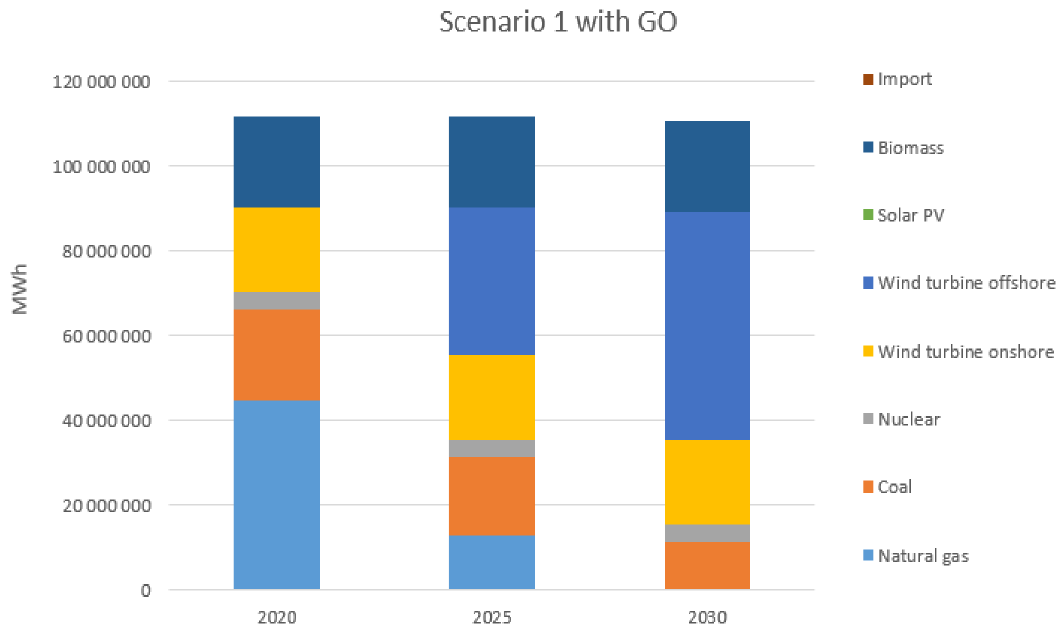


Figure 17 Scenario 1 with GO - Evolution of electricity generation by source

The graph above presents the results for Scenario 1, where the Dutch government do not impose any limit on minimum or maximum electricity generation from different sources, and where renewable electricity producers benefit from the GO system. The implementation of GOs allows wind onshore to appear in the energy supply already in 2020; whereas for Scenario 1 without GO, it only appears in 2025. As we can see from the graph above, the share of biomass is also higher in 2020 than for Scenario 1 without GO. Indeed, biomass is not the marginal technology when we implement GO to Scenario 1, meaning that biomass is running at its full capacity. The marginal technology for the years 2020 and 2025 is now natural gas. The increase in generation from other technologies leads to a reduction in generation from natural gas. For the years 2020 and 2025, the share of renewable energy generation in the total energy supply is higher in Scenario 1 with GO than in Scenario 1 without GO, and is equal in 2030. In 2025, thanks to the GO system, the share of renewable energy goes from 37% for Scenario 1 to 68% for Scenario 1 with GO. This large increase is due to the use of wind offshore technology at maximum capacity that becomes more affordable than natural gas. In 2030, there is almost no difference between Scenario 1 with or Scenario 1 without GO. The share of renewable electricity generation is almost the same in both cases. However, the marginal technology is wind offshore in Scenario 1 without GO, and coal in Scenario 1 with GO. We can conclude that in the long term (2030), the GO system does not have a big impact on the share of renewable electricity generation in the total supply. This can be explained by the fact that some renewable technologies have already become more affordable than fossil fuel technologies due to reductions in learning curves and increases in efficiency. However, the impact of implementing a GO system in the short and medium term (2020, 2025) is significant in this Scenario, where no limits on generation from fossil fuel technologies are imposed by the government. Indeed, between Scenario 1 without GO and Scenario 1 with GO the share of renewable energy goes from almost 0% to 37% in 2020.

For the year 2025, we can also see that the share of electricity generated by wind technology is larger in Scenario 1 with GO than in Scenario 2 without GO. This means that wind production is more stimulated by the implementation of the GO system than by the minimum generation limits imposed by the government on wind onshore and wind offshore. Thus, we can conclude that the GO system, with a price of GO equal to 10€/MWh, is more effective than the current minimum requirements on electricity generation from renewables imposed by the government.

Scenario 2 with GO

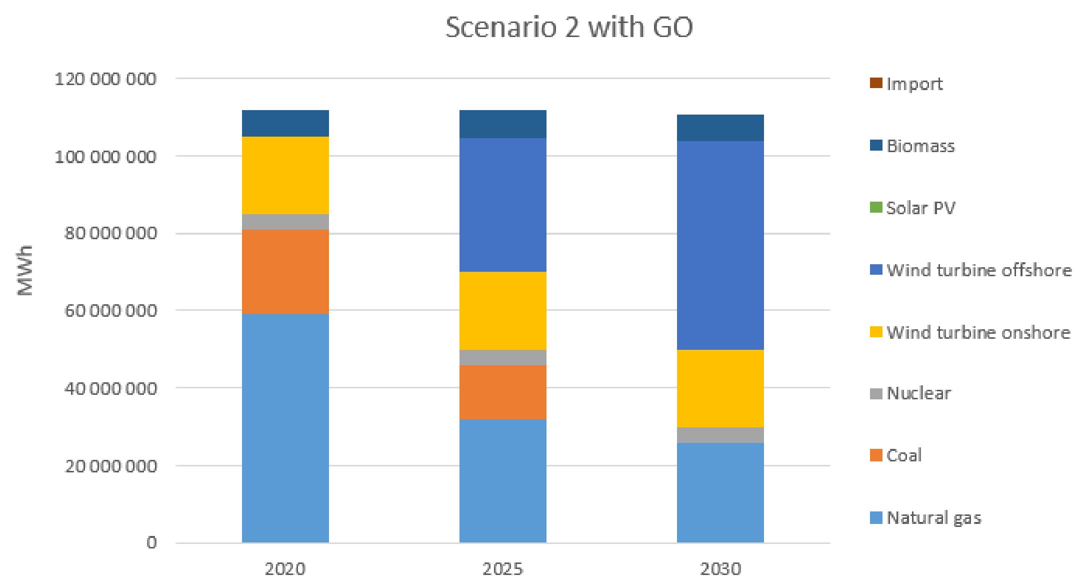


Figure 18 Scenario 2 with GO - Evolution of electricity generation by source

The graph above presents the results of Scenario 2, where the Dutch government imposes minimum and maximum electricity generation limits for some technologies, and where renewable electricity producers benefit from the GO system. In 2020, the implementation of GOs leads to an increase of biomass and wind onshore production. Electricity generation from wind onshore reaches its maximum capacity and the level of electricity generation from biomass meets the maximum limit imposed by the government. The share of renewable electricity in 2020 is 24%. Natural gas is now the marginal technology, while it was biomass in Scenario 2 without GO. In 2025 without GO, electricity generation from wind offshore was at the minimum limit imposed by the government. With GO, the amount of electricity from wind offshore increases to maximum generation capacity. The share of renewable electricity in 2025 increases from 41% in Scenario 2 without GO, to 55% in Scenario 2 with GO. For this year, natural gas is the marginal technology. For the year 2030, there is no difference between Scenario 2 with and without GO. Indeed, even if the LCOE for renewable technologies have become lower with the implementation of the GO system in Scenario 2 with GO, the restrictions imposed by the government alone lead to a maximum electricity generation from renewable sources that could have benefitted from GOs in Scenario 2 without GO. As for a comparison with Scenario 1 with and without GO, we can conclude that for Scenario 2 the implementation of a GO system has an impact on the share of renewable electricity generation on total supply in the short and medium term, but it does not influence the electricity supply in the long term.

Compared to Scenario 1, the share of renewable energy is smaller in 2030 due to the restriction imposed on biomass generation. The share of biomass in total electricity production is then reduced from Scenario 1 to Scenario 2 with GO. However, coal generation is replaced by natural gas generation, which has a smaller CO_2 emission factor and is thus less armful for the planet. In the all four scenarios, the import price is higher than the domestic price for a number of technologies that are sufficient to cover the national electricity demand. Thus, there is no import.

6.2 Analysis of the scenarios with changes in parameters

In this section, I will analyze the impact of changes in the GO price and CO_2 price on the Dutch electricity supply for a specific year.

Changes in the GO price

I made three assumptions for the GO price that correspond to a low, medium and high price. The low price is equal to 3€/MWh, the medium price is equal to 10€/MWh and the high price is equal to 20€/MWh. The medium price is the base case price, that was used in the previous section. I will look at the impact of a change in GO price on Dutch electricity generation for Scenario 1 as there is no influence from the government on the minimum or maximum electricity generation for different electricity sources. The model analyses the impact of different GO prices for the year 2020, as in the short term the renewable electricity potential is particularly untapped.

The result is presented on the graph below and the numerical details can be found in Appendix B.

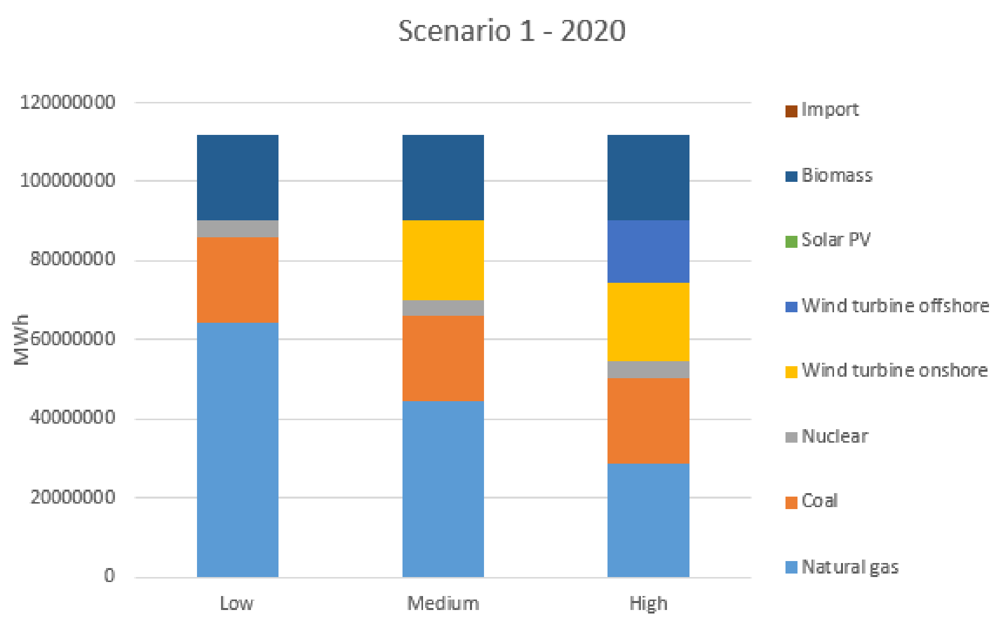


Figure 19 Change in the GO price for Scenario 1 – 2020

The results indicate that a GO price of 3 €/MWh allows biomass to compete with fossil fuel technologies. Compared to Scenario 1 without GO, where biomass production account for less than 1%, in Scenario 1 with a low GO price, biomass production runs at its maximum capacity and the share of natural gas is reduced. Indeed, the marginal technology in Scenario 1 with low GO price is natural gas. An increase in the GO price from 3 €/MWh to 10 €/MWh leads to an increase in the renewable electricity share from 19% to 37%. When the price increases from 10 €/MWh to 20 €/MWh, the share of renewable electricity increases due to wind offshore production. A GO price of 20 €/MWh in 2020 leads to a share of electricity from wind onshore and wind offshore close to the minimum requirements imposed by the government in 2025. We can conclude that the higher the GO price is, the more renewable technologies are used for electricity generation. The share of renewable electricity increases with the GO price.

Changes in the CO_2 price

The CO_2 price is volatile, especially in recent years. CO_2 price forecasts often vary greatly from one year to another. Most of the recent forecasts have failed to predict the substantial increase that happened in 2018. The future of the CO_2 price is uncertain. As discussed in the part 5.2, the CO_2 price will probably increase in the coming years. This made it interesting to look at the impact of different CO_2 prices for Scenario 1 in the short term, for the year 2020. The three scenarios for the CO_2 price are 15 €/t CO_2 as a medium price, 30 €/t CO_2 as a high price and 50 €/t CO_2 as a very high price. The medium CO_2 price is the price used in the previous analysis.

The figure below presents the results for medium, high and very high CO_2 price for Scenario 1 without GO for the year 2020.

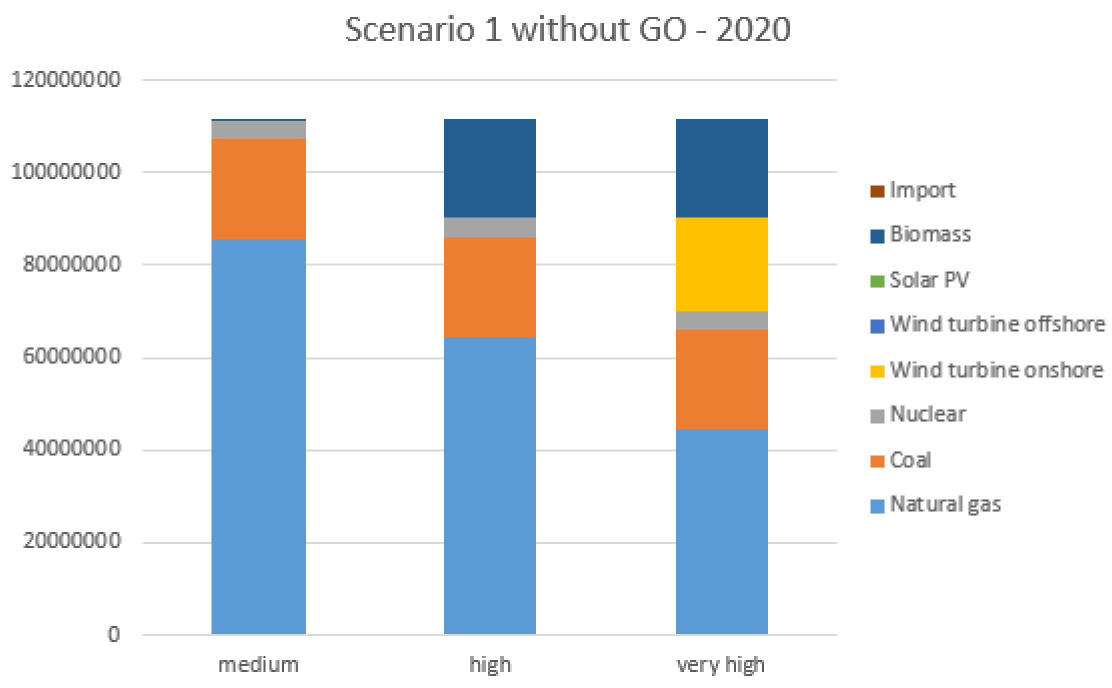


Figure 20 Changes in the CO2 price for Scenario 1 without GO – 2020

In Figure 20, we can see that increases in the CO_2 price in the short term, for the year 2020 have a significant impact on renewable electricity generation. When the CO_2 price is 15€/t CO_2, renewable electricity represents less than 1% of the total electricity generated. For this price, the marginal technology is biomass. When the price increases from 15€/t CO_2 to 30€/t CO_2, biomass is running at its maximum capacity and the share of of natural gas in the total electricity generation is reduced. For a high CO_2 price, the marginal technology is natural gas. The marginal technology is also natural gas for the very high CO_2 price of 50€/t CO_2, and its share is smaller than for the high price. Indeed, with the very high CO_2 price, wind onshore become cheaper than natural gas. Even though coal has a higher CO_2 emission factor than natural gas, its production share is not impacted by increases in CO_2 price due to its very low LCOE.

The figure below presents the results for the medium, high and very high CO_2 price for Scenario 1 with GO for the year 2020.

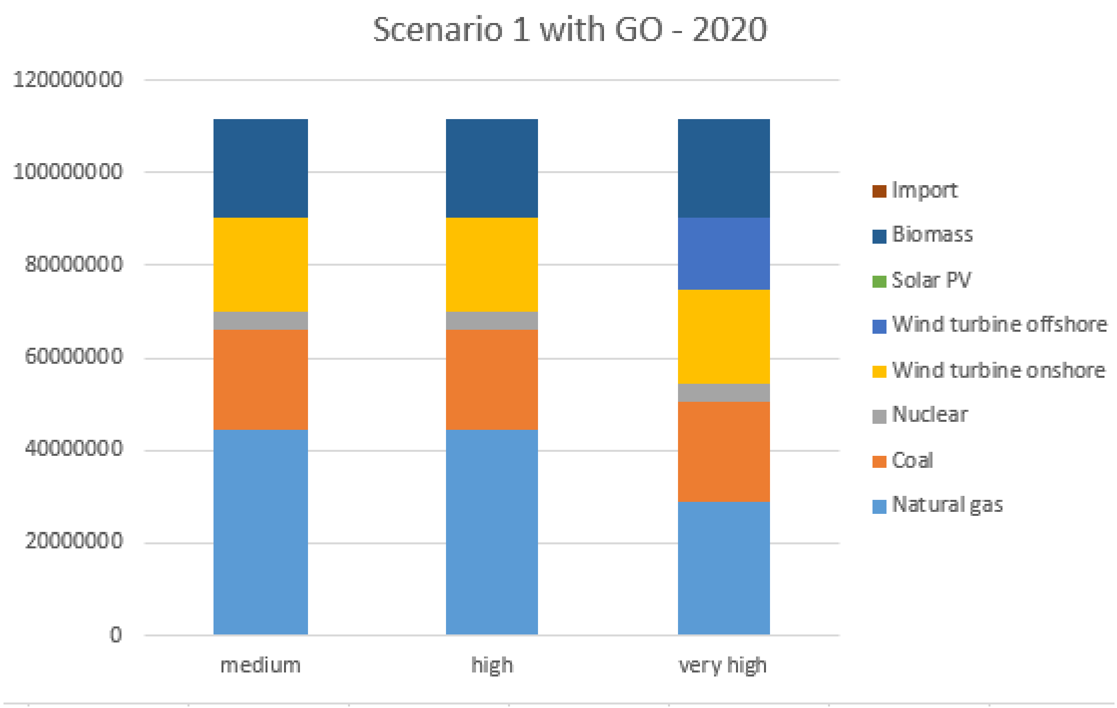


Figure 21 Changes in the CO2 price for Scenario 1 with GO – 2020

In the graph above, we can see that increases in the CO_2 price have less impact when there is a GO system compared to when there is none. Indeed, the electricity supply of a medium CO_2 price with GO corresponds to the electricity supply of a very high CO_2 price without GO. The results from a change in the CO_2 price show that an increase of the CO_2 price from 15 €/t CO_2 to 30 €/t CO_2 does not impact the electricity supply. For these two prices, the electricity supply corresponds to the Scenario 1 with GO electricity supply in 2020 presented in section 6.1. However, when the price rises from 30 €/t CO_2 to 50 €/t CO_2, the share of natural gas in the total electricity generation is reduced, and wind offshore generates electricity at its maximum capacity. We can conclude that for Scenario 1 with GO, an increase in the CO_2 price in 2020 that is lower or equal to 30 €/t CO_2 does not impact the model presented above.

Changes in demand

In the model, the electricity demand is fixed, and does not react to changes in the electricity price. As mentioned in part 6.1, all of the most affordable technologies are used at their maximum capacity to meet the electricity demand, and the most expensive technology is typically used at a level that is below its maximum capacity. For this reason, decreases in demand that are smaller than the quantity generated by the most expensive technology do not impact the electricity market price. If the decrease is higher than the level of electricity generated by the most expensive technology, this technology will stop running and the electricity market price will fall to the price corresponding to the new most expensive technology in production. Similarly, there is no difference in the electricity market price if the electricity demand increases at a level that is lower than the quantity of electricity between the maximum generation capacity of the most expensive technology and its current generation. If the increase in demand is higher than this level, the price increases to the price of the second most expensive technology needed to meet this larger electricity demand.

For example, an increase of 10% in the electricity demand does not impact the electricity supply in 2020 and 2025. Thus, the electricity price does not change either. In the long term, for the year 2030, an increase in the electricity demand of 10% has no impact on Scenario 2 but does impact Scenario 1 with or without GO. The marginal technology that was wind offshore is not sufficient to cover the increase in demand, thus natural gas has to be used to meet the demand. The electricity price will then increase by 2.64 €/MWh for Scenario 1 without GO and by 12.64 €/MWh for Scenario 1 with GO.

6.3 Model assumptions, simplifications and limitations

Assumptions and simplifications have been made in order to limit the scope of this thesis. I will present these assumptions and simplifications to allow for a better interpretation of the results of my model.

A determining factor in the model is the LCOE. We assume that the LCOE is fixed for each technology. However, in reality LCOE for a technology can vary among power units. For example, parameters that impact the LCOE for wind can differ. The price of the land where the onshore turbines are installed can vary within a county, and the intensity of the wind can depend on the location of the onshore or offshore turbines. The efficiency of coal or natural gas power plants is also different among power plants.

As presented in section 2.1, GO transactions are usually not done directly between the renewable electricity producer and consumer, but are processed through third party actors. Most of the transactions are done through middlemen, like traders or brokers, who take a part of the profits generated by the GOs. In my model, I consider that the entire price of GO as going to the renewable electricity producer.

As mentioned in section 4.2, the GO price represents the WTP of the consumers for renewable energy. The price can be different among different technologies and places. Typically, GOs from large Norwegian hydro power plants are cheaper than local solar or wind production, because consumers realize that there is a higher probability that the purchase of GOs from local wind or solar will create an incentive to increase renewable production. In the scenarios with GO, it is assumed that the GO price is fixed. In reality this price is not fixed. There is only one demand for electricity in the model, and that demand can be met with or without GO, without any limitations. In reality, there are two distinct demands for renewable and non-renewable energy.

In the model, implementation does not impact the import price. However, as the GO system is a European system, the import price could decrease when GOs enter the model. We use the German market electricity price as the import price. As mentioned previously, in Germany renewable energy producers cannot benefit from governmental subsidies and GOs at the same time. This means that GOs do not cover all renewable electricity production in Germany. It is difficult to predict the future German renewable electricity production covered by GO, as it depends on the future share of renewable electricity, the price of GOs and the level of subsidies provided by the government to renewable electricity producers.

Like in most of the economic literature, we assume that the actors are rational. Thus, when making an investment decision, they will choose the least costly. However, many other parameters come into play when investing in electricity generation, including sustainability and ecological character. As mentioned before, GOs translate this parameter into economic value as the WTP. However, in my model solar panels do not benefit from GOs since they are private and the electricity generated is not sold but used by the solar panel owner. We saw that the LCOE for solar panels is the highest LCOE among the technologies present in the Netherlands. Nevertheless, solar panels could be more attractive in reality for households and companies due to a higher WTP for generating their own renewable energy than for buying it. This WTP is not included in my model, meaning that it could underestimate future levels of use of solar technology.

In the analysis presented in this paper, I look at the annual market of electricity, which implies that there is only one electricity price for the year. In fact, the electricity price is changing over time, depending on, among other things, the season or hour of the day. Thus, technologies that are sensitive to these changes in price will run when their LCOE are lower than the electricity price (typically renewables, natural gas and coal), but technologies like nuclear that cannot adjust to those changes promptly are running at a constant intensity.

The Dutch demand for electricity in the model follows the forecast presented in the National Energy Outlook (Netherlands Environmental Assessment Agency, 2017). The variations of electricity sources can impact the market price. As the demand is price responsive, the demand should decrease with an increase in the electricity price. However, in the model the demand is fixed for each year. Moreover, there is a substantial use of natural gas in the Netherlands, for example for non-electricity purposes like heating, that could shift to electricity in the next years in order to reduce the total natural gas consumption. Thus, electricity demand could increase due to this shift in energy consumption.

7 Conclusion

Throughout this thesis, we have tried to analyse the impact of the GO system on investment in renewable energy. The results presented in this paper suggest that the GO system has a positive impact on investment in renewable energy technology in the Netherlands.

We compared the impact of the GO system for two scenarios. One scenario where there were no restrictions imposed on fossil fuel and no minimum generation target set for renewable electricity by the government. For the second scenario, the government imposes a maximum limit on fossil fuel sources and a minimum limit on renewable electricity. The results indicated that the GO system has a positive impact on the share of renewable electricity in both scenarios. The implementation of a GO system has a bigger impact on renewable electricity generation when there are no restrictions imposed by the government. The share of renewable electricity increases by a higher rate in this case. The results also showed that the share of renewable electricity is higher when there is a GO system without restriction imposed by the government, than when restrictions are imposed by the government without a GO system. This means that the GO system is more efficient than government restrictions. However, this result depends crucially on the GO price and the restrictions imposed.

We also found that the GO system in both cases has a bigger impact in the short term, in 2020, than in the long term, in 2030. In the short term, the gap between the cost of electricity generation from fossil fuel and renewable sources is higher than in the long term. Indeed, in the long term, some renewable electricity sources are cheaper than fossil fuel. Thus, the share of electricity from renewable sources that are competitive with fossil fuel is almost not impacted by the GO system. To conclude, the GO system allows an earlier shift to green electricity and helps approaching the 2020 target of 14% of renewable electricity production in the Netherlands.

Taking part in the GO system is voluntary and based on the willingness of the electricity consumers to pay an extra amount of money for renewable electricity. Policy instruments are also used to help the development of renewable electricity production and consumption. Further studies need to be made to determine if the GO system is cost-efficient for increasing renewable electricity share and whether the GO system rather should work alongside policy instruments.

The research has some limitations that should be considered to allow a better interpretation of the results. For this study, we used a linear function to represent the electricity generation function. However, the real electricity generation function is probably a more complex function. We also find data to determine the LCOE of the technologies. The data, though, vary greatly from one study to another, as they are characterized by a high uncertainty. We used the data that we consider the most realistic. Nevertheless, they may turn out to be far from the real number, especially in the long term. The LCOE is an important parameter in the model that has a substantial impact on the results. Other parameters like the GO price and the CO_2 price are subject to uncertainty. We considered only one GO price for each year every year and every renewable source. However, the GO price is a variable function that depends among others on the renewable electricity demand and also depends a lot on the public opinion and willingness to pay for renewable electricity.

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Appendix 1: Overview of the power generation units in the Netherlands

A1: Map of the power generation units in the Netherlands.

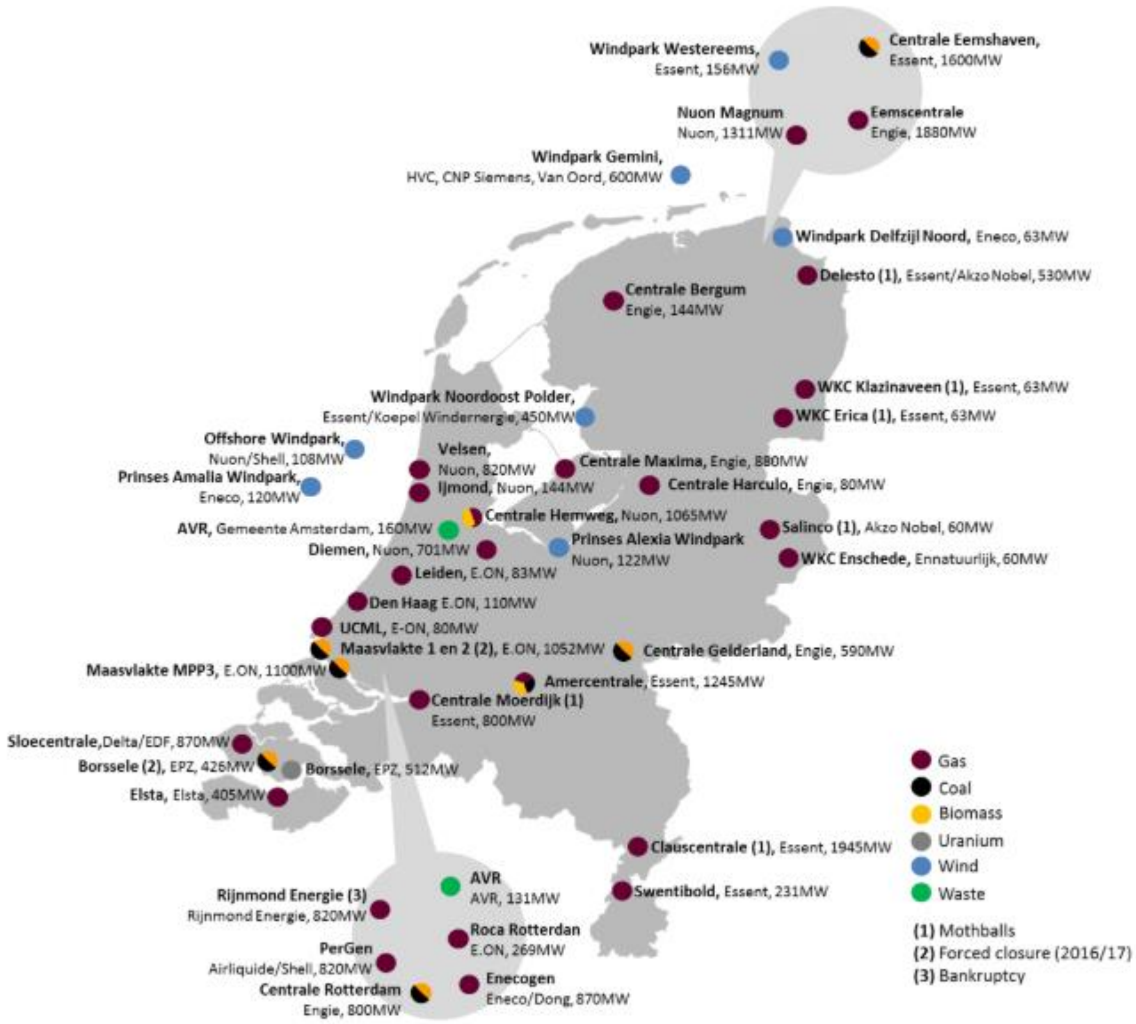

Figure 22 Overview of power generation units in the Netherlands

Source: Energy Outlook, 2015

http://energy.sia-partners.com/end-conventional-power-generation-3

A2: Power generation units' information

Table 12 Coal power generation units in the Netherlands

Site	GWh	Forced closure	Excepted closure[1]
Eemshaven	6 400	2030	2054
Borssele	1 704	2015	2028
Gelderland	2 306	2016	2022

Maasvlakte 1&2	4 208	2017	2028
Maasvlakte 3	4 400	2030	2053
Amercentrale	3 320	2024	2033
Centrale Rotterdam	3 200	2030	2057
Hemweg	4 260	2024	2035

[1]: expected closure following a lifetime of 40 years after the unit is operational.

Table 13 Nuclear power units in the Netherlands

Site	GWh	Operational	Closed
Borssele	4 096	1974	Still operational
Dodewaard	464	1963	1997

Table 14 Natural Gas power units in the Netherlands

Site	GWh
Delesto[1]	4 240
WKC Klazinaveen[1]	504
WKC Erica[1]	504
Salinco[1]	480
Centrale Moerdijk[1]	6 400
Rijnmond Energie[2]	6 560
Clauscentrale[1]	15 560
Eemscentrale	15 040
Nuon Magnum	10 488
Centrale Bergum	1 152
WKC Enschede	480
Centrale Harculo	640
Centrale Maxima	7 040
Centrale Hemweg	4 260
Ijmond	1 152
Velsen	6 560
Diemen	5 608
Leiden	664
Den Haag	880
UCML	640

Amercentrale	3 320
Sloecentrale	6 960
Elsta	3 240
PerGen	6 560
Roca Rotterdam	2 152
Enecogen	6 960
Swentibold	1 848

[1]: Mothballs

[2]: Bankruptcy

Table 15 Biomass generation units in the Netherlands

Site	GWh
Centrale Rotterdam	3 200
Maasvlakte3	4 400
Amercentrale	3 320
Centrale Hemweg	4 260
Centrale Eemshaven	6 400

Appendix B: Electricity generation by sources

Table 16 Scenario 1 - Electricity generation by source

In TWh	2020	2025	2030
Natural gas	85,64	47,71	0
Coal	21,58	18,26	18,26
Nuclear	4,1	4,1	4,1
Wind onshore	0	20	20
Wind offshore	0	0	46,77
Solar	0	0	0
Biomass	0,47	21,58	21,58
Import	0	0	0

Table 17 Scenario 2 - Electricity generation by source

In TWh	2020	2025	2030
Natural gas	85,64	47	25,91
Coal	21,58	14	0
Nuclear	4,1	4,1	4,1
Wind onshore	0	20	20
Wind offshore	0	19,58	53,76
Solar	0	0	0
Biomass	0,47	6,9	6,9
Import	0	0	0

Table 18 Scenario 1 with GO - Electricity generation by source

In TWh	2020	2025	2030
Natural gas	44,53	13	0
Coal	21,58	18,26	11,27
Nuclear	4,1	4,1	4,1
Wind onshore	20	20	20
Wind offshore	0	34,7	53,76
Solar	0	0	0
Biomass	21,58	21,58	21,58
Import	0	0	0

Table 19 Scenario 2 with GO - Electricity generation by source

In TWh	2020	2025	2030
Natural gas	59,17	31,9	25,9
Coal	21,58	14	0
Nuclear	4,1	4,1	4,1
Wind onshore	20	20	20
Wind offshore	0	34,7	53,76
Solar	0	0	0
Biomass	6,94	6,94	6,94
Import	0	0	0

Table 20 Scenario 1 - 2020 Low, Medium and High GO price

In TWh	Low	Medium	High
Natural gas	64.53	44.53	28.89
Coal	21.58	21.58	21.58
Nuclear	4.1	4.1	4.1
Wind onshore	0	20	20
Wind offshore	0	0	15.64
Solar	0	0	0
Biomass	21.58	21.58	21.58
Import	0	0	0

Table 21 Scenario 1 without GO - 2020 Medium, High and Very high CO2 price

In TWh	Medium	High	Very high
Natural gas	85.64	64.53	44.53
Coal	21.58	21.58	21.58
Nuclear	4.1	4.1	4.1
Wind onshore	0	0	20
Wind offshore	0	0	0
Solar	0	0	0
Biomass	46.8	21.58	21.58
Import	0	0	0

Table 22 Scenario 1 with GO - 2020 Medium, High and Very high CO2 price

In TWh	Medium	High	Very high
Natural gas	44.53	44.53	28.89
Coal	21.58	21.58	21.58
Nuclear	4.1	4.1	4.1
Wind onshore	20	20	20
Wind offshore	0	0	15.64
Solar	0	0	0
Biomass	21.58	21.58	21.58
Import	0	0	0

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