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How will REPowerEU affect Norwegian competitiveness in the renewable energy sector?

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List of Abbreviations

ACER:	Agency for the Cooperation of Energy Regulators
APS:	the Announced Pledges Scenario
bcm:	billion cubic metres
CCS:	Carbon Capture and Storage
EC:	the European Commission
EEA:	the European Economic Area (EØS-avtalen)
EGD:	European Green Deal
ETS:	Emission Trading System
EPREL:	European Product Registration for Energy Labelling
EU:	the European Union
FF55:	Fit-for-55
GHG:	greenhouse gas
GWh:	gigawatt hour
IRES:	intermittent renewable energy sources
KWh:	kilowatt hour
LCOE:	Levelized Cost of Energy
MOE:	merit order effect
MSR:	Market Stability Reserve
mt:	million tonnes
MWh:	megawatt hour
NOK:	Norwegian kroners
NSD:	The Norwegian Centre for Research Data (Norsk senter for forskningsdata)
NZE:	the Net Zero Emissions by 2050 Scenario
PV:	photovoltaics
RE:	renewable energy
R&D:	Research & Development
R&I:	Research & Innovation
RES:	renewable energy sources
RET:	renewable energy technologies
RRF:	recovery and Resilience Facility
STEPS:	the Stated Policies Scenario
TWh:	terawatt hour

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Abstract

In response to Russia’s invasion of Ukraine in February 2022, the European Commission presented the REPowerEU plan with the goal to reduce EU member states’ reliance on Russian oil and gas. The plan encompasses various measures, including the reduction of energy consumption, the exploration of alternative suppliers of gas and oil, and increased investment in renewable energy production. To facilitate the establishment of new energy infrastructure and systems required, the initiative incorporates financial and legal support. Amidst these developments, an important question arises: can REPowerEU foster the transition towards clean energy?

Norway, with its favourable geographic characteristics and access to renewable energy sources, as well as strong competence clusters and research environments, is influenced by EU legislation through its membership in the European Economic Area. This thesis aims to explore the pathways for overcoming dependency on Russian natural gas as outlined in the European Commission’s REPowerEU plan. It investigates the potential impact of these actions on Norwegian competitiveness in the renewable energy sector, with a focus on strategic integration of hydropower, expanding wind power capacity, and the potential for green hydrogen production. How competitiveness is affected is assessed from both short-term and long-term perspectives, and further we delve into the potential for Norway to enhance its own competitiveness while also supporting Europe's transition to green energy.

Sammendrag

Som et svar på Russlands invasjon av Ukraina i februar 2022 presenterte Europakommisjonen REPowerEU-planen med målet om å redusere EU-medlemslands avhengighet av russisk olje og gass. Planen omfatter ulike tiltak, inkludert reduksjon av energiforbruket, utforskning av alternative leverandører av gass og olje, og økt investering i produksjon av fornybar energi. For å lette etableringen av ny energiinfrastruktur og nødvendige systemer, inkluderer initiativet økonomisk og juridisk støtte. Midt i disse utviklingene oppstår et viktig spørsmål: Kan REPowerEU støtte det grønne skiftet?

Norge, med sine gunstige geografiske egenskaper og tilgang til fornybare energikilder, samt sterke kompetansemiljøer og forskningsmiljøer, påvirkes av EU-lovgivningen gjennom sitt medlemskap i Det europeiske økonomiske samarbeidsområdet. Denne avhandlingen tar sikte på å utforske mulighetene for å overvinne avhengighet av russisk naturgass slik det er beskrevet i Europakommisjonens REPowerEU-plan. Den undersøker den potensielle påvirkningen av disse tiltakene på norsk konkurransekraft innen fornybar energisektor, med fokus på strategisk integrering av vannkraft, utvidelse av vindkraftkapasitet og potensialet for produksjon av grønt hydrogen. Hvordan konkurransekraften påvirkes vurderes både på kort- og lang sikt, og videre ser vi på potensialet for at Norge kan styrke sin egen konkurransekraft og samtidig støtte Europas overgang til grønn energi.

1. Introduction

Over the last decades, climate change has received increased focus due to its impact on humans and natural systems across the world. The number of countries that have pledged to reach net-zero emissions by mid-century continues to grow, but so does the global greenhouse gas (GHG) emissions. Action is imperative as the entire world faces pressure to expedite the transition from fossil fuel sources to greener alternatives.

The combined efforts of transitioning away from fossil fuels and setting new targets for electrification, accompanied by the anticipation of enhanced economic growth, have sparked a surge in the demand for renewable energy. The world faces a two-fold challenge; supplying the market with the energy that is demanded, while reducing global emissions in line with the ambitions of the Paris Agreement (NHO, 2018). The Russian invasion of Ukraine in February of 2022 added a new urgency to the European climate action, and the European Union (EU) has been forced to strengthen their efforts through the REPowerEU plan. The invasion is first and foremost seen as a humanitarian crisis, but the war has also severely affected the energy situation in Europe. The abrupt reduction in gas supplies from Russia to the EU created significant market strain, resulting in a natural gas crisis (IEA, 2023).

Due to favourable geographic characteristics, Norway has ample access to renewable sources of energy, as well as strong competence clusters and research environments within the relevant fields. Through membership in the European Economic Area (EEA), Norway is affected by the new EU legislations that comprehends energy policy and regulations. With the increased focus on climate ambition in Europe, we are intrigued to explore the potential impact of those developments on Norwegian competitiveness in the renewable sector.

1.1. Contextualising the Problem

The world is facing a global energy crisis, which has far-reaching effects on markets, policies, and economies worldwide. The Russian invasion of Ukraine has intensified the predicament, but it did not originate solely from that event (IEA, 2022h). This chapter provides an overview of the global energy crisis, EU climate policy and the REPowerEU initiative and how the invasion of Ukraine is reshaping energy markets.

1.1.1. Global Energy Crisis

Global energy markets experienced a notable tightening in 2021 as energy prices have been on the rise. This is due to multiple factors, including the swift economic recovery, diverse weather conditions, the backlog of postponed maintenance work caused by the pandemic, and prior choices made by oil and gas companies and exporting nations to curtail investments (IEA, n.d.-b). While there are similarities between today's energy crisis and the oil shocks experienced in the 1970s, there are significant distinctions. The current crisis encompasses all fossil fuels, whereas the price shocks of the 1970s primarily affected oil. During that period, the global economy relied heavily on oil and had a lesser dependence on gas (IEA, n.d.-b).

The global energy crisis presents a complex and pressing challenge, that spans economic, environmental, and social dimensions. The energy crisis refers to the increasing concerns and challenges related to the availability, accessibility, and sustainability of energy resources on a global scale. The escalating demand for energy driven by population growth, urbanisation, and industrialisation has strained traditional fossil fuel sources. Not only are these sources increasingly limited, but they also have detrimental environmental impacts. Consequently, there is an urgent need to transition to sustainable and renewable energy (RE) options. Climate change has underscored the importance of adopting cleaner and greener solutions. Governments, businesses, and individuals must now prioritise diversifying energy sources, investing in innovative technologies, and implementing energy efficiency measures. These actions are crucial for mitigating the crisis and securing a sustainable energy future for generations to come (IEA, n.d.-b).

1.1.2. EU Climate Policy and the REPowerEU initiative

The EU has long been at the forefront of global efforts to combat climate change through ambitious climate policies. In recent years, the bloc has made significant strides towards decoupling economic growth from climate emissions and resource consumption. In 2019, the European Green Deal (EGD) was launched, which is a comprehensive plan aimed at achieving climate neutrality by 2050 (European Commission, n.d.-a).

Despite the challenges posed by the war in Ukraine, the EU remains committed to its climate policy and views climate action as crucial for resilience and a sustainable future. To address energy security concerns and reduce reliance on fossil fuels, the EU presented the

REPowerEU plan in March 2022. This plan aims to significantly decrease the EU's demand for Russian gas by 2023 and become independent of Russian energy imports well before 2030. The EU plans to achieve this by investing in electrification, promoting renewable energy sources, and improving energy efficiency (European Commission, 2022e; Energi Norge, 2022).

1.1.3. How the invasion of Ukraine is reshaping energy markets

Russia's aggression towards Ukraine triggering a series of far-reaching consequences. The United States and the European Union responded by imposing a range of sanctions on Russia, while several European countries expressed their determination to reduce dependence on Russian gas imports. Simultaneously, Russia has been progressively reducing or even shutting down its export pipelines. It is crucial to recognise that Russia was the leading global exporter of fossil fuels, playing a vital role as a supplier to Europe. In fact, as of 2021, one-fourth of the European Union's energy consumption relied on Russia (IEA, n.d.-b).

The global energy landscape has undergone a significant transformation. In the short term, the EU has notably increased its gas imports from non-Russian suppliers (Energi Norge, 2022). This shift in energy dynamics has introduced an element of unpredictability and instability in the European energy markets, primarily due to the resulting disruptions in gas flows. Russia’s deliberate reduction in gas supplies, wielding it as a means of exerting influence, has directly impacted the price of electricity generated from gas power plants, leading to an unprecedented surge in energy prices. The invasion has led the EU to re-evaluate its dependence on Russian energy imports and actively seek alternative sources and suppliers. The disruptions caused by the war has heightened the global energy crisis and emphasised the need for diversification of energy sources to ensure energy security (European Commission, 2023d; IEA, n.d.-b).

1.2. Objective and Research Question

Considerable portions of Norway's energy-based production are interconnected with global and European demand. As a result, we are heavily influenced by the politics and decisions made in neighbouring countries, particularly in Europe and by the EU (NHO, 2018). The implementation of the EGD will have a substantial impact on the Norwegian economy due to its close integration with the European market (Regjeringen, 2022a).

The Norwegian Climate Law aligns Norway's commitments with those outlined in the Paris Agreement and the EU. It establishes a legal framework for Norwegian climate policy and sets a target to reduce GHG emissions by 90-95% by 2050 compared to 1990 levels. Electrification is identified as a crucial measure to achieve this target, leading to an increased demand for renewable energy in power production. Proposed regulatory changes may overlap with existing and planned Norwegian regulations, and some adjustments and further regulations may be necessary. The exact consequences will only be determined once the new climate regulations proposed by the Ministry of Climate and Environment are adopted and discussed (NOU, 2023).

Given Norway's abundant energy resources and substantial investments in the development and expansion of renewable energy, it is worthwhile to examine how the country can contribute to Europe's transition while simultaneously meeting its own climate targets and supporting the green shift. With Europe's increasing sense of urgency, Norway possesses two vital energy sources: natural gas and renewable power. While there is currently high demand for both gas and power in Europe in the short term, the long-term solution remains a topic of debate. Building upon the discussion of Norway's significant role in the renewable energy sector and its potential to support Europe's transition to green energy, an important question arises:

How will the REPowerEU initiative impact Norwegian competitiveness in the renewable energy sector?

To support the conclusion to this problem statement, we have worded two sub-problem statements that will be addressed throughout the thesis:

1. *How will the implementation of REPowerEU affect Norwegian competitiveness in the short-, mid- and long-term?*

2. *What opportunities exist for Norway to support the clean energy transition in Europe?*

The first question directly addresses the impact of REPowerEU on the competitiveness of the Norwegian renewable sector, considering different timeframes. The second question explores the potential opportunities for Norway to contribute to the European transition towards clean energy. By investigating the opportunities available, we can assess how Norway’s expertise and natural resources can be utilised to foster the green transition and potentially enhance its own competitiveness in the process.

The EU has been addressing its dependency on Russian fossil fuels for several years, but this concern has intensified significantly in the aftermath of the invasion of Ukraine. Over the past decades, the EU has heavily relied on gas as an energy source, with Russia accounting for approximately 40% of Europe's total gas consumption in 2021 (IEA, 2022). In response to this, the EU and countries within its internal energy market are taking action through the REPowerEU plan. The primary objective is to achieve complete independence from Russian gas by 2027, while concurrently accelerating the transition towards green energy to reduce emissions. Norway has been recognised as a part of the solution, not only through gas supply but also by investing in and scaling up the production of renewable energy sources. Our investigation aims to explore Norway's role in this solution while fostering opportunities for the Norwegian industry to enhance competitiveness.

The thesis is divided into several chapters, each dedicated to a specific area of focus. Chapter 2 will provide the necessary background for the research. In Chapter 3, a theoretical framework will be developed to investigate the research question and clarify the associated models, theories, and scenarios employed. Chapter 4 will present the methodology and techniques used in the research, including a description of relevant data, as well as any limitations encountered. The results and analysis will be presented in Chapter 5, while Chapter 6 will contain the final discussion that forms the basis for the conclusion.

2. Background and Literature Review

The renewable energy sector has witnessed significant growth in recent years, driven by concerns about climate change, security of supply and economic competitiveness. This has led to increased investment in renewable energy technologies and policies aimed at their deployment. However, the transition to a low-carbon economy has not been without challenges. Policymakers and industry stakeholders are increasingly recognising competitiveness as a critical issue. They face the challenge of finding a delicate equilibrium between the pursuit of a sustainable energy future and the essential drive to uphold economic growth and competitiveness.

In order to gain deeper insights into the complexities and potential advantages linked to these factors, this chapter will examine several significant subtopics. These include the dimensions of competitiveness and how they relate to the renewable energy sector, the green transition in Norway and cross-border electricity trade. In addition, we will discuss the impact of policy initiatives on the renewable energy sector and EU climate policy amid the war in Ukraine.

2.1. Competitiveness and its Dimensions

Competitiveness is a term that is widely used in the fields of economics and business. It refers to the ability to compete effectively in the global marketplace and is influences by various factors such as quality of infrastructure, availability of resources, innovation, and overall environment. There are several dimensions of competitiveness that can be used to measure the competitive strength of an entity and understanding these is essential for policymakers and stakeholders to develop strategies that can enhance their competitive advantage and promote economic development.

2.1.1. Definition of Competitiveness

According to the European Commission (EC) (n.d.-b), clean energy competitiveness is defined as the “capacity to produce and use affordable, reliable and accessible clean energy and compete in the global clean energy markets”. By strengthening the competitiveness of the clean energy sector in the European Union, it will lead to a more robust energy system capable of tackling challenges associated with pricing, materials, and skills (European Commission, n.d.-b). To deliver on the objects outlined in REPowerEU, research and innovation will be essential to getting clean technologies ready for the market and further strengthening competitiveness.

2.1.2. Competitiveness in the Renewable Sector

The cost competitiveness of renewable energy sources (RES) has reached unprecedented levels, allowing some of today's renewable technologies to directly compete with fossil fuel-based power generation even without financial assistance (Amin, 2015). Since the beginning of 2021, we have witnessed higher costs on raw materials and freight, leading to higher prices on both RE and fossil fuels (IEA, 2022g). Increasing the prices on fossil fuels at a far greater pace, it has contributed to making renewable energy cost-competitive against power plants fuels by coal and natural gas. Solar and onshore wind power are now being offered through long-term contracts at prices below average wholesale rates, indicating a significant improvement in their competitiveness (IEA, 2022g).

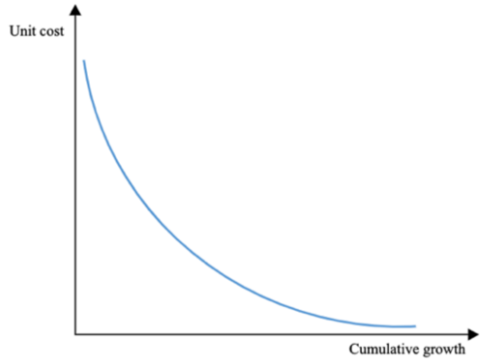


Figure 1: Learning curve showing the relationship between unit cost and cumulative growth of RETs.

For the world to shift towards low-carbon electricity, it is crucial that the cost of RES is lower than that of fossil fuels. RETs often follow learning curves, meaning their price declines with each doubling of cumulative installed capacity, while the price of electricity from fossil fuels does not (Roser, 2020). This is why power from new renewables is now cheaper than power from new fossil fuels in most places in the world. Outlined by the theory, increasing installed capacity of renewable technologies drives down the cost and makes them more attractive at an earlier stage.

The cost competitiveness of substitute technologies can further unlock the cost-reduction potential and accelerate the deployment of renewables (Amin, 2015). Research shows that the price of the renewable technology can affect a producer's incentive to facilitate learning spillovers, which would further reduce costs throughout the renewable energy sector. If one technology threatens to displace another in the energy system due to declining prices, this will create incentive for producers to facilitate spillovers and this will benefit the whole system (Leibowicz, 2015).

2.1.3. European and Norwegian Renewable Energy Markets

Renewable energy is a well-established technology, with a firm foothold in Europe. Europe is one of the world's largest markets for renewable energy, with large investments in wind, solar and hydropower. In 2019, the EU's electricity generation from wind and solar sources surpassed that of coal, marking a significant milestone as renewable energy has become increasingly cost-competitive with or cheaper than traditional fossil fuels in many regions (European Commission, 2020b). The renewable energy market in Europe is dominated by wind and solar power, which accounted for respectively 36% and 14% of the EU's renewable energy generation in 2020 (Eurostat, 2022). The EGD and European Climate Law are expected to drive further growth in the sector in coming years. Germany, Spain, Italy, France, and the UK are some of the largest markets for RE in Europe. Moreover, Europe is ahead of other regions like China and the US in both renewable energy production and installed energy per capita (IEA, 2022h).

Norway has also committed to achieving a low-emissions society by 2050, by establishing ambitious goals to reduce GHG emissions. With its abundance of RES, including cost-effective hydropower, Norway is in a unique position to lead the energy transition. The ample supply of hydropower has facilitated growth of energy-intensive industries and enabled widespread electrification of residential and commercial buildings with minimal GHG emissions. However, as a significant producer and exporter of oil and gas, Norway needs to adapt its energy sector to align with the worldwide energy transition (IEA, 2022e).

2.2. Renewable Sector and the Green Transition

A critical element of achieving the ambitious emission reduction targets and promoting the green transition is the deployment of renewable energy and the electrification of society. Norway has clear advantages through natural resources, expertise, and well-founded businesses, which means that we are well positioned to contribute to both meeting future energy needs and the reduction of GHG emissions (NHO, 2018). Looking at previous development, as well as the current situation and future prospect, we hope this will give further insight in the potential role and competitiveness of the renewable sector in Norway.

2.2.1. Development

For decades, Norway has had access to both non-renewable and renewable energy sources due to its geographical location. The electrification of Norway started towards the end of the 1800th century, and due to the extensive access to hydropower, Norway is more electrified than any other country. While the production of RE has historically centred around hydropower, concerns over environmental conflicts arising from extensive construction have prompted significant investments in alternative renewable sources such as wind power, bioenergy, and solar energy (Hofstad & Rosvold, 2022).

Norway is commonly referred to as an energy nation due to its substantial economic value stemming from its position as a significant energy supplier, with Europe serving as its foremost market (NHO, 2018). Since the liberalisation of the power market in 1991, value creation in the renewable sector has been steadily increasing (Energi Norge, 2020). As seen in figure 2, value creation and public revenue generated from the renewable sector has been on the rise, with noticeable increases over the past two years. This highlights the potential in which this sector can have for the Norwegian economy in the years to come.

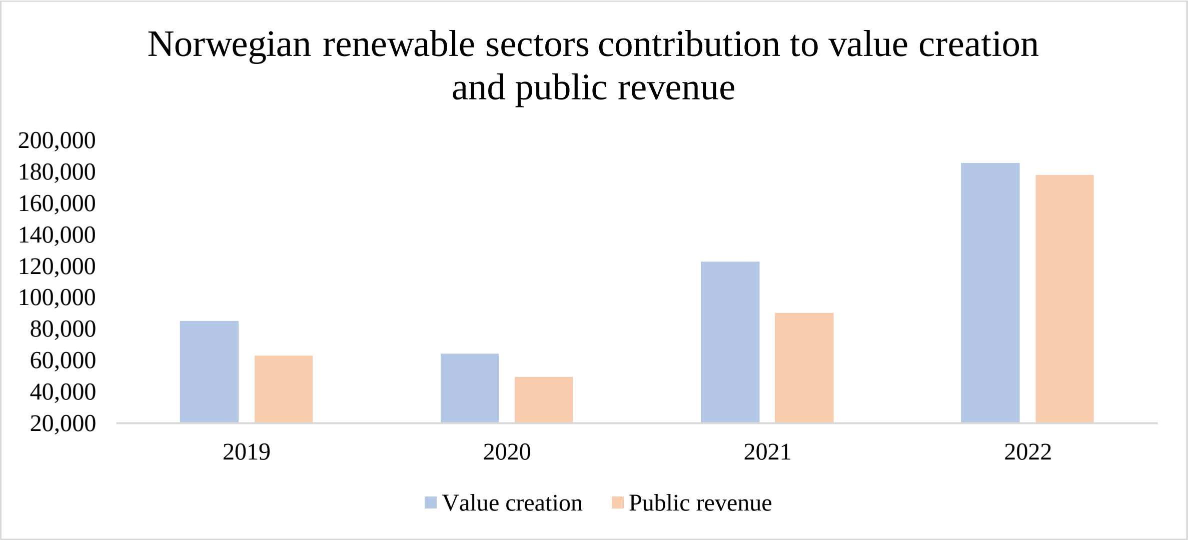


Figure 2: Norwegian renewable sectors contribution to value creation and public revenue (Fornybar Norge, personal communication by e-mail, May 2023).

In terms of productivity, the renewable industry is the second most productive the industry in Norway measured in turnover per employee. The corona crisis hit this industry hard and is responsible for the large drop in turnover per employee in 2020. Businesses shut down all over Europe, leading to decreased power prices from both the demand and supply side (Vista Analyse, 2020). The numbers have undergone a significant shift, with productivity reaching levels never recorded before.

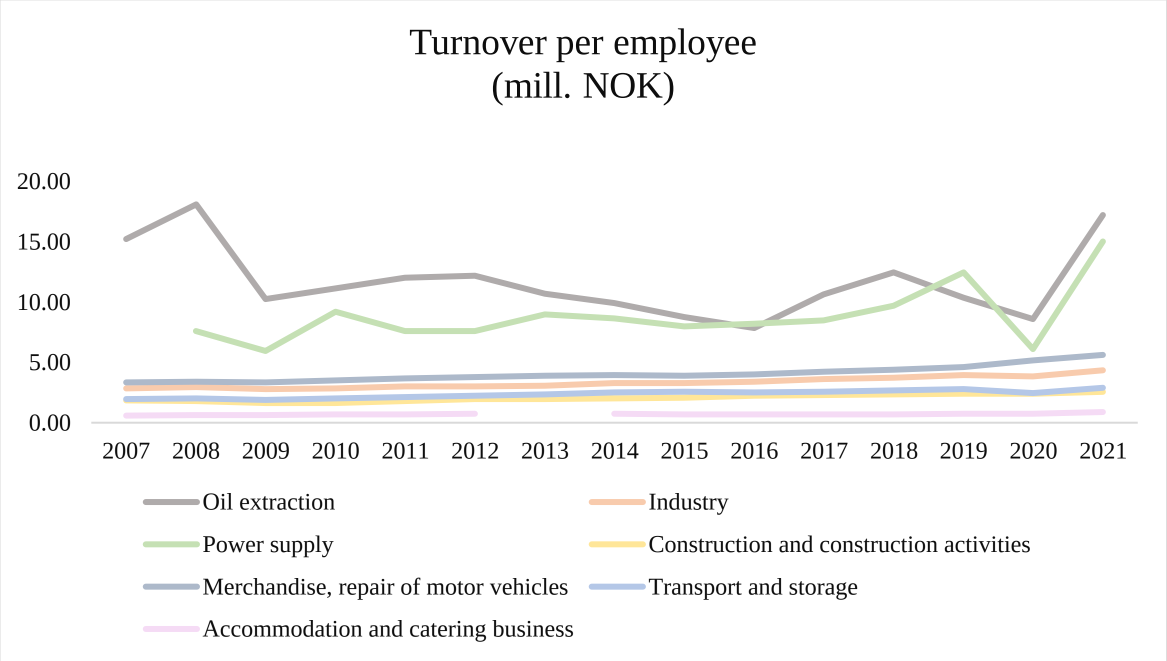


Figure 3: Turnover per employee in different industries in Norway in mill. NOK (Statistisk sentralbyrå, 2022a; Statistisk sentralbyrå, 2022b; Statistisk sentralbyrå, 2022c; Statistisk sentralbyrå, 2022d).

2.2.2. Current Situation

The Norwegian renewable sector is continuously growing, and 2021 turned out to be a record-breaking year for the renewables suppliers with a growth in revenue of 12% (Regjeringen, 2022d). The turnover in the international markets experienced the most growth compared to turnover in the national market and export turnover. Offshore wind power dominates with a turnover of 25.3 billion NOK where hydropower only accounts for 1.2 billion NOK (Multiconsult, 2022). Land-based wind power witnessed a decline in turnover, likely attributed to a slowdown in installations in key markets such as China and USA, which are major players in the wind power industry. According to the Global Wind Energy Council, the decline in China is mainly due to the out-phasing of a central feed-in-tariff support scheme (Hovland, 2022).

The electricity share of total energy consumption is a good measure of how far Norway has come in electrifying society and can be used as an indicator of where we stand in terms of the transition towards a low-emission society. In 2021, the share was measured to be 42% (Norwegian Ministry of Petroleum and Energy, 2022b). In comparison to other nations, Norway has a high and increasing electricity share of total energy consumption. Norwegian power generation consists of hydropower, wind power and thermal power. Hydropower accounted for 91.5% of the Norwegian power supply in 2021 and depends on the annual precipitation. This differs from the European power systems, where thermal power production still dominates (Norwegian Ministry of Petroleum and Energy, 2022b).

2.2.3. Predominant energy sources and carriers

Norway has various natural advantages when it comes to electricity generation, as our position geographically gives a unique access to exploiting renewable sources of energy. Considering the high mountain peaks combined with watercourses and steady rainfall, Norway is a country that is well suited for hydropower. In addition, hydropower and wind power interact very well, as we can save water in the reservoirs when the wind conditions are good and utilise our hydropower when there is no wind. Moreover, renewable energy access is vital to produce green hydrogen, which is anticipated to play a crucial role in driving the green transition. Norway has a long experience with hydropower, as well as an increasing deployment of wind power and clear ambitions for green hydrogen, which is why we have chosen these two energy sources and one energy carrier to be at the heart of our analysis.

2.2.3.1. Hydropower

Electricity generators utilise a variety of primary energy sources to power turbines and generate electricity. These sources include water, wind, fossil fuels, biofuels, nuclear fuels, and geothermal energy. When turbines are propelled by water, it results in the generation of hydropower. This can be achieved through unregulated river flows, commonly referred to as run-of-river hydropower. Additionally, hydropower can be derived from dams with limited storage capacity that exceed the natural water flow, as well as from reservoirs capable of storing several years' worth of inflow (Førsund, 2015).

Hydropower accounts for most of the Norwegian power supply and the total capacity corresponds to 70% of national electricity consumption (Ministry of Petroleum and Energy, 2021). The ability to store water allows more than 75% of Norwegian production capacity to be flexible, allowing for quick low-cost changes in production within an hour as well as over weeks and seasons. Due to its characteristics, hydropower is an ideal match for a future Norwegian power system that incorporates more intermittent power from energy sources as wind and solar (Statkraft, n.d.-a).

Although hydropower production does not generate harmful emissions, the exploitation of hydropower sites represents environmental issues. Norwegian reservoirs are mostly based on natural lakes in remote areas turned into reservoirs, hence they hold ecosystems with local species. These systems also consume the natural environment through visible pipelines, turbines, and so called "monster master", as well as altering the levels in reservoirs may create troubles for aquatic life and agriculture. This has led environmental groups to act and in the mid 1980s, the Norwegian parliament made a compilation with a list the protecting 60% of the remaining hydro resources from exploitation (Førsund, 2015).

The EU Water Framework Directive provides guidelines for comprehensive water management in Europe and was implemented as The Norwegian Water Regulation in 2007 as a part of the EEA agreement. The objective is to ensure protection and sustainable use of water, and therefore affects hydropower production (NVE, 2021). There are several environmental goals incorporated in this directive, and they are considered as met when both ecological and chemical states are satisfactory. If this is not the case, the government will assess what actions are necessary to improve aquatic environment (Vannportalen, 2022).

By 2050, the world's electricity generation is expected to double, but hydropower generation will only account for 13% of total electricity supply, compared to 16% in 2020. Although hydropower generation will increase in absolute terms, its share will be replaced by solar and wind power (DNV, 2022b). Since the start of 2020, 126 new hydro power plants have been approved for operation by NVE and the Norwegian Ministry of Petroleum and Energy (NVE, 2022), with a total capacity of 3,182 GWh. As mentioned above, The Norwegian Water Regulation sets some boundaries to the potential of hydro power plant construction in Norway in the years to come due to their environmental cost. Even though there are new projects planned for expanding hydro power production, the room of opportunity is smaller than for the other clean technologies currently expanding their position in the power market.

2.2.3.2. Wind power

A more diverse energy production mix is predicted for Norway in the coming years, and according to DNV (2022a), domestic demand for electricity is anticipated to double from 2021 to 2050. Annual average hydropower generation, however, is only predicted to grow 3% in the same period, and the remaining gap will be closed mostly by wind power (DNV, 2022a).

Wind turbines operate in a similar manner to hydropower systems, harnessing energy from the wind using mechanical power to spin a generator and create electricity. The underlying technology employed by both onshore and offshore wind turbines to generate electricity is fundamentally identical. Where they differ is in position, size, scale and how the generated electricity is transferred. Profitability varies with wind conditions, local costs, wind technology and policies, but land-based and bottom-fixed wind is generally considered profitable without subsidies in most areas. There is a difference between bottom-fixed and floating offshore wind, where floating wind turbines provide more access to deeper water which is characterised by higher and steadier wind as well as reduced visibility (Stewart et al., 2016). According to DNV (2022), offshore wind is expected to grow rapidly in the years towards 2030 because of reduced costs, sustained government support and increasing opportunities for trade in electricity.

The Norwegian government has decided that future power production will mainly come from offshore wind, and the ambition is to build out approximately the same amount of unregulated power at sea, as exists in Norwegian hydropower plants today (Regjeringen, 2022b). This equals a potential total production of 140 TWh and considerable amounts is expected to be transmitted to other countries. By reducing the concession processing time and increasing investments in the national budget, the Norwegian government are working to speed up the deployment (Regjeringen, 2022c). Several countries are trying to position themselves as frontrunners in the offshore wind industry. However, the decades-long experience from schemes in the offshore oil and gas sector gives Norway some possible advantages in the industry.

In large parts of the world, it is now cheaper to build new wind power plants than it is to establish new coal and gas power plants (Statkraft, n.d.-b). There has been a drastic decline in cost for bottom-fixed over the past few years, and further decrease is expected for both bottom-fixed and floating offshore wind. A stronger cost decrease for offshore wind will result in the technology being more competitive, as well as trigger a higher share of offshore wind in the supply mix (Thema, 2020). Growth and development will, however, depend on the relative cost developments for the technology compared to other renewable power generation technologies.

Like with most power plants, there is a trade-off between the negative effects on nature and profitability of the plant. One of the biggest disadvantages is that wind turbines create some noise when operating, both because of the mechanical operation and the wind vortex created by the rotating blades. Wind turbines also negatively affect the aesthetic value and the utility value of natural areas, which particularly affects local inhabitants, and the biological diversity of untouched nature, which has value for the whole society (Grimsrud et al., 2022). This is mostly true for onshore wind, however noise generated from offshore wind turbines pose a potential threat to fish and marine animals (WWF, 2014).

2.2.3.3. Green hydrogen

By 2050, renewable electricity is projected to play a substantial role in reducing the carbon footprint of the EU's energy system. However, for the parts of the energy system that cannot be reached by electricity, hydrogen is being recognised as an effective solution for decarbonisation. That's why the European Green Deal incorporates a hydrogen strategy (European Commission, 2020a) with the goal of setting up 40 gigawatts (GW) in Europe of renewable hydrogen electrolysers by 2030.

Because hydrogen does not exist freely in nature, it must be produced from other sources of energy, making it a so-called energy carrier. Colour codes has been implemented within the energy industry to separate the different types of hydrogen, where the most familiar are grey, blue, and green hydrogen (National Grid, n.d.). Green hydrogen is produced by electrolysing water, which separates hydrogen and oxygen, using electricity from RES. Emitting zero CO_2-emissions, green hydrogen contrasts with blue and grey hydrogen, which is produced from fossil fuels with and without carbon capture and storage (CCS). Green hydrogen currently constitutes a small percentage of the overall production, but this is expected to change as it is a clear priority in EU's energy strategy (SINTEF, n.d.). Considering green hydrogen being the most compatible alternative within the EU's goal of climate neutrality, we will focus our analysis accordingly.

In recent years, it has appeared many hydrogen ventures in Norway, and these emerging high-competence actors puts us in a position to be a leading producer for domestic industry and exporter of green hydrogen. According to Bain & Company (Hovland, 2021b), hydrogen can reach an export value of 100 billion NOK in a 2040 to 2050 perspective. They further believe that Norway has the potential to become a major supplier of hydrogen to the EU. It will require a lot of electricity to still have a power surplus while using large amounts of green hydrogen, and scaling up wind power production will be key if we are to succeed in building up the hydrogen industry in Norway (Hovland, 2021b). Production costs for green hydrogen are expected to fall in line with the extensive deployment of renewables, and studies conducted by IRENA and IEA indicate that green hydrogen costs will be lower or equal to blue hydrogen in the 2030-time horizon. Further, green hydrogen can serve as a backup for seasonal variations being a vector for RE storage. Another advantage is giving regions the opportunity to not depend on importing energy (SINTEF, n.d.).

2.3. Interconnectors and Cross-Border Electricity Trade

The wholesale electricity market involves power producers, suppliers, and various industry players buying and selling power, competing against each other (NVE, 2022). This market enables the import and export to and from Norway, facilitated by the close integration of the Norwegian power system with other systems, both through physical grids and market integration (NVE, 2021). Power systems in Northern Europe differ due to fundamental disparities in both supply and demand.

Today, Norway possesses a significant proportion of adaptable hydropower, Denmark has a considerable amount of wind power, whereas Sweden and Finland have substantial amounts of thermal production (NVE, 2023c). Norway’s significant surplus of power during periods of good hydrological conditions is largely attributed to its large hydropower capacity. When faced with oversupply, exporting power to other countries becomes a profitable option for Norway. Countries like Denmark experience higher energy production during windy periods, leading to lower prices, and importing power from Denmark becomes lucrative during these periods. Consequently, Norwegian hydropower producers can preserve water in the reservoirs for future use when it holds higher value. Building interconnections makes it possible to utilise differences in the power system, increasing social welfare for larger areas while enabling society to achieve the same level of security of supply (NVE, 2023c).

Security of supply is a recurring theme in national energy policies, as well as at the European and global levels (Chevalier, 2006). The academic literature recognises that the definition of energy security varies from one context to another. The European Commission (2000) has defined it as ensuring the uninterrupted physical availability of energy products on the market, while respecting environmental concerns and looking towards sustainable development. Further, the term refers to a country or region's ability to ensure a dependable and continuous supply of energy to meet the demand. Interruptions in the supply of energy can have significant economic and social consequences. Several measures can be taken to ensure security, such as diversifying sources of energy, investing in infrastructure to improve reliability, and developing domestic sources of energy. However, security of supply may face challenges if consumption growth exceeds production and grid capacity growth (Statnett, 2023).

Interconnectors link the national power grids of Europe, facilitating cross-border electricity trade and ensuring a secure energy supply in the long term. Referred to as the European internal energy market, is has been at the core of the European Union's energy policy for years (Amprion, n.d.). The increasingly interconnection of electricity in Europe has led to the development of EU-wide network guidelines. These are legally binding regulations implemented by the EC and manage the electricity flows in the internal European electricity market (European Commission, n.d-b). Norway currently has 17 cables to foreign countries, where export typically constitutes most of the power flow transmitted through the newest cables to Germany, Great Britain, and the Netherlands (NTB, 2022). Norway's cross-border export capacity has since 2015 increased from around 6,200 MW to 8,950 MW, where the majority of the increase can be assigned to these new additions (IEA, 2022b). The construction of new cables to England and Germany in 2021 has sparked a national debate concerning the effect on Norwegian electricity prices. Where some claims the cables are the main reason for the high electricity prices, others point at the high prices on gas and emission quotas (Hovland, 2021a). According to a note produced by NVE, the electricity price would be around 2-3 times higher if Norway had no interconnecting cables and thus had to hold back on hydropower production (Viseth, 2021).

Figure 4: Map of Norway's electricity transmissions showing grid capacity of interconnectors in megawatts (IEA, 2022b).

Norway has interconnectors linking it to several foreign nations, including Sweden, Russia, Finland, Denmark, Germany, England, and the Netherlands. The earliest of these power lines was constructed in 1960, connecting Norway to Sweden, and since the early 1990s, Norway has been trading electricity in the European market (Viseth, 2021). With most of these interconnections having been paid off, the cumulative value of these connections yields a net income. The cross-border capacity has increased significantly during the last decade, due to mainly the two new additions of NordLink to Germany and North Sea Link to the UK (IEA, 2022b). Statnett has further commissioned two new international connections to Germany and England with the total capacity of 2,800 MW recently, and a further increase in cross-border capacity will depend on the experience of how the two latest interconnectors influences system operations (Statnett, 2021). Statnett also acknowledges that Norway will attain a solid socio-economic benefit by the construction of new interconnectors, as well as the increased transmission capacity will be essential for the EU to meet its ambitious climate targets.

2.4. Impact of Policy Initiatives on the Renewable Energy Sector

Policy instruments play a critical role in influencing growth and development of the renewable energy sector, and governments can implement various policies to promote the adoption of renewable energy technologies (RET) and growth in the sector. One of the most important ways in which policy can support the renewable energy sector is through the establishment of regulatory frameworks and financial incentives that encourage the deployment of RETs. These policies can take many forms, including feed-in tariffs, tax credits, various subsidies, renewable portfolio standards (RPS), among others. The competitive position of subsectors in RET is primarily determined by economic policy (Jankowska et al., 2021). Additionally, simplifying administrative procedures is necessary to reduce the time and costs involved in preparing investments. By influencing the renewable energy sector through policy initiatives, significant effects can be observed, effectively molding its trajectory of growth and long-term development.

2.4.1. The Dual Nature of Policy Instruments

Over time, policy instruments can lead to changes in the market and make RES more competitive than fossil fuels. A notable example of this phenomenon can be observed in the wind energy industry. In the past, wind energy was heavily dependent on government subsidies to be economically competitive. However, because of technological advancement and economies of scale, the cost of wind has dropped significantly, and, in many regions, wind is cost-competitive without subsidies. According to IRENA, costs of generating electricity from onshore wind has fallen by around 40% and costs of generation offshore wind has fallen by 29% since 2010 (REVE, 2020).

When it comes to supporting renewable energy, it’s not always the case that combining policy instruments is better than implementing only one. In some cases, the implementation of multiple overlapping policy instruments can make things worse. Therefore, it is crucial for policymakers to have a comprehensive understanding of how these instruments work, both individually and interconnectedly. This is especially important given that the interaction of different policy instruments can create synergies that amplify their effectiveness, or alternatively, can create conflicts that undermine their impact. For example, a feed-in tariff policy that incentivises the deployment of RETs may be less effective if it is implemented alongside a carbon pricing policy that increases the cost of fossil fuels, as this may reduce the economic competitiveness of RETs (Böhringer & Rosendahl, 2009).

The transition towards RES is not always straightforward and can result in unintended consequences, as seen in the phenomenon known as the waterbed effect. Despite efforts to support renewables, total emissions may not decrease if a shift towards one energy source leads to an increase in the use of another. For instance, policies aimed at reducing coal or oil consumption may inadvertently lead to a rise in natural gas or renewable energy usage. This effect can also occur at a regional or global level, where the relocation of energy production to less regulated countries can offset emission reductions made elsewhere (Appunn, 2019). To avoid such unintended consequences, policymakers must take a holistic approach and consider the broader impacts of their energy policies and regulations. Such considerations are crucial in achieving effective and sustainable energy transitions.

2.4.2. EU Taxonomy

The EU taxonomy is a classification system provided by the EC and establishes a list of what economic activities are environmentally sustainable (European Commission, n.d.-g). A crucial factor for the successful transition is the mobilisation of adequate capital, as it plays a vital role in scaling up sustainable investments and implementing the EGD (Michelsen, 2022; European Commission, n.d.-g). This climate delegated act came into force the 1st of January 2022 and can affect Norwegian hydropower producers though new extensive document requirements. It is important to highlight that the taxonomy does not determine what is legal and illegal, but being taxonomy compliant is important for the position of the individual producers in the market, for the contract partners and for access to low-cost capital (Michelsen, 2022).

2.4.3. Exploring Energy Sector Trajectories

The International Energy Agency (IEA) has developed three scenarios to explore the potential trajectories of the global energy sector towards a sustainable future, and these are illustrated in Appendix A. The different models explore various scenarios, each of which is constructed based on diverse underlying assumptions regarding the energy system’s potential response to the present global energy crisis and its subsequent evolution. The scenario known as the Net Zero Emissions by 2050 (NZE) is prescriptive as it aims to achieve specific objectives, including limiting the temperature increase in line with the Paris Agreement, attaining universal access to modern energy services, and enhancing air quality. This scenario also offers a potential roadmap to realise these goals. On the other hand, the Announced Pledges Scenario (APS) and the Stated Policies Scenario (STEPS) are investigative because they establish a set of initial circumstances, such as policies and objectives, and then explore the possible outcomes based on models that represent energy systems, market forces, and technological advancements (IEA, 2022b).

2.5. Climate Policy amid the War in Ukraine

The world has witnessed an unprecedented confluence of global events that have shaped political landscapes, challenged international relations, and posed significant environmental concern. One such event is the ongoing war in Ukraine, which has not only ignited geopolitical tensions but has also raised pressing questions about the intersection of conflict and climate policy. This chapter will delve into Norway's energy cooperation with the EU, the EU's energy mix and its transition towards clean energy, and the EU's climate policy amid the war.

2.5.1. Norwegian Energy Cooperation with the EU

Despite not being a member of the European Union, Norway has an association with the EU by virtue of its membership in the EEA. In recent years, the scope of regulations for the EU’s internal energy market has expanded, and regulations and the following legislation affect Norway directly through this agreement (Norwegian Ministry of Petroleum and Energy, 2019a). All member countries are obliged to follow the rules that are set, as well as ordinances and regulations by the EU, meaning countries like Norway in practice are considered an EU member in the areas that deal with energy policy. When the EU adopts new nationally binding climate measures, this results in Norway having to comply with new regulations and directives.

As a member of the EEA, Norway also participates in the Agency for the Cooperation of Energy Regulators (ACER). ACER is a regulatory agency of the EU with the primary mission to assist in creating and maintaining a single European energy market (ACER, n.d.). Their responsibilities include facilitating the cooperation and coordination of energy regulators across the EU, monitoring the functioning of energy markets, and ensuring the development of network codes and guidelines for electricity and gas markets. ACER also provides advice and support to the European Commission and national governments on energy-related matters (ACER, n.d.). ACER plays a crucial role in the implementation of the REPowerEU initiative by providing technical support and expertise to national energy regulators, assisting in the development and integration of RES into the electricity grid and helping coordinate cross-border cooperation among EU member states.

Norway holds a significant position in Europe's energy landscape owing to the unique combination of resources available, including hydropower, petroleum, and emerging renewable sources. The nation's oil and gas production has assumed even greater importance for European energy security in the aftermath of the unjustified war on Ukraine. It is widely acknowledged that Norway will continue to play crucial role in the European energy market in the years ahead.

2.5.2. The EU's Energy Mix

Energy supply in the EU originates from both internal sources and imports from other countries (Eurostat, n.d.). The EU's energy mix primarily consists of petroleum products, natural gas, renewable energy, nuclear energy, and solid fossil fuels. With the aim to reach climate targets under the Paris Agreement, many EU members have had the intention to phase out coal-fired power plants by 2030. Germany, which is an important power producer in Europe, is also phasing out nuclear power production. Over time, this has given gas a more prominent role as a stable and relatively less polluting energy source in the transition phase, especially in periods where power production from solar and wind have been low (NOU, 2023).

The energy transition refers to the shift of the global energy sector from fossil-based sources of energy production and consumption to renewable sources (S&P Global, 2020). The war in Ukraine has been referred to as an important external shock for the EU, as its energy policy-relations are dependent on external suppliers, hereunder Russia. The transition in the European energy sector could come about even more rapidly than planned because it is no longer just about cutting emissions but obtaining a security of supply. The large-scale conversion from fossil fuels to RES was initially dependent on gas in the mix. Europe's, and especially Germany's, dependence on Russian gas has increased over the past decade. However, now the transformation must happen more rapidly because of reduced supply of gas.

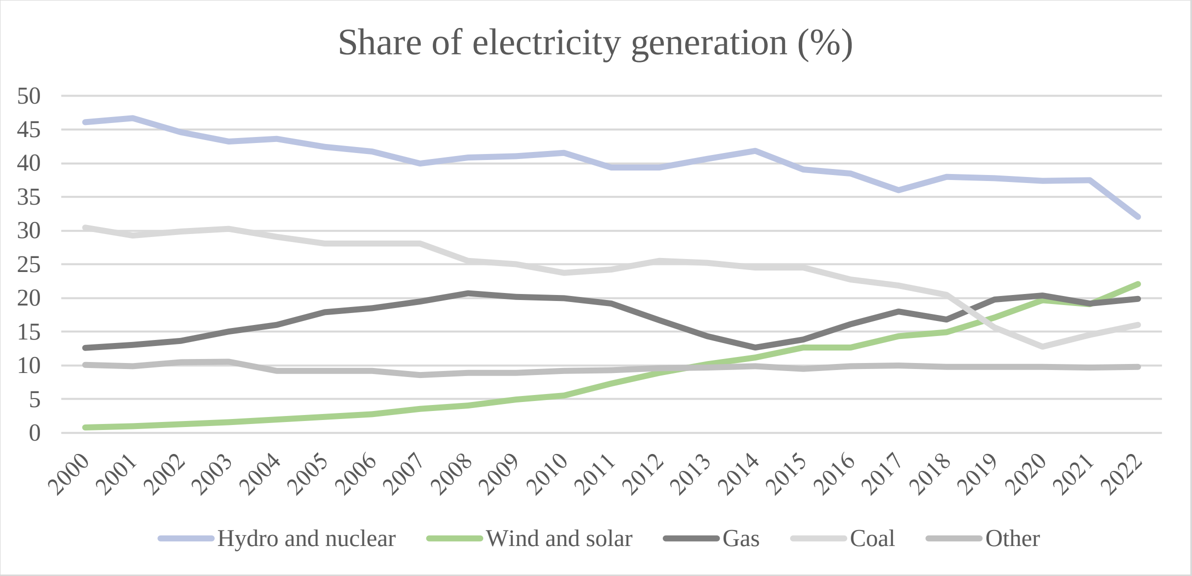


Figure 5: Annual distribution of electricity generation in the EU (Ember, 2023).

To better understand the process in transitioning from fossil fuels to renewables, the European Electricity Review analyses electricity generation and demand in all member countries yearly. In 2022, wind and solar generated a fifth (22%) of EU electricity, overtaking gas power (20%) and remaining above coal power (16%). In 2023, wind and solar power is expected to accelerate even further. In addition, hydropower production is expected to increase, nuclear power from France will return, and total electricity demand is likely to fall. Further, gas generation is expected to have the most rapid decline, as gas is expected to remain more expensive than coal until at least 2025 based on current forward prices. According to the review, the power sector is likely to be the most rapid decreasing segment of gas during 2023, guiding European gas markets towards a life without Russian gas (Ember, 2023).

2.5.3. From Gas Dependency to Energy Diversification

The relationship between the EU and Russia has a long and intricate history, and the trade of natural gas plays a crucial role in this. Russia has been a significant supplier of both pipeline gas and liquified natural gas (LNG) to the EU since the 1970s (European Commission, 2023d). The war has disrupted the flow of gas through Ukraine, which was once the primary transit route towards the EU, and as a result, European markets have experienced increased uncertainty and volatility (European Commission, 2023c). Additionally, Russia's use of gas as a weapon has directly impacting the price of electricity generated from gas power pants and overall electricity prices (IEA, 2022; Council of the European Union, 2022).

Gas is a primary source for power generation, household heating, and various industrial processes in the EU (European Commission, 2023d). In 2021, gas consumption in the EU reached 412 billion cubic metres (bcm) across its 27 member countries, with Russia supplying approximately 40% of this (IEA, 2022). However, as European countries have increased their non-Russian gas supplies and reduced consumption, Russia's share of European gas demand dropped from 23% in 2022 to less than 10% in January 2023 (IEA, n.d.-b).

The European Union's diversification away from Russian gas is shown in Appendix B. The reduction of pipeline deliveries has created pressure on global gas markets, causing European gas prices to reach historic hights. Despite this, the EU managed to achieve a record increase in its gas storage levels in 2022, thanks to three factors. Firstly, Russia supplied 60 bcm of natural gas throughout the year. Secondly, Europe successfully secured LNG imports from diverse nations. Lastly, the onset of mild weather at the start of winter, coupled with reduced energy consumption, led to a decrease in gas demand (Hellenic Shipping News, 2023). The EU, having previously focused on imposing sanctions on most pipeline gas imports from Russia, is now directing its attention towards controlling the influx of Russian LNG into the bloc (Humpert, n.d.).

While gas prices are still high in 2023, they have declined to roughly the same level as before the war in Ukraine broke out. Power prices were rising in 2021 due to a significant gas demand in the wake of the corona pandemic. The following winter in Europe was long and cold, generating less wind power than usual. At the same time, the price of CO_2 in the quota market increased, gas demand in Asia increased, and Russia started limiting gas exports as easily as the summer months of 2021. Overall, these factors contributed to high gas prices, resulting in increased power prices. Unfavourable weather conditions in Europe followed in 2022, leading to low inflow to hydropower plants, challenges with transporting coal to thermal power plants, and challenges with cooling water for nuclear power plants. Delays in maintenance of nuclear power plants have also characterised the French power sector. All these factors combined have led to record high power prices in Europe and Norway, posing significant challenges for industry, business, and households. Both high power prices and concern regarding security of supply present significant challenges in the current situation (NOU, 2023).

The current energy shock serves as a reminder of the fragility and unsustainability of the existing energy system. An important question to consider is whether the current crisis will lead to an acceleration in energy transitions or if short-term policy decisions and economic upheaval will hinder progress. While high prices and increasing emissions of fossil fuels provide compelling reasons to shift towards alternative energy sources or to improve their efficiency, concerns about energy security could prompt a resurgence in investments for fossil fuel infrastructure and supply (IEA, 2022h).

2.5.4. The REPowerEU Initiative

Today's geopolitical and energy market realities require us to drastically accelerate our clean energy transition, in addition to increase Europe's independence from unreliable suppliers and volatile fossil fuels (EU, 2022). In response to the global disturbance caused by the Russian invasion of Ukraine and Russia using gas as a weapon of war, EU leaders agreed to phase out Europe's dependency on Russian energy imports as soon as possible. Already in March 2022, the EU presented an action plan to make Europe independent from Russian fossil fuels well before 2030.

The Commission proposed an outline on March 8th of 2022, to reduce Europe's reliance on Russian fossil fuels significantly and achieve absolute independence by 2030. From March 24th-25th, the EU leaders endorsed the plan's objective, and the Commission subsequently introduced the comprehensive REPowerEU plan, which has been adopted today (European Commission, 2022e). The power plan involves accelerating the clean transition and joining forces to achieve a more resilient energy system to reduce dependence on Russian fossil fuels (European Commission, 2022c) with three primary actions to:

i) Save energy by reducing energy consumption to both industry and households,
ii) Diversify energy sources by finding other energy suppliers or gas and oil that can replace Russian supply, and
iii) Accelerating the clean transition by investing in new renewable energy production.

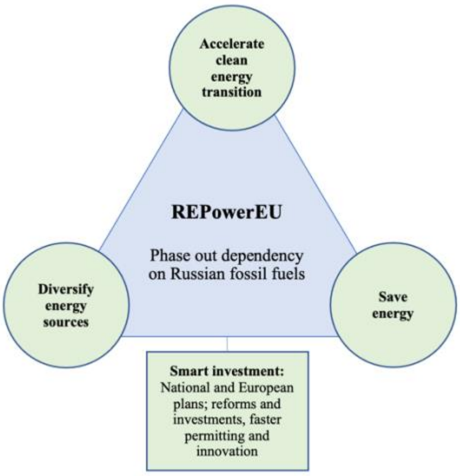


Figure 6: REPowerEU action plan to make Europe independent of Russian fossil fuels (European Commission, 2022c).

A fourth and equally important measure is smart investments, which play a crucial role in achieving the other actions. It is essential to note that this action overlaps with the other actions in the plan, and to attain these, smart investments are required in each area. Both the private and public sectors must contribute to these investments at the national, cross-border, and EU levels to provide the necessary financial resources.

The measures in the plan are meant to structurally transform the EU’s energy system, and they require effective coordination between regulatory and infrastructure means, as well as combined investments and reforms (European Commission, 2022c). Elements in the plan include new subject-specific legal goals for 2030, such as an increased ambition from 9% to 13% on energy savings proposed by the Energy Efficiency Directive, as well as an increase from 40% to 45% in the European renewable target proposed by the Renewable Energy Directive. The main ambition of the Fit-for-55 (FF55), as a part of the European Green Deal legislation, is not modified by the REPowerEU plan. The goal of achieving a 55% reduction of net greenhouse gas emissions by 2030 compared to 1990 and becoming the first climate neutral continent by 2050 remains (Revistaunio, 2022).

3. Theoretical Framework

This chapter lays the theoretical foundation for the research that will be conducted in this thesis. The theoretical framework consists of an explanation of the different factors that affect supply and demand in the electricity market, both in the short term and in the longer term. In addition, an explanation of both a two-period model for optimal allocation of electricity and a model for electricity trade will be introduced and explained. In the longer term, investments in various technologies varies based on several factors, and we will therefore also investigate levelized cost of energy in this chapter.

3.1. Understanding the Drivers of Supply and Demand in an Electricity Market

The price and quantities of electricity in the electricity market are determined by the interplay between supply and demand, with each factor influencing each other. Electricity markets are relatively sensitive to shocks and events, and predicting market prices can be challenging. The demand of electricity is closely linked to the price, which is determined where the supply and demand curves intersect.

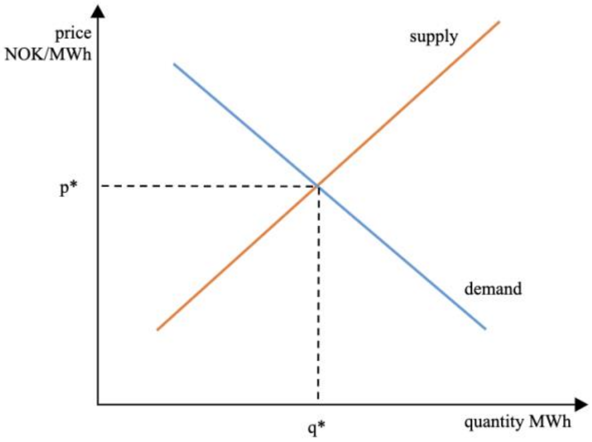


Figure 7: Demand and supply of electricity in MWh.

Numerous factors could potentially impact the supply and demand dynamics in the electricity market, both in the short-term and long-term. In this thesis, we have opted to highlight some factors that we consider significant, while acknowledging that the outcomes of these factors are uncertain.

3.1.1. Short-term Drivers

What drivers that are perceived as relevant change accordingly with the development in the power system (Multiconsult & THEMA Consulting Group, 2022) and depends on whether we are considering short-term or long-term. Where short term-markets are used to manage the balance between demand and supply given the real-time capacities, long-term markets are used to secure demand and supply over a longer period. This allows for new investments to be made, providing stability and predictability. As the short-term market provide flexibility necessary for meeting immediate changes in supply and demand, this makes prices highly volatile compared to long-term.

Prices in the short-term market are influenced by a variety of factors, including weather conditions, fuel prices, and unexpected changes in demand or supply. As for wind, production will in the short-term contribute to lowering electricity prices during hours with high wind power production (Multiconsult & THEMA Consulting Group, 2022), because it increases supply in the matching period. Other weather conditions like precipitation and sunlight are also equally important drivers for supply. Prices on CO_2 and fossil fuels, which is further determined by climate policies like the EU ETS, also represent central drivers that will affect electricity prices through increased marginal costs.

3.1.2. Long-term Drivers

When looking at long-term drivers of supply and demand, there is a higher degree of uncertainty, which is important to highlight. It is still important to discuss these factors, as their expected effect also influence decisions made today. Infrastructure is generally viewed as an important driver for both consumption and production, as interconnectors will link us more closely to our neighbouring electricity markets (Multiconsult & THEMA Consulting Group, 2022). The expected increase of production capacity of renewable energy in the long-term, mainly dominated by solar and wind in the EU and wind power in the Nordics, will further increase supply and reduce average price. The potential expansion of this infrastructure is further politically determined and will to a large extent depend on the feasibility and societal acceptance. The innovation in flexible solutions like batteries and power-to-gas will contribute to increasing profitability (Multiconsult & THEMA Consulting Group, 2022), and will also play an important role in reducing price volatility. Being able to store electricity at a low cost can contribute to increasing supply and will affect price depending on whether it is made available in periods with low or high demand. Another important factor that is essential to mention is climate change, which will affect the supply of intermittent renewable energy sources (IRES) through changing weather patterns, more extreme weather events causing disruptions to infrastructure, and changes in water availability affecting hydropower production (EPA, 2022).

Electricity demand is expected to increase mainly due to economic growth, as energy consumption is positively correlated with gross national product. Other important factors that affect demand are temperature, energy efficiency measures and the changes in the structure of the economy. This structural change includes the increase of electric motors, heat pumps, energy efficiency improvements, the production of hydrogen and other energy intensive technologies that is needed to reach a zero-emission society (IEA, 2023).

Taxes, subsidies, and other regulations will also affect the demand of electricity as they can either make it cheaper or more expensive to produce and consume. This also holds for long-term electricity demand, depending on the scope and duration of the implemented policies. Following the increased electrification of society, increased consumption in power intensive industries especially is expected to reduce the power surplus and become an important driver for electricity price (Multiconsult & THEMA Consulting Group, 2022).

Emerging economies are economies of countries that are experiencing rapid growth and industrialisation (Corporate Finance Institute, 2022a). These are generally characterised by a transition from traditional agriculture-based economies to more modern industrial and service-based economies, and hence by a rapid GDP growth rate (Corporate Finance Institute, 2022). According to Bayar & Özel (2014), economic growth and electricity consumption in emerging economies affect each other meaning that increases in a country’s economic growth will raise its electricity consumption. Therefore, this is important to mention when looking at long-term drivers of demand.

3.2. Static Modelling for Electricity Markets

The need to maintain a balance between production and consumption is an important characteristic of the electricity market. This balance is crucial as production and consumption can fluctuate throughout the day, even within hours (Norwegian Ministry of Petroleum and

Energy, 2021). As a result, the wholesale electricity price is determined by the intersection of supply and demand of electricity at each point in time.

In economic theory, a static model is a simplified representation of a market of economy that assumes all variables are constant and unchanging. In other words, this is a model that does not consider changes over time, but rather examines the state of a market at a single point in time. A short-term static model in economics typically have a time perspective of one year of less, but it can also demonstrate the impact within a matter of weeks or within days.

3.2.1. The Merit Order Effect

The correlation between electricity prices and renewable energy production has been the focus of extensive research in several fields of energy economics. Findings reveal that when the share of renewables in the electricity mix increases, electricity prices tend to decrease (Halkos & Tsirivis, 2023; Sensfuß et al., 2008).

Typically, different power generation technologies complement each other in a wholesale electricity market. This is determined by the “merit order”, which considers the availability and marginal cost of production during any period (Benhmad & Percebois, 2017). Both fossil fueled-based power, nuclear power, and hydropower generation can be called upon or adjusted to meet demand. The complexity of electricity prices arises from the shape of the supply curve, where the steps represent the marginal cost and capacity of different generators, such as wind, hydro, nuclear, coal and gas (Morthost et al., 2010). The differences between costs are mainly due to the technology used and fuel that is consumed. The curve begins with the lowest marginal cost generation from the bottom left to the most expensive generation at the top right. The electricity supply curve is also known as the merit order curve, and the two terms will be used interchangeably. The intersection of the demand curve with the merit order curve defines the market clearing price, more specifically the electricity spot market price.

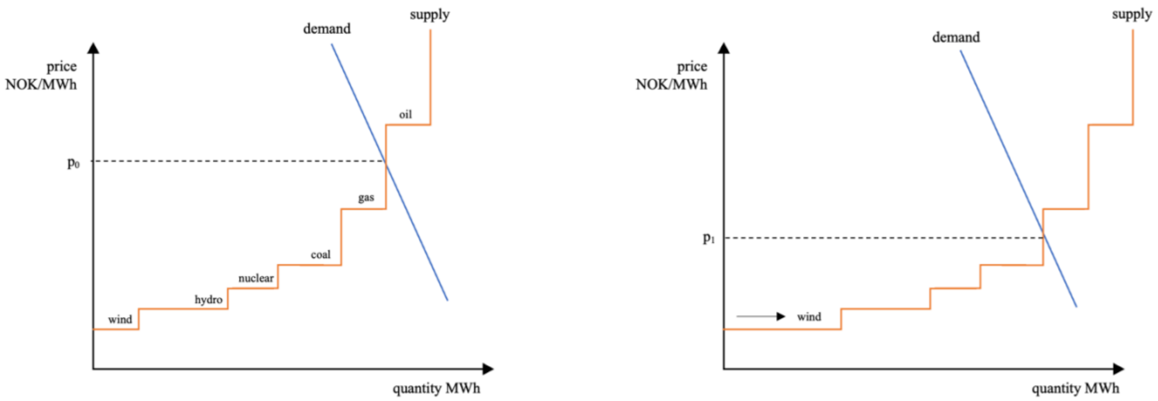


Figure 8: The merit order effect (Morthost et al., 2010).

The demand curve in this model is relatively steep, implying a highly inelastic demand. This implies that changes in the price of electricity have a relatively small impact on the consumption of consumers, meaning that even if the price of electricity increases, consumers may not significantly reduce their consumption. This can be explained by the fact that electricity is regarded as an essential good for consumers and it is not easily distributed, reflecting consumers limited ability to change their consumption in the short run.

The inelasticity of demand also results in that small changes in the supply can result in significant fluctuations in price. The feed-in of RES with lower marginal costs results in a shift to the right of the merit order, moving the intersection to a lower marginal price level and thus lower electricity spot price as illustrated in figure 8. This reduction in price is the merit order effect (MOE) (Collins et al., 2015).

CO_2 pricing puts a price on carbon emissions, making fossil fuel-based electricity generation more expensive and creating an economic incentive to switch to lower-carbon alternatives. The effect of a rising CO_2 price on the merit order curve will depend on the relative marginal costs of different types of electricity generation. As the CO_2 price increases, the marginal cost of fuel-based electricity will also increase, resulting in a shift to the right in favour of lower-carbon or carbon-free alternatives (IEA, n.d.). In other words, generators with lower marginal costs and lower emissions such as wind and solar, would be dispatched earlier on the merit order curve, displacing more carbon-intensive generators. Additionally, an increasing CO_2 price could incentivise the deployment of new-carbon technologies, such as CCS and hydrogen. This could lower their marginal costs over time and lead to further shifts in the merit order curve.

Accounting for the potential long-term consequences, a more complex model is required due to the increased number of variables that need to be taken into consideration. Profitability of new investments change, while long-term electricity rise due to the increased cost of certain technologies. CO_2-free electricity production often becomes more profitable, resulting in more renewable power being introduced in the market.

3.3. Two-Periodical Model for Optimal Allocation of Electricity

To show how electricity production can vary between seasons we will use two-periodical bathtub diagrams to illustrate the optimal allocation of electricity generated by a hydropower plant. The key economic question in these models is the time pattern of the water used from the reservoirs given the periodic production capacity and intermittent power available. We will analyse two different two-periodical models, also referred to as hydropower models, to show the effect of including intermittent power on electricity price. The models used are based on the original models on hydropower in Førsund (2015).

3.3.1. Hydropower Model with Storage Scheme

With the expanding integration of non-dispatchable energy sources, the demand for energy storage has increased. The ability to ensure a secure supply has become crucial for all energy systems, necessitating the inclusion of energy storage solutions. (Skar et al., 2018). In addition to balancing out the mismatch between electricity demand and supply, hydropower production with a storage scheme gives the opportunity to produce electricity when the price is at its highest. These are also referred to as regulated power plants, allowing to produce according to demand (Bye, 2014, p. 327). To examine what the optimal use of water in a hydropower system with a storage scheme that has a limited reservoir capacity and seasonal inflow of water, a two-period bathtub diagram is employed. This approach aims to maximise the social surplus, encompassing both the producer and consumer surplus, in order to achieve an optimal outcome. The model is derived under the assumption of no operating costs and no discounting, given that the costs are minimal and the time frame is relatively short, making it impractical to incorporate them. We also assume production to be equal to consumption, as there is no trade and other production, meaning social surplus can be simplified to maximising the area under the demand curve (Bye, 2014, p. 327). Water represents the only feasible cost in the form of an opportunity cost called water value, where the cost today is the benefit lost from using water tomorrow (Førsund, 2015, p. 16).

3.3.1.1. Optimisation Problem

We want to maximise the social surplus given the following constraints:

$$R_t \leq R_{t-1} + w_t - e_t$$

Equation 3.3.1.1-1

$$R_t \leq R^*$$

Equation 3.3.1.1-2

The first constraint (Equation 3.3.1.1-1) can be explained as the amount of water in the reservoir at the end of period 1 which is determined by how much water stored at the end of the preceding period, plus the inflow in the current period, minus the amount used to produce electricity in the current period. This constraint must hold for each period in our two-period model and resultantly gives us one constraint for each period. The constraint on producing hydropower without storage scheme naturally differs from the abovementioned, as the only constraint is the total amount of available water in each period.

The second constraint (Equation 3.3.1.1-2) tells us that the reservoir filling cannot exceed the reservoir capacity R*, which represents the upper limit of the amount of water that can be stored in the reservoir. There are two possible cases, as the reservoir constraint may or may not be binding. If the filling does not exceed the capacity of the reservoir, the constraint is not binding, and we will have equal prices in the two periods. However, the filling equals or exceeds the capacity, the constraint is binding and the price in period two will be higher due to higher demand.

The two first terms in the Lagrange function are the social surplus in each period, that together equal the sum of the social surplus in both periods, which is what we want to maximise. This is followed up by the three constraints mentioned above with corresponding Lagrange multipliers, giving us the following Lagrange function (Equation 3.3.1.1-3):

$$L = \int_0^{e_1} p_1(z)\,dz + \int_0^{e_2} p_2(z)\,dz - \lambda_1(R_1 - R_0 - w_1 + e_1) - \lambda_2(R_2 - R_1 - w_2 + e_2) - \gamma_1(R_1 - R^*)$$

Equation 3.3.1.1-3

To find the first order conditions for the optimal solution, we take the derivate of L with respect to the demand in period 1, the demand in period 2 and the amount of water in the reservoir in the end of period 1. We initially assume an interior solution for each condition, which means that the variables $e_t>0$ and $R_1>0$. The reason behind this is that it seems unrealistic to have zero production/consumption in a model with only hydropower production, but it is a more realistic scenario in models where we have other power production also taking place. Taking the derivative of L, this gives us the following equations:

$$L'_{e_1} = p_1(e_1) - \lambda_1 = 0$$

Equation 3.3.1.1-4

$$L'_{e_2} = p_2(e_2) - \lambda_2 = 0$$

Equation 3.3.1.1-5

$$L'_{R_1} = -\lambda_1 + \lambda_2 - \gamma_1 = 0$$

Equation 3.3.1.1-6

We will assume production in period 1, (e_1) and in period 2 (e_2), and the amount of water in the end of period 1 (R_1), to be bigger than zero, so that we have an interior solution and equality in all first order conditions.

We have two possible cases in the third first order condition (Equation 3.3.1.1-6), as the reservoir filling at the end of period may be less than or equal to the reservoir capacity. In the first case we assume $R_1 < R^*$, which means the reservoir constraint will not be binding and γ_1 will be equal to zero. In the second case we assume $R_1 = R^*$, which means that the reservoir capacity is binding and γ_1 is greater than 0.

3.3.1.2. Illustration

The marginal willingness to pay for electricity is defining the demand function for electricity $p_t(e_t)$, and we will assume it to have normal properties. The two demand functions are measured along the left- and right-hand vertical axes for period 1 and 2, where demand is higher in period 2. They intersect at A, showing the ideal solution. Marking the reservoir constraint R*, there are drawn two walls B and C showing this distance. This implies that the maximum consumption on period 1 is the distance from O1 to C, and the maximum consumption in period 2 is the distance from B to O2. The shadow price γ_t on the reservoir constraint tells us the increased social value of increasing the reservoir size R* by one unit, excluding the investment costs of increasing the reservoir. The total available water corresponds to the horizontal length of the bathtub and is denoted W, and w_t is the inflow of water for each period (Førsund, 2015, p.22).

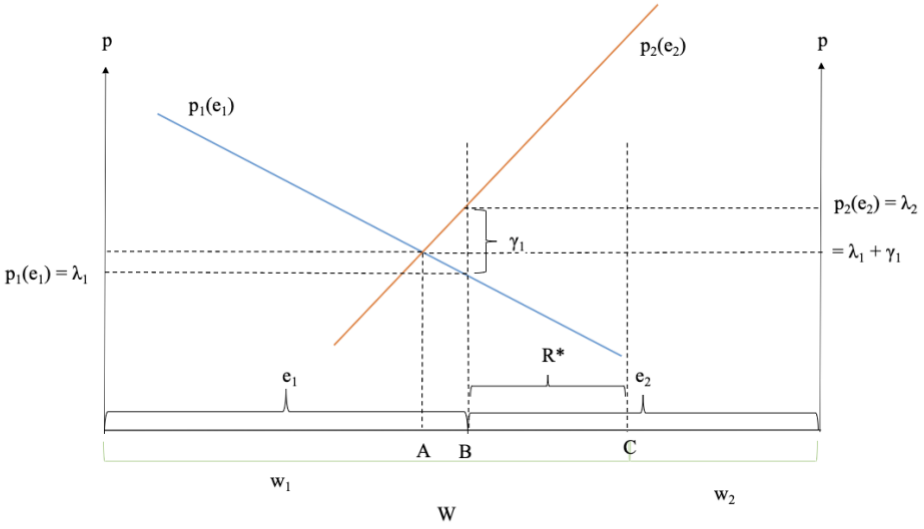


Figure 9: Optimal hydropower production with a limited reservoir capacity storage scheme between two periods (Bye, 2014).

Water inflow and installed capacity determines the amount of hydropower the system can produce, and we assume the capacity to be large enough to produce the desirable amount. The inflow of water varies considerably during the year, where it is typically highest in spring with a decline towards the summer and is generally low during the winter (Ministry of Petroleum and Energy, 2021). This is reflected in the model with a period with high levels of inflow w_1, and period with a substantially lower inflow w_2.

First considering the case without a binding storage capacity $R_1 < R^*$, the reservoir constraint will not be binding, and we would be at point A in figure 9. From the third first order condition (Equation 3.3.1.1-6), we get that the water value is the same in the two periods, hence the shadow price on the reservoir constraint γ_1 equals zero.

In the case where the reservoir constraint is binding $R_1 = R^*$, we would like to save more water from period 1 to period 2, but as the reservoir is already full making this impossible. We will then save the maximum amount meaning the reservoir is full at the end of period 1. The maximum amount is given by R* and will be used to produce electricity in period 2 in addition to the inflow w_2. Given that we have a binding reservoir constraint, the water value in period 2 is now equal to the water value in period 1 plus the shadow price γ_1. In every period with a binding reservoir constraint, an increase in the reservoir size creates a benefit (Førsund, 2015, p. 47).

As we can see from figure 9, the water value in period 1 is lower than in 2, meaning that the social benefit of the water is highest in period 2. In other words, if it had been possible to transfer slightly more water to period 2, we would have done it. The optimal allocation is now namely to store R* in period 1 because the water value is higher in the second period. As mentioned previously, the maximum amount of water that can be used in the first period is the inflow of water w_1, and in the second period the maximum amount equals the inflow of water w_2 and the reservoir capacity R*. In this case, we wave as much water as possible to the next period resulting in an optimal solution at B which shows the distribution of electricity production in the two periods, e_1 and e_2. The economic interpretation of the solution is that the electricity should be allocated between periods such that you maximise the social surplus, hence shift the maximum possible amount of production to the periods when the water value is at its highest (Førsund, 2015, p. 24).

3.3.2. Hydropower Model Including Intermittent Power

IRES are energy sources that are not dispatchable, as wind power, solar power, and run-of-river. While hydropower production from storage schemes can be regulated, intermittent energy must be produced when the weather conditions allow for it (Bye, 2014, p. 327). Therefore, intermittent power often leads to varying prices over time, as their supply is exogenously given and determined by the weather conditions.

There are seasonal variations in the generation of intermittent power, and the patterns will vary across energy sources. In Norway, run-of-river power production is particularly large during the spring during the snowmelt, and large periods of water flow down Glomma, Gudbrandsdalsvågen and Vorma. In these areas, there is limited amount magazines, and power must be produced when the water flows (Bye, 2014, p. 22). Wind and solar has different seasonal profiles in Europe, where wind power generation is much stronger in the winter months than in the summer months (Heide et.al., 2010). The opposite holds true for the generation of solar power, and they are to a certain extent able to counterbalance each other following the seasonal load curve. In a future Europe with significant renewables share, the power supply system will have to adapt the seasonal behaviours of the different sources.

To show the effect of including intermittent power in the hydropower plant model, we have chosen to look at run-of-river, as it follows the opposite production pattern compared to hydropower. Illustrating this effect, we introduce intermittent power in the hydropower plant model from 3.1.1. As mentioned previously, intermittent power is exogenous and cannot be controlled. Building on the previous model and formulas, total consumption for each period is now $e_t + u_t$, where u_t equals intermittent power in period t.

3.3.2.1. Optimisation Problem

There are no changes in the constraints, meaning that the three constraints from 3.1.1 are applicable also for this model. The only difference is that we have added intermittent power u_t to the integrals since the consumption now is the sum of hydropower and run-of-river. This is also included in the new Lagrange function (Equation 3.3.2.1-1):

$$\begin{aligned} \mathrm{L} = &\int_0^{\mathrm{e}_1+\mathrm{u}_1} \mathrm{p}_1(\mathrm{z})\,\mathrm{dz} \\ &+ \int_0^{\mathrm{e}_2+\mathrm{u}_2} \mathrm{p}_2(\mathrm{z})\,\mathrm{dz} - \lambda_1(\mathrm{R}_1 - \mathrm{R}_0 - \mathrm{w}_1 + \mathrm{e}_1) \\ &- \lambda_2(\mathrm{R}_2 - \mathrm{R}_1 - \mathrm{w}_2 + \mathrm{e}_2) - \gamma_1(\mathrm{R}_1 - \mathrm{R}^*) \end{aligned}$$

Equation 3.3.2.1-1

To find the first order conditions for the optimal solution when including intermittent power, we take the derivate of L with respect to the same variables as in 3.1.1. We do not take the derivative of u_t, simply because we cannot control it. This leaves us with almost the same conditions as before, the only difference is that the price depends on total consumption of $u_t + e_t$ in each period. Taking the derivative of L, this gives us the following equations:

$$L'_{e_1} = p_1(e_1 + u_1) - \lambda_1 \leq 0 \qquad \{= 0 \text{ if } e_1 > 0\}$$ *Equation 3.3.2.1-2*

3.3.2.13.3.2.1

$$L'_{e_2} = p_2(e_2 + u_2) - \lambda_2 \leq 0 \qquad \{= 0 \text{ if } e_2 > 0\}$$ *Equation 3.3.2.1-3*

$$L'_{R_1} = -\lambda_1 + \lambda_2 - \gamma_1 \leq 0 \qquad \{= 0 \text{ if } R_1 > 0\}$$ *Equation 3.3.2.1-4*

Another important thing to note is that since we have intermittent power in addition, production from the hydropower plant may be zero without consumption being zero. Assuming we produce nothing from the reservoir in period 1 ($e_1=0$) due to a lot of available intermittent power, we will obviously produce in period 2 ($e_2 >0$). This means we will have inequality in the first first order condition (Equation 3.3.2.1-2) and equality in the second first order condition (Equation 3.3.2.1-3).

Further, we assume that the reservoir filling at the end of period 1 is bigger than zero ($R_1>0$) meaning we have equality in first order condition 3. Focusing on the effects of intermittent power, we assume that the reservoir filling at the end of period 1 is not exceeding the reservoir capacity ($R1\leq R^*$). Laying these assumptions to ground, we can see from first order condition 3 that the shadow price on this constraint is zero ($\gamma_1 = 0$) and we get the following equation:

$$p_1(u_1) < \lambda_1 = \lambda_1 = p_2(e_2 + u_2)$$ *Equation 3.3.2.1-5*

The result is that the large production of intermittent power in period 1 affects the price, and it is lower than in period 2 as a result. Ideally, we would like to save some of this electricity to period 2 but this requires this energy to be stored as either hydrogen or in batteries, which we have chosen not to include in this model.

3.3.2.2. Illustration

The horizontal length of the bathtub is now the sum of all electricity we can produce during the two periods, which equals the inflow of water and available intermittent power in both periods ($w_1+w_2+u_1+u_2$). To simplify the model, we assume there is no production of intermittent power in period 2 ($u_2=0$). The maximum amount of electricity we can consume in period1, is the inflow of water plus the intermittent power in period 1 (w_1+u_1). Further, the maximum amount of electricity we can consume in period 2 is the reservoir capacity plus the inflow of water in period 2 (R^*+w_2). These are drawn in the figure as two walls (B+A), in addition to a wall marking that we are not able to consume in period 2 or any of the intermittent power produced in period 1 (U1). Hereafter, A will be referred to as the "capacity constraint" and U1 the "intermittency constraint".

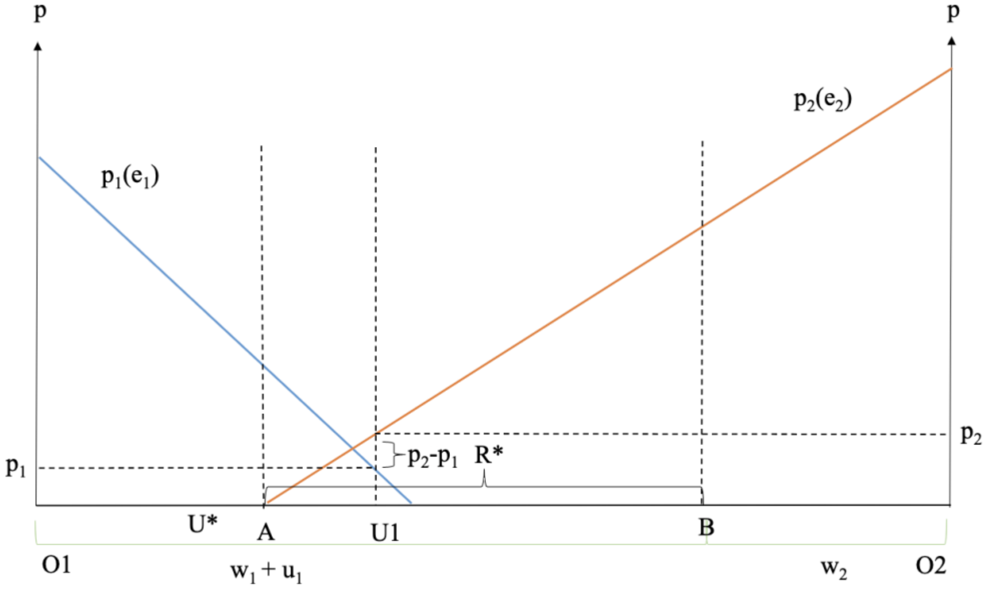


Figure 10: Optimal hydropower production including intermittent power.

The optimal solution must lie between U1 and B, as we must use at least U1 as it cannot be stored and used in period 2. Further, this is determined by the amount of intermittent power produced in period 1. Either the intermittency constraint or the reservoir constraint may be binding, and this is further determined by the amount of intermittent power and the size of the reservoir. The capacity constraint will be binding in any case where U1 is to the left of A because the reservoir has a limit, and we cannot save all the water we would like to. In the opposite case where U1 is to the right of A as in figure 10, the intermittency constraint might be binding as this is a non-dispatchable energy source and followingly whether dependant. Generally, the solution cannot be to the left of either of the constraints.

In our example, the optimal solution is at U1 as we are not able to save any intermittent power in period 1 to period 2. This gives us different prices in the two periods, and as mentioned above the price will be higher in period 2. The economic interpretation of the solution is that to maximise social surplus when including intermittent power to hydropower production, the production should be shifted to periods with less intermittent as this cannot be stored and needs to be used when the conditions allow for it. Including intermittent further leads to varying prices over time, and the lowest price is when there is substantial intermittent power production.

3.4. Economic Modelling of Electricity Trade

Interconnectors across Europe facilitate the exchange and distribution of surplus electricity, enabling trade and collaboration among different regions. Electricity generated by wind power can be used to either cover on-site energy demand or transmitted through an electricity grid for wider distribution. Trade networks establish vital links between production regions, fostering economic exchange withing a country and facilitating international trade (Winkler et al., 2010). Engaging in the transmission of electricity from countries with lower prices to those with higher prices is a lucrative endeavour, facilitated by the presence of transmission lines, which make this type of trade highly feasible. Figure 11 illustrates a conventional partial equilibrium model for trade between two regions in one period. The importing region is represented on the left side, while the exporting region is represented on the right side. In this particular scenario, region 1 represents the European Union and region 2 represents Norway. While the model portrays both regions as roughly equal in size, it is important to acknowledge that the actual trade dynamics between Norway and the EU do not exhibit this balance. Nevertheless, the fundamental concept and mechanisms remain the same, and the initial conditions are illustrated through the supply and demand curves in their respective regions (Winkler et al., 2010).

Norway and the EU have an active electricity trade relationship, with power being transmitted through various interconnectors. Norway is known for its abundance of RES, particular hydropower, making it an attractive partner for the EU as it seeks to diversify its energy sources and reduce reliance on fossil fuels. Because of the differences in their energy profiles, there is a strong economic incentive for trade. We begin with a scenario of closed market where supply matches demand within each region. In region 1 there is significant demand relative to production capacity, leading to higher prices compared to region 2. However, when free trade is introduced without any limitations on capacity, region 2 starts exporting to region 1. This leads to a convergence of prices between the two regions, making them more similar. In this situation, high-price regions import while low-price regions tend to export.

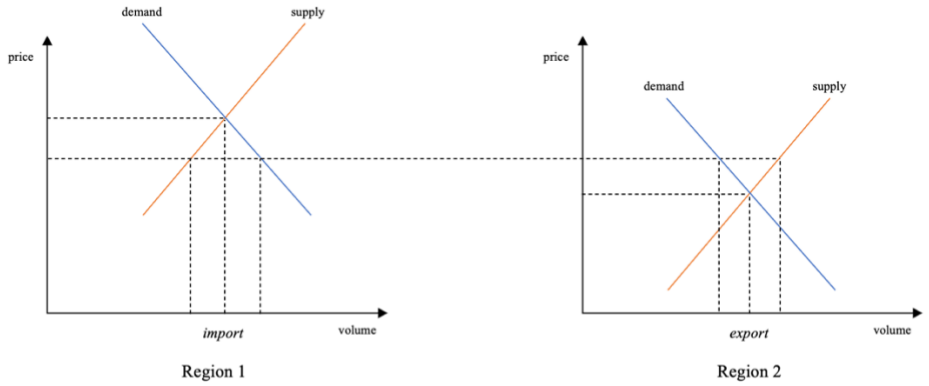


Figure 11: Electricity trade with no transmission constraints.

Nevertheless, transmission lines frequently have limited capacity, necessitating the inclusion of a capacity constraint in the model. In this scenario, we enable trade between the identical regions, but the amount of export from region 2 to region 1 is now constrained to match the capacity of the transmission cable. Region 1 continues to have the highest price, and the overall impact remains virtually unchanged, resembling the effects observed with increased intermittent power generation.

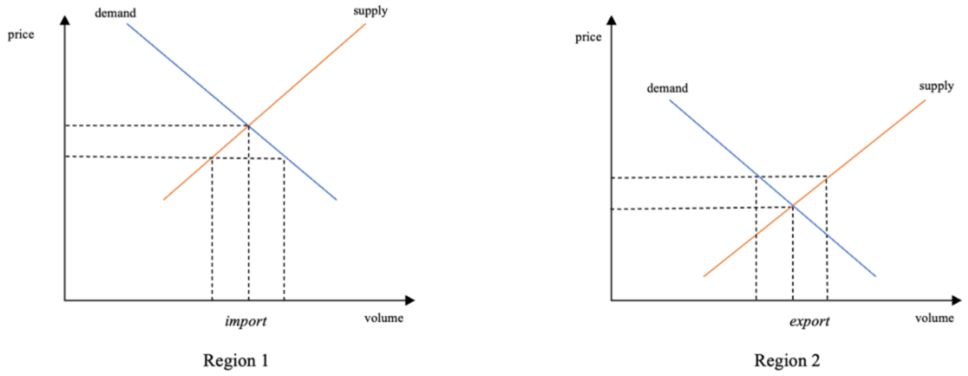


Figure 12: Electricity trade including transmission constraints.

The installation of extra transmission cables connecting two regions usually yields advantages for both regions. However, construction of these cables is associated with high costs so balancing costs and benefits becomes important. While the overall region might benefit in such a scenario, it is possible that either producers of consumers could be adversely affected. Typically, electricity producers in exporting countries benefit while consumers necessarily do not. Engaging in trade with larger regions tends to align domestic prices more closely with international prices, meaning that Norwegian prices, in this case, would resemble those in region 1. However, when engaging in trade with significantly larger markets that have transmission constraints, domestic prices may deviate from international prices.

3.5. Calculating the Levelized Cost of Energy

In the chapter so far, we've looked at situations where production capacities have been provided in forms of either exogenous inflow or storage schemes and intermittent power. For the longer term, investments in various power technologies are usually influenced by various factors, including the cost of energy production. When assessing a project's financial potential, it is crucial to consider the investment, operating and maintenance costs. One of the methods used to calculate these costs is the levelized cost of energy (LCOE).

From an economic perspective, LCOE can be seen as an "average" electricity price that must be brought in by a generation source to break-even. The LCOE estimates the average cost of producing one MWh over the entire life of the project. This metric is used to determine the profitability of a project, with a higher market price than the LCOE indicating potential profitability and a lower market price indicating lack of profitability.

The formula used to calculate the LCOE is:

$$\frac{\text{Present Value of Total Cost Over the Lifetime}}{\text{Present Value of All Electricity Generated Over the Lifetime}}$$

Total costs associated with the project include the initial investment expenditures, maintenance, and operations expenditures as well as any fuel expenditures. The total output of the power-generating asset includes the sum of all electricity generated. The discount rate of the project and the life of the system must also be considered in the equation (Corporate Finance Institute, 2022b).

Put mathematically, the simplified LCOE calculation is:

$$= \frac{\sum_{t=1}^{n} \frac{\mathrm{It} + \ \mathrm{Mt} + \mathrm{Ft}}{(1+\mathrm{r})\mathrm{t}}}{\sum_{t=1}^{n} \frac{\mathrm{Et}}{(1+\mathrm{r})\mathrm{t}}}$$

Equation 3-5
3.3.2.23.3.2.2

where

I_t = Investment expenditures in year t (including financing)

M_t = Operations and maintenance expenditures in year t

F_t = Fuel expenditures and CO_2 price in year t

E_t = Electricity generation in year t

r = Discount rate

n = Life of the system

Certain costs are interdependent and can influence each other in various ways. For instance, fuel costs can be influenced by the efficiency of equipment used. More efficient equipment can generate the same amount of electricity using less fuel, resulting in lower fuel costs and a lower LCOE. Several costs, like fuel expenditures and CO_2 pricing, as well as certain aspects of operations and maintenance costs, are highly influenced by production. On the other hand, investment expenditures and other parts of operations and maintenance are independent of production.

The production costs for onshore wind power, solar power, and new hydropower plants in Norway are based on actual construction projects from recent years. However, estimates for gas power, coal power, and nuclear power rely on European prices, making them less certain. Onshore wind has grown significantly but will face limitations due to public opposition and a slowdown in new concessions (Reed, 2022). The deepening of the North Sea will reduce the share of bottom-fixed offshore turbines, making floating wind projects more cost-effective in Norway (DNV, 2022a).

The LCOE of different power production methods fluctuates over time, and assumptions about production costs, fuel expenditures, and CO_2 prices are uncertain (NVE, 2023a). Factors such as labour costs, raw materials, and regulatory environments can also affect

LCOE, which can vary between countries and regions. Countries with abundant wind or solar resources may have a relatively low LCOE, while those with limited resources may have a higher LCOE. Therefore, LCOE calculations provide only a momentary evaluation of costs within a certain timeframe and must consider several factors that can vary significantly between regions.

3.6. The Paradox of Energy Efficiency

In the fields of environmental and energy economics, the so-called rebound effect is a phenomenon where an increase in efficiency of resource use leads to an increase in resource consumption. Vivanco et al. (2022) define this effect as the difference between the expected and the actual environmental savings from efficiency improvements. Because of behavioural responses, one can often observe an increased demand for energy services. Increased energy efficiency often makes energy services cheaper, resulting in an increase in demand. The magnitude of the effect varies, but it is often strongly linked to the price elasticity of energy demand.

The rebound effect can arise through efficiency improvements that lower the cost of a good or service, or through changes in consumption patterns aimed at reducing costs, which are references as sufficiency strategies. Three primary categories of rebounds are: direct, whereby money saved is reinvested in the same good or service; indirect, whereby savings are redirected towards other goods and services; and macroeconomic effects, which refer to the broader impact of efficiency improvements or changes in consumption (Bjelle et al., 2018).

When energy efficiency is improved, the market demand curve for energy shifts downwards (i.e., to the left), causing both consumers and producers to adjust until a new equilibrium is established. For instance, an energy efficiency improvement in the EU can lead to a decrease in the global electricity price, which in turn increases the global quantity of electricity demanded. Figure 13 illustrates the macroeconomic price effect associated with energy efficiency policy that shifts demand inward. The figure shows how an initial increase in energy efficiency leads to a shift in the global demand curve from D to D´, resulting in reduced demand from point a to point b. However, because of the reduced price, energy use is less reduced than anticipated, and the equilibrium point ends up being at point c. The rebound effect's magnitude is dependent on the sloped of the demand and supply curves, with more inelastic supply and more elastic demand leading to a higher rebound effect (Gillingham et al., 2015).

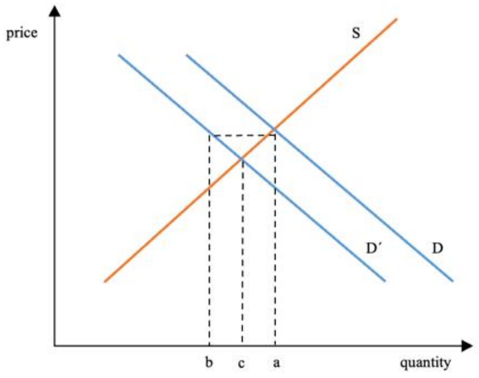


Figure 13: The price effect associated with energy efficiency policy (Gillingham et al., 2015).

The rebound effect is expected to occur when advancement in technology or shifts in behaviour result in a decrease in the number of resources used per unit of input, leading to an increase in the overall level of resource use, negating the intended advantages of the efficiency gains. This effect takes place among consumers and the market in general, as energy efficiency improvements change relative prices and real income. As a result, the gains from resource efficiency improvements may be partially of fully offset by a corresponding increase in resource use, thus undermining efforts to reduce overall resource consumption (Gillingham et al., 2015).

A model for the rebound effect can show both short-term and long-term effects, depending on the scope and timeframe of the analysis. In the short term, a model for the effect may focus on the immediate response to a change in the price or availability of a resource. In the long-term a model may consider how changes in technology, infrastructure, and behaviour can lead to sustained changes in resource consumption.

4. Methodology

The methodology chapter provides a comprehensive overview of the data collection methods, sources, and analysis techniques employed in the study, along with an exploration of the associated limitations and constraints. Additionally, it outlines the research design and approach utilised.

In formulating the research design, the study incorporates the REPowerEU plan as a framework for its structure. This plan encompasses a series of key actions that guide the analysis. Notably, the research design adopts a strategic split between a short-term perspective and a mid- to long-term perspective. By encompassing these time perspectives, the study endeavours to present an analysis that reflects how the REPowerEU measures will display over time.

4.1. Data Collection Methods and Sources

In this thesis, we have used data from the REPowerEU documents posted by the European Commission. The REPowerEU documents include reports, guidelines, and other materials related to renewable energy deployment in the EU. These are publicly available on the EC's website and have been collected and curated by the Commission as part of their ongoing efforts to promote renewable energy. Using REPowerEU documents for this thesis research offers several benefits, one of which is their provision of a comprehensive and authoritative information source regarding the deployment of renewable energy in the EU. Because the European Commission is a leading authority on renewable energy policy and practice in Europe, these documents offer a reliable source of data to support our research.

In addition, we have gathered data and information from other sources such as the IRENA, Statnett, NVE, Statkraft and Regjeringen. These sources have provided valuable insights and perspectives on the topic at hand, allowing a comprehensive approach. By utilising a variety of sources, we aim to ensure that our research is well-rounded and provides a complete understanding of the topic. Moreover, by using REPowerEU documents in our research, we are attempting to contribute to the ongoing efforts to promote renewable energy in Europe and in Norway. By studying the policies, practices, and challenges related to renewable energy deployment, we aim to help advance the understanding of this critical issue and to support the development of more effective policies and practices in the future.

4.2. Data Analysis Techniques

To acquire an in-depth understanding of the main policies and measures proposed in the documents published by the EC, we conducted a comprehensive review of the documents, focusing on their content and structure. To review these documents, we used a qualitative analysis technique, involving a detailed examination of the content of each document, looking for common themes, objectives, and policy recommendations. In addition, we conducted a thematic analysis which involves identifying patterns or themes and organizing them into categories. The REPowerEU plan has four main actions, and the underlying policy themes and objectives outlined in the documents are explained thereunder.

The IEA produces an abundance of reports and documents on energy markets, policies and technologies, and these materials are also an invaluable resource for conducting data analysis in the energy sector. These reports provided valuable insights into trends in global energy supply and demand, as well as the technological and policy developments that are shaping the future energy industry.

4.3. Research Design and Approach

As mentioned, the research design in this study is structured into four subchapters, corresponding with the four main actions identified in the REPowerEU plan. Within each sub-chapter, we will provide a detailed analysis of the relevant action, including an in-depth definition and potential effects. This approach allows us to thoroughly examine each action and its implications, contributing to a more comprehensive understanding of the transition to a sustainable and resilient energy system in Europe.

Each subchapter for the specific actions also distinguishes between the concrete measures in the short- term and the mid- to long term, where they reflect the different time horizons and investments requirements associated with RE projects. Short-term can be defined as a time frame ranging from a few months to a few years and may include projects that can be completed quickly and generate revenue within a relatively short period of time. Further mid-term can be defined as a time frame ranging from a few years to a decade and in the context of RE, these larger projects typically focus on reducing dependence of fossil fuels and requires longer planning and development. This creates time for new investments to be made in term of production capacity, as new wind power plants. Finally long-term can be defined as a time frame raging from a decade or more and includes large-scale infrastructure projects that require significant capital investments with long-term view of returns. In this time frame, the development of and cost reductions for technologies like hydrogen, batteries, and floating offshore wind, will be a desired and expected outcome.

4.3.1. Action 1: Save Energy

According to the European Commission (2022g), the cheapest and easiest way to address the current energy crisis is through saving energy. The Commission's suggestions consist of adding more extensive measures to the EU's current FF55 package, and saving energy could immediately reduce demand for gas, oil, and electricity. The overall goal is to use less energy while maintaining the same level of service or productivity. The Commission presents a two-longed approach, which involves achieving immediate savings through behavioural changes by targeting households and industry and strengthening structural efficiency measures in mid-to long-term (European Commission, 2022).

4.3.1.1. Short-term

It is essential to look at immediate measures to reduce energy consumption, as the structural energy efficiency measures has a longer time frame and action is needed now considering the pressing geopolitical situation (European Commission, 2022b). Most of these immediate measures will need to result from voluntary choices and if they lead to a change of habits, they will represent important measures into the mid-to-long term. The potential for short-term savings is highest in household and service heating, in addition to some in industry sectors (European Commission, 2022b).

Driven by the current high market energy prices, change in consumption is already happening (European Commission, 2022b). This may still fall short due to the lack of information on the best savings opportunities and the risk of society's most vulnerable forced taking too much of the bill compared to the wealthier. All this considered, two categories of support actions are being taken to help accomplish immediate energy savings: information actions and incitement and supporting actions. The key advantage of these measures is the potential immediate effect as well as it entails very small up-front investment (European Commission, 2022b).

Information actions are needed to make sure that energy users understand how they can contribute and the importance of reducing their consumption (European Commission, 2022b). This can be done by introducing targeted information campaigns and nudging, which is using behavioural tools to encourage individuals making certain choices to reach a desired outcome (Viale, 2022). The campaign "Playing my part" launched by the EC in cooperation with IEA provides information on how contribute to reducing energy imports from Russia and is a way for regions to empower their citizens (European Commission, 2022c).

Incitement and supporting actions are measured implemented to help users reduce their energy consumption by offering incentives on energy efficient purchases (European Commission, 2022b). These could include reduced VAT on heating systems, energy pricing to encourage heat pumps and other efficient appliances. To support this effort, the EC will launch the European Product Registration for Energy Labelling (EPREL) to help consumers and procurers by making it easier to choose more efficient appliances.

4.3.1.2. Mid- to long-term

The second part of the EC's approach includes proposing a higher EU energy efficiency target, as well as strengthening the energy efficiency measures. Indicating a higher EU energy efficiency target, the Commission proposed an increase to the binding EU energy efficiency target from 9% to 13% in 2030. REPowerEU further includes increasing the ambition of national energy savings obligation, given by the Energy Efficiency Directive (European Commission, 2022b).

Fast-tracking already existing policies as well as implementing additional energy efficiency measures will be key for all Member States to deliver more savings the context of REPowerEU (European Commission, 2022b). These measures include increasing national energy saving ambitions, phase out subsidies for fossil fuels, introduce a Minimum Energy Performance Standards for buildings and increase energy efficiency in transport. Research shows that policies aimed at improving energy efficiency can provide wider benefits as reducing energy poverty, increasing business competitiveness, and enhancing energy security (European Commission, 2022b).

4.3.2. Action 2: Diversify Energy Sources

One crucial aspect of guaranteeing secure and cost-effective supplies for Europe is to expand the range of supply routes. This entails identifying and building new routes that reduce the reliance of EU countries on a solitary source of natural gas and other energy resources (European Commission, n.d.-c). Historically, the EU has relied on a limited number of energy suppliers, this has led to the development of over-dependency concerns (Leonard et al., 2021). These concerns have particularly been raised regarding the supply of natural gas, at is relies heavily on pipeline infrastructure and long-term contracts making it notably rigid compared to oil. For months, the EU has been working with international partners to diversify supply. Around 30% of the households in the EU use gas for heating (European Commission, 2023d), which puts pressure on finding alternative gas suppliers. Cooperation on green hydrogen and technologies are important measures.

We choose to highlight the security of supply that diversifying represents in this action, as EU works to promote broader energy partnerships especially by increasing the number of reliable suppliers. It's important to note that energy security is a complex and ongoing issue, and the situation can change rapidly depending on various geopolitical factors and events.

4.3.2.1. Short-term

Action 2 in the power plan seeks to diversify the EU’s gas supply by leveraging the power of the European market through a joint purchasing mechanism for negotiation and contracting on behalf of member states (European Commission, 2023d). The EU Energy Platform on common purchase of gas (pipeline gas, LNG, blue hydrogen) is expected to lead to estimated short-term volumes of 30-70 bcm. This can be achieved by making trade agreements with a selection of supplier countries, including USA, Qatar, Australia, Algeria, and Norway.

One key advantage of diversifying the EU’s gas supply is reducing the risk of being over-dependent on a single supplier (Leonard et al., 2021). By making trade agreements with a selection of supplier countries, this could also contribute to reducing the threat of supply shortages. Furthermore, the joint purchasing mechanism will ensure sufficient gas supplies and avoid inflation in prices by making sure EU companies do not bid on the same gas (European Commission, n.d.-c).

4.3.2.2. Mid- to long-term

Diversification of the energy mix has been described as a way of mitigating emissions and is an area of focus in REPowerEU as well as in the Paris Agreement among others (Rubio-Varas & Muñoz-Delgado, 2019). In the mid- to long-term perspective on the energy mix in the EU, a broader energy partnership combining energy cooperation on both gas and hydrogen is promoted to ensure the green transition (European Commission, 2022a). As described in the External Energy Engagement Strategy, the REPowerEU plan increases the already planned amount of hydrogen under the FF55 by an additional 10 million tonnes (mt) of renewable hydrogen (European Commission, 2022a). Including 10 mt of imported hydrogen, the EC aims to enter hydrogen partnerships with three major corridors including the North Sea region and hence Norway.

According to NTNU (2022), Norway is in a good position to be one of the major exporters of both blue and green hydrogen on a global scale. Further, one of the largest manufacturers of low temperature water electrolysis is in Norway with their systems installed worldwide (NTNU, 2022). Being an energy carrier, hydrogen presents promising opportunities as a provider of flexibility as well as securing supply, which we will discuss in the next subsection. The EC is currently preparing the EU for renewable hydrogen trade, and this represents a clear opportunity for Norway considering our already strong position in this market.

4.3.3. Action 3: Accelerate Clean Energy Transition

The transition to clean energy is of utmost importance in reducing global warming, boosting economic growth, improving living standards globally, as well as addressing potential risks to energy security and pricing. Accelerating the transition involves a range of actions aimed at promoting the development and deployment of clean energy technologies. This includes several sub-actions such as increasing the use of RES, promoting the electrification of transport, and implementing policies and regulations to support the development and growth of clean energy industries (European Commission, 2022a).

4.3.3.1. Short-term

According to REPowerEU, the significant hurdle in achieving the full potential of RE is the slow and complicated permitting process. To address this issue, the Commission has put forward a Permitting Recommendation that suggests strategies to simplify the process at the national level. This action will facilitate the commencement of renewable energy ventures, while considering legitimate concerns of citizens and adhering to environmental regulations (European Commission, n.d.-f).

The Commission has agreed on a directive requiring member states to map areas suitable for RE projects within 18 months of entry into force and adopt plans designing “renewables go-to areas” within 30 months. These areas would be chosen for their suitability for specific RETs and lower environmental risks. The directive would subject plans for renewables go-to areas to a simplified environmental impacts assessment, rather than an assessment for each project. Permit-granting processes for renewable go-to areas would not take longer than one year for renewables projects, and two years for offshore renewables projects (Ask, 2023a; Council of the European Union, 2022b).

4.3.3.2. Mid- to long-term

According to the European Commission (2022g), speeding and scaling up renewable energy in power production, industry, buildings, and transport can accelerate independence, boost the green transition and over time, reduce prices. The action sets two key targets; increasing the target in Renewable Energy Directive to 45% by 2030 (up from 40%) and increasing total renewable generation capacity to 1,236 GW by 2030 (up from 1,067 GW).

The EU has a strong dedication to taking charge of and accelerating the global green transition, while also providing aid to their partners throughout the process. The Commission and the EU High representative have launched the “Global Gateway”, which aims to enhance smart, clean, and secure connections in digital, energy and transport sectors (European Commission, 2022a).

Renewable energy will receive a significant boost through the combination of solar power, onshore and offshore wind. Furthermore, the initiative includes the acceleration of efforts to deploy hydrogen infrastructure and scaling up sustainable biomethane production is included in this action (European Commission, 2022). To achieve an effective deployment of RES and enhance energy efficiency, it is essential to adopt a comprehensive “system approach” that considers electricity production, transmission, and consumption as a whole (European

Commission, 2022a). The most effective utilisation of RE capacity is possible when it is integrated into flexible and open regional markets. Interconnectors play an important flexibility role to the European energy sector, and integrating Norwegian hydropower storage capacity can enhance this flexibility in the electricity market (NTNU, 2022).

4.3.4. Action 4: Smart Investment

The actions presented in the power plan require huge investments, and the EC presents a separate fourth action, incorporating so-called smart investments. While delivering on the main actions mentioned in previous chapters, REPowerEU calls for additional investment of over €200 billion. These investments are on top of what is needed to realise the objectives of the FF55 proposals (European Commission, 2022).

The plan prioritises investments in various areas, including improving interconnection and infrastructure, providing support for storage projects, and enhancing security of supply. Furthermore, increasing investment in the power grid and offering policy support are also critical components of the plan (A&L Goodbody, 2022).

The Recovery and Resilience Facility (RRF) offers supplementary funding from the EU and lies at the centre of the implementation of the plan. To direct investments towards REPowerEU priorities and undertake essential reforms, member states are encouraged to include a REPowerEU chapter in their Recovery and Resilience Plans. Member states have the option to use the remaining RRF loans, currently amounting to €225 billion, as well as new RRF grants, which are funded by auctioning Emission Trading System (ETS) allowances currently held in the Market Stability Reserve (MSR) and valued at €20 billion (European Commission, 2022f).

Implementing REPowerEU requires investments in multiple areas. Meeting the rising demand for renewable hydrogen will require an increase in the installed capacity of electrolysers. Under the FF55 plan, this capacity was set at 44 GW, but for REPowerEU, it will need to be increased to 65 GW. Additionally, the installed capacity of wind and solar power will also need to increase to supply electrolysers with the necessary renewable electricity. REPowerEU calls for an additional 41 GW of wind and 62 GW of solar capacity

(European Commission, 2022d). An overview of the investments by 2030 for reaching REPowerEU objectives can be found in Appendix E.

The effects of this action are not limited to the short-term or mid- to long-term, rather it will have significant impact on both time frames which is why this chapter is not divided correspondingly. It is still important to note that RE investments are typically considered from a long-term perspective as they require high upfront costs and are subjected to longer payback periods, as well as regulatory and policy changes. This contrasts with more traditional energy sources like fossil fuels, but once the plant is operational it will provide as a long-term source of revenue for investors as it has a lower production cost.

Further it is also important to note that this action overlaps with the other actions in the power plan, as to reach the previous mentioned goals it will require significant investments in the distinctive areas. Smart investments, particularly those in renewable energy technologies, are essential in achieving the overall goals of the plan. Both the private and public sectors must meet these investments at the national, cross-border, and EU level to provide the necessary financial resources to support the development and deployment of different technologies.

4.4. Limitations and Constraints

This research is conducted from an energy economic perspective and is based on economic theory, which means that it draws upon a particular set of concepts, principles, and models. One limitation of using this perspective is that analysing energy systems often fails to consider non-economic factors such as social and political considerations. Economic models and approaches are often designed to optimise economic efficiency and may overlook crucial social and environmental factors, which can be critical for sustainable development. Furthermore, these models may not accurately account for the complexity of energy systems and may oversimplify the dynamic interactions between different energy sources, demand, and policy choices. While an energy economic perspective can provide useful insights into energy systems' performance, it is important to acknowledge its limitations and to complement it with other perspectives to ensure a comprehensive and holistic analysis.

Furthermore, economic theory is often based on a set of assumptions about human behaviour and the functioning of markets that may not always hold true in the real world. For example, it assumes that individuals and firms are rational and self-interested, and that markets are efficient and competitive. However, people may not always react in their own self-interests, and markets may not always function perfectly.

Therefore, it is important to acknowledge the limitations of the thesis and to recognise that there are other ways of understanding and addressing issues related to REPowerEU and the transition towards a more sustainable economy. In addition, this thesis is a perspective and research in a specific point in time and based on the ongoing war in Ukraine. Changes or development in the political situation, such as international sanctions or negotiations, may impact the feasibility or effectiveness of measures or actions that have been implemented.

5. Results and Analysis

Due to the strong relationship between Norway and the EU, the country is greatly influenced by the EU's climate policies and future developments. The analysis conducted in this chapter delves into the potential effects of the REPowerEU plan on both the power market and Norway's competitive standing within the renewable energy sector. It differentiates between the impact on short-term and the mid- to long-term, as we evaluate the measures in each action different in terms of their relevance based on these time perspectives. Furthermore, this chapter includes a discussion of the results, including the feasibility of the initiative.

Table 1: Chapter 5 Literary Roadmap.

Action in the REPowerEU Initiative	**Short-term Perspective**	**Mid- to long-term Perspective**
Action 1: Save Energy	5.1.1. Immediate Steps to Reduce Energy	5.2.3. Smart Investments for the Future
Action 2: Diversify Energy Sources	5.1.2. Diversify Energy Supplies	5.2.1 Hydrogen's Role in Flexibility and Diversification 5.2.2 Linking Energy and Trade
Action 3: Accelerate the Clean Transition	5.1.3. Effects of High Wind Penetration in the Electricity Market 5.1.4. Balancing the Energy Mix with Increasing Intermittent Power	5.2.1 Hydrogen's Role in Flexibility and Diversification 5.2.2 Linking Energy and Trade
Action 4: Smart investments	5.1.1. Immediate Steps to Reduce Energy 5.1.2. Effects of High Wind Penetration in the Electricity Market	5.2.2 Linking Energy and Trade 5.2.3 Smart Investments for the Future

The table above offers a valuable reference for this chapter and the implementation of the REPowerEU plan, providing a clear and concise overview of the relevant actions from the plan along with their corresponding short-term and mid- to long-term measures. By consulting this table, readers will gain a comprehensive understanding of the plan and its execution as they proceed through the rest of this chapter. The chapter presentation aims to highlight the plan's complex and interconnected actions, and table 1 visually illustrates how actions may overlap or be challenging to differentiate. This approach aims to provide clarity, a holistic view, and enhanced understanding of the plan's intricacies and interdependencies.

5.1. Short-term perspective

In the short-term, the plan proposes several measures that can be promptly executed to tackle the most pressing issues related to energy security. These include efforts to improve energy efficiency in industry and households, as well as diversification of gas pipeline routes, additional LNG infrastructure and industry gas prioritisation. Further, we analyse how immediate measures to increase IRES in the energy mix can affect prices and market dynamics.

5.1.1. Immediate Steps to Reduce Energy

To save energy in the short term, it is necessary to take both informational and motivational actions. These measures can involve nudging and spreading awareness about the importance of energy conservation, as well as implementing energy efficiency and conservation measures in both households and businesses. Although there is widespread support for energy conservation, there are divergent views on its feasibility. Additionally, progress in achieving energy savings has been slow, indicating that the issue is not as straightforward as it may seem. It is also important to consider the time perspective, as immediate action is needed but the effects implementing appropriate policies may not appear instantly.

5.1.1.1. Demand Growth and Rebound Effects

In addition to the challenges associated with implementing energy efficiency measures in the short-term, it is important to consider the potential impact of future demand. The share of electricity in final energy consumption is expected to continue growing in the coming years. According to the IEA (2021a), the share increased from 15% in 2000 to 20% today and is set to grow to 24% by 2040, assuming countries stay on their present course. However, the actual impact of energy efficiency measures on future demand is challenging to forecast. On one hand, behavioural changes and increased energy efficiency can lead to less demand. On the other hand, electrification of various sectors could lead to increased demand. It remains to be seen whether these two opposing forces will cancel each other out, or if one will have a more significant impact on future energy demand. Researchers also find that rebound effects are not sufficiently accounted for in energy models used by the IEA amongst others, which could result in an underestimation of the upcoming increase in global energy demand (Brockway et al., 2021). As such, it is crucial to implement energy efficiency measures in the short-term while also considering the potential impact on future demand through incorporating a comprehensive set of rebound mechanisms in energy modelling.

The rebound effect is particularly relevant in the context of the REPowerEU plan, which aims to save energy through various measures such as building retrofits, improved industrial processes, and renewable energy deployment. Improved energy efficiency is not only a key measure in this initiative, but also plays a central role in reducing GHG-emissions in both the Paris Agreement and the SDG's (Brockway et al., 2021). While energy efficiency measures are expected to reduce emissions and save energy, there is risk that some of these gains may be lost if businesses or consumers increase energy consumption in response to more efficient appliances. To mitigate the effect, policymakers need to consider factors such as the price elasticity, consumer behaviour and overall energy market dynamics. While an energy improvement of x% may not necessarily lead to energy savings of x%, in the short-term, the rebound effect is generally thought to be smaller as it takes time for individuals and businesses to adjust their behaviour in response to changes. Price elasticities also play a role in determining the magnitude of the rebound effect, as the demand for energy services are more elastic in the long run which will strengthen the effect. As you can see in figure 14, the rebound effect is determined by the steepness of the demand curve, hence the price elasticity of demand. The steeper the demand curve is, the higher rebound effect will occur. To give an example, energy efficiency measures taken in a market will lead to an indirect rebound effect, shifting the demand curve inwards and lower prices. We expect the new quantity consumed to be b, but because of the rebound effect new equilibrium ends up being at point c.

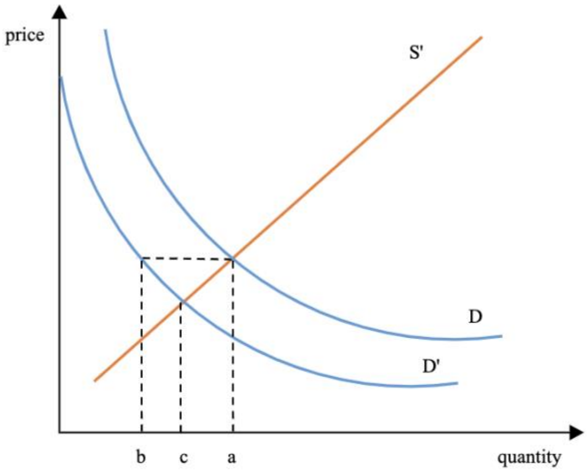


Figure 14: Illustration of the rebound effect and how price elasticities determine the total effect.

5.1.1.2. Measuring and Mitigating the Rebound Effect

Measuring economy-wide rebound effects is highly challenging, but over the past decade evidence has grown considerably. According to Brockway et al. (2021), rebound effects may cut energy savings from improved energy efficiency in half. The importance of improved energy efficiency is unquestionable as it contributes with several other economic benefits, but it is important to highlight that global climate action may rely too heavily on this measure. That may result in leaning more heavily on negative emission technologies and supply of low-carbon energy sources to meet the projected targets. These approaches will require additional ambitious policies and substantial investments and will be politically challenging as well as not applicable from a short-term perspective (Brockway et al., 2021). While considering the elements mentioned above, the rebound effect clearly highlights the importance of efficient use of energy resources, the IEA also presses the importance of increasing investments in clean energy and efficiency to reach the overall goal of NZE in 2050 (Norwegian Ministry of Trade, Industries and Fisheries, 2022).

A significant topic of discussion in both the EU and Norway is the design policies as a way of addressing the urgent need to improve energy efficiency, without further reducing the incentive to save energy and gas. Even though energy efficiency has been continuously increasing, primary energy consumption has continued to rise possibly explained by a lower price diminishing the motivation to save energy (Vivanco et al., 2022). Such a policy could be implementing an electricity subsidy scheme for households that is paid regardless of the individual's consumption, the incentive to save electricity will not be reduced. The subsidy scheme will be designed so that the amount of support will fluctuate in line with electricity prices, making everyone still faced by the market price of electricity. This further means that when market price is high, the individual will have increased incentive to save electricity which is essential for the green shift (Lund & Rosendahl, 2022). Implementing this kind of subsidy scheme such as equal payment to all, or mostly to low-income households, is a more effective form of support compared to reduced or capped prices. It is worth noting that fairness could be a crucial aspect to consider in this context, and it may be beneficial to delve further into this issue.

5.1.1.3. Effects on Norwegian Competitiveness

In the transition to a low-carbon society, improved energy efficiency will be vital to reach independency as well as carry out the green shift. The Norwegian Government has set out a path to pursue policies towards energy that is efficient, and that contributes to their ambitions relating to the green transition (Norwegian Ministry of Trade, Industry and Fisheries, 2022). Through more efficient use of resources, there are opportunities for increased value creation while also staying on track to reach the goal of having the world’s cleanest and energy-efficient process industry. Further, RE producers improving their energy efficiency can lead to reduced operating costs making clean energy systems more cost-competitive with traditional fossil fuel-based energy sources. As a result, renewable energy producers can offer lower prices to consumers as well as freeing up resources, which can improve their competitiveness in the market. Spillovers from energy efficiency improvements may decrease or increase energy consumption in other sectors (Gillingham et al., 2014), which has the potential to affect overall competitiveness.

Exactly how implementing energy efficiency measures will affect competitiveness is hardly an unequivocal answer, it depends on the size of rebound effect, spillover effects, incentives, and feasibility amongst others. Previously defined, the concept of competitiveness in the RE sector encompasses the ability to give access to clean energy at a reasonable and affordable price. Norwegian industrial sector aspires to deliver this, which means that RE production must be increased while ensuring efficient energy consumption.

5.1.2. Diversify Energy Supplies

Following the disruption of gas supplies after the invasion, the EU swiftly implemented measures to ensure the efficient functioning of its gas infrastructure and reduce dependence on Russia. To diversify gas supply, the EU explored alternative sources such as importing gas through pipelines from Norway and Algeria, and purchasing LNG from the United States, Qatar, and Nigeria. Initially, concerns were raised about Europe's ability to procure enough LNG to replace Russian gas due to limited terminal capacity. However, investments were made in additional terminals and infrastructure, alleviating these concerns. Three new terminals were operational last year, and five more are planned for 2023, increasing overall capacity to 50 bcm (Ameland, 2023; European Commission, 2023d). Nevertheless, these alternatives still face global high demand, resulting in limited supplies and high costs. To address escalating prices, the EU called for member states to reduce their consumption, collectively purchase gas, and prevent competition from inflating prices further.

A framework was implemented to achieve coordinated gas demand reduction, with each member state agreeing to decrease their consumption by a minimum of 15%. As a result, gas consumption dropped over 19% from August 2022 to January 2023, saving 42 bcm of gas. Furthermore, a common storage policy was introduced, leading to storage levels reaching 95% by November 2022, more than double the previous year's underground storage levels. As of March 2023, storage levels stood at around 57%. These measures aimed to safeguard against gas shortages and address high energy prices, which are expected to remain unstable due to restricted LNG availability, potential resurgence of the Chinese economy, and reduced imports of Russian pipeline gas to Europe (European Commission, 2023c; Liboreiro, 2023).

To enhance bargaining power and coordinate gas supply and demand, the EU implemented the joint gas purchasing mechanism. Under this mechanism, member states negotiate gas contracts collectively, with the objective of achieving predictable prices and conditions. It allows for a more effective response to disruptions in the gas market and is open to all natural gas companies and gas-consuming companies that meet the specified criteria outlined in the Council Regulation. The joint purchasing mechanism has played a crucial role in enhancing gas supply security in Europe (European Commission, 2023b; Poyner, 2023). The disclosure of participants in the joint purchasing mechanism is the responsibility of the participating companies, rather than the Commission. The Norwegian state-owned company Equinor has declared its intention to sell gas through this platform (Ask, 2023b). There have been discussions about whether this cooperation could grant the EU significant market influence and potentially decrease prices. However, the outcome will depend on the quantity of gas brought in compared to the existing gas supply in Europe.

5.1.2.1. The Role of Norwegian Gas

Following Europe's efforts to diversify gas supply, the price of gas surged. Norway emerged as Europe's largest supplier, exporting over 120 bcm of gas, resulting in record-breaking revenues for the Norwegian government (Adomaitis et al., 2023). The significant increase in gas exports contributed to a trade surplus for Norway. In 2022, the value of exported goods amounted to 2,601 billion Norwegian kroners (NOK), with imports reaching 1,027 billion NOK, resulting in a trade surplus of 1.574 billion kroners, approximately three times higher than in 2021. The surge in gas exports played a significant role in this increase, with the value of natural gas exports nearly tripling from 2021 and reaching 1,357 billion NOK (Rørhus & Mysen, 2023).

The role of gas in the energy sector towards 2050 is a topic of considerable interest and discussion. Some studies indicate that natural gas is expected to pay a significant role in the power sector in the coming decades, even without the implementation of CCS technology (Egging & Tomasgard, 2018; IEA, 2019; Neumann et al., 2021; Skar et al., 2018). However, the role may change significantly if CCS becomes a commercially viable option. By 2050, successful implementation of it could significantly impact the volume of natural gas used in the power sector. Without CCS, the projected volume of natural gas utilised would only be half of what is anticipated with the implementation of it. Despite the slight reduction in the proportion of renewable energy sources in the generation mix, natural gas with CCS offers several system benefits. The availability of CCS not only minimises overinvestment in renewables but also reduces the need for transmission investments, resulting in cost savings for the overall system. This cost reduction directly benefits energy consumers through lower prices. Additionally, the presence of controllable generation capacity from natural gas with CCS enhances the security of the power supply by providing flexibility to manage fluctuations in energy demand and the intermittent nature of renewable energy sources. By offering an alternative pathway for balancing the energy system and improving its resilience, CCS in conjunction with natural gas plays a crucial role in optimising renewable energy integration and ensuring a stable and secure power supply (Neumann et al., 2021).

Flexibility is expected to be a fundamental characteristic of future energy systems due to the increased deployment of RES. Natural gas power with post-combustion CO_2 is seen as a technology that can provide the required flexibility while keeping GHG emissions relatively low (Skar et al., 2018). The use of this technology expands with the scale of the carbon price. However, without CCS, natural gas markets may peak and decline as the world increases its ambition towards the goals outlined in the Paris Agreement. To meet the consumption levels of natural gas, trade and an increase in LNG are crucial. If CCS is widely implemented and hydrogen is used as a feedstock to reduce carbon footprints in industrial processes, the role of natural gas towards 2050 remains robust in a global context (Cavcis, 2022; Neumann et al., 2021). However, in Europe, model studies suggest that the demand for natural gas may decline, making Europe a less significant consumer of natural gas (Neumann et al., 2021).

5.1.2.2. Effects on Norwegian Competitiveness

While the EU plans to discontinue long-term gas contracts after 2050, some believe that Norway will still be able to sell gas, particularly in the British market and through LNG exports. Furthermore, a significant portion of Norwegian gas is projected to be sold as hydrogen in the future (Ask, 2023b). As industrial sector requires emissions-free operations, there is recognition that there won't be sufficient green hydrogen too meet the increased demand, making blue hydrogen crucial in filling the gap.

However, while natural gas emits less GHG-emissions compared to coal, there are long-term considerations associated with investing in natural gas that may affect the achievement of climate objectives negatively. Some research indicates that natural gas plays a role in mitigating emissions in the immediate future, although this can lead to potential unintended consequences in the long run which could further disrupt the shift from fossil energy towards RE (Gürsan & Gooyert, 2020). As continuing to invest in natural gas might crowd out renewable investments, it is important that European countries put relatively more effort into increasing the proportion of renewables in the energy mix. They face the dual challenge of meeting immediate energy demand while pursuing ambitious renewable targets.

Norway has made remarkable progress in renewable energy projects and pursuing natural gas in the longer term could potentially hinder further growth and advancement of the Norwegian renewable sector (Gürsan & Gooyert, 2020). Diverting resources and investments toward natural gas may slow down the development of RETs and infrastructure in Norway, as it results in reducing costs and making it more attractive. This outcome poses a challenge to the country’s ability to achieve climate goals and uphold a prominent position in the clean energy transition.

5.1.3. Effects of High Wind Penetration in the Electricity Market

REPowerEU sped up the approval process for renewable energy projects, specifically targeting solar and wind power. Member states can identify areas with high potential for renewable energy generation and low environmental risk, and these will have simplified licencing procedures implemented. Last year marked a significant milestone as the electricity generated from wind and solar surpassed that produced by gas (Vetter, 2023). The EU experienced a historic achievement in solar energy with the installation of 41 GW of new capacity, while wind capacity increased by 15 GW. As a result, RES accounted for 39% of total energy generation during the same period (European Commission, 2023c).

To gain insight into the potential short-term effects of increased renewable power generation on prices, we will utilise the merit order curve with focus on wind power. As the share of wind power increases in the energy mix, it is expected that traditional fossil fuel plants will be dispatched less frequently. The MOE illustrates the reduction in power price due to RES feed-in. Declining electricity production costs in the renewable sector forces conventional power plants to take a position further back, meaning an increase in wind power generation in the market shifts the merit order curve to the right. This shift, influenced by market dynamics, determines a new price point. Figure 15 illustrates a reduction in electricity prices from p0 to p1. Naturally, the extent of the effect depends on the slope of the demand curve as well as the amount of wind generation.

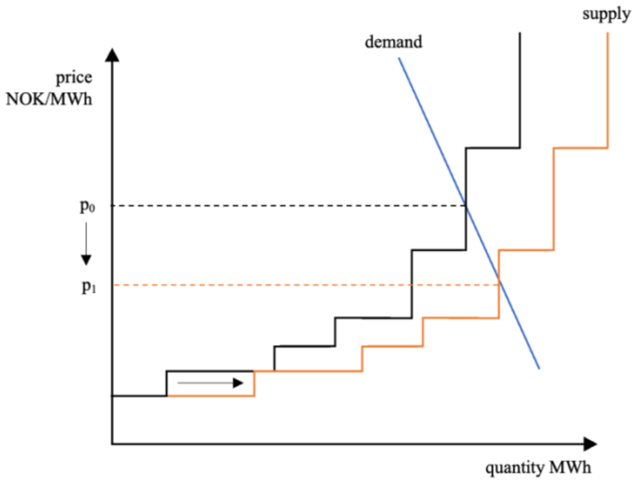


Figure 15: The merit order effect on electricity price caused by RES feed-in.

5.1.3.1. Volatility and Daily Fluctuations

RES are known for their volatile nature, which directly impacts the merit order curve. This curve can shift in and out daily and even within a single day. When there is a high amount of generated wind power, the supply curve is shifted to the right. Wind power is one of the cheapest sources of electricity and is dispatched first. As a result, more expensive power plants may be taken offline, leading to a decrease in the overall cost of electricity at a given level of demand (Morthost et al., 2010).

During periods of ample power supply, particularly during midday when the demand for electricity is at its peak, most of the available power generated will be used. This scenario can have a substantial impact on the spot price, significantly reducing it from pL to pH, as shown in figure 16 (Morthost et al., 2010). Conversely, if there is an abundance of wind-generated electricity during the night when power demand is low, the impact of wind power on the spot price can be minimal. During periods of low wind generation, more expensive power plants may be dispatched to meet demand, resulting in an increase in the cost of electricity. This effect tends to be more pronounced in electricity markets with high levels of wind penetration, where wind power plays a significant role in meeting overall demand. The variability of wind conditions throughout the day can create significant shifts in the dispatch of power plants, causing fluctuations in the overall cost of electricity (Morthost et al., 2010).

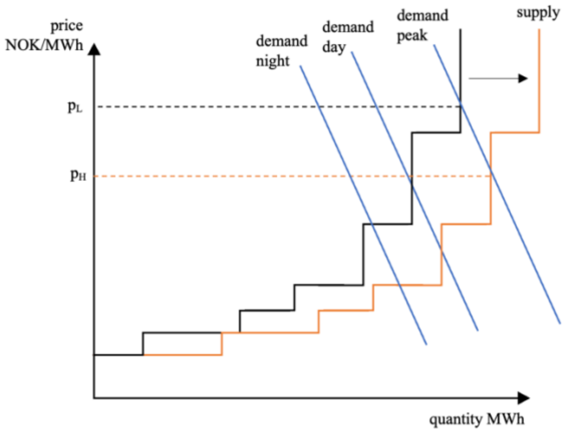


Figure 16: Effect of wind power at different times during the day (Morthost et al., 2010).

When there is an increase in wind or solar power production, the need for fossil fuel-based power plants, such as coal or gas, decreases. Followingly, the contribution of fossil fuels to the electricity market becomes narrower, or less important, as RES become more prevalent. As a result, the merit order curve becomes steeper, meaning that there is larger difference in price between the cheapest and most expensive sources of electricity. This shift can lead to higher electricity prices during periods when there is limited wind power available. In these scenarios, greater reliance on more expensive sources of electricity to meet demand can be necessary, meaning that higher-prices sources that were previously dispatched less frequently may now need to be dispatched more often, resulting in more volatile prices for consumers. Understanding the impact of RES on the merit order curve is crucial for effective energy planning, as it allows for better management of electricity prices and the overall energy market.

5.1.3.2. Developing Wind Power Deployment

Norway, known for its high potential for wind power production, has prioritised the expansion of offshore wind as a strategic decision for future power generation. As mentioned in Chapter 2, the government aims to develop offshore capacity that matches the current capacity of Norwegian hydropower plants, which is approximately 140 GW. The successful integration of Norwegian wind into the market depends on factors such as the LCOE, reliability, profitability compared to other renewable sources, and the availability of grid infrastructure and suitable wind farm locations. If Norwegian wind power demonstrates a competitive LCOE compared to other electricity sources, its increased supply has the potential to displace more expensive generators on the merit order curve, particularly during periods of high wind production. This displacement can lead to a decrease in the average price of electricity, benefiting consumers.

The proposed increase in Norwegian offshore wind production is expected to create a surplus of power that can be exported to other countries. However, the variability of wind power generation poses challenges for grid stability and dispatchability. There may be potential transmission congestion, especially during periods of high wind (Morthost et al., 2010). Additionally, the location of wind farms in relation to existing grid infrastructure and demand centres will influence their integration into the merit order curve. While expediting the approval process can streamline the implementation of wind projects, ensuring suitable conditions for their success, such as adequate grid infrastructure and favourable wind farm locations, is essential.

As we've explored in previous chapters, the LCOE is a crucial factor in determining the competitiveness of renewable energy sources. The IRENA Renewable Cost Database (2022) indicates that the LCOE of renewable energy has consistently improved since the 2010s. This emphasises the importance of low-cost renewable in achieving decarbonisation and meeting climate goals. As technology progresses and market fluctuations occur, the profitability of specific renewable technologies may vary. However, the upward trend in the cost of carbon allowances and permits, combined with technological advancements, makes CO_2-free electricity production more financially attractive (IRENA, 2022). Consequently, renewable energy is gaining increasing traction in the energy marketplace.

The impact of wind on power prices is a topic of interest in the energy industry. While it is generally acknowledged that the integration of wind power can lead to short-term price reductions, the outcome can be influenced by various factors. Effective interconnections and electricity grids across Europe act as stabilising mechanisms, minimising price fluctuations and reducing volatility. Nevertheless, the integration of wind power into the market will continue to have a significant impact on prices as renewable energy feed-in increases in the years to come although estimating these depends on specific circumstances and factors such as the existing energy mix, demand levels, and the scale of wind power integration.

While Norway is actively expanding its wind power capacity, it is important to note that it is not the only country pursuing such endeavours, particularly in offshore development. Several other European countries, including the UK, Germany, Denmark and the Netherlands, are also making significant investments in offshore wind projects. The presence of multiple offshore wind projects near one another can lead to interactions and potential challenges. The phenomenon of cannibalization can impact the wholesale electricity price, and this occurs when renewables with similar generation patterns generate electricity concurrently. In the context of wind power, cannibalization takes place when the addition of new wind turbines within an already established wind farm results in a reduction of the wind farm's total power output, despite the increase in installed capacity (Kanellakopoulou & Trabesinger, n.d.).

5.1.3.3. Effects on Norwegian Competitiveness

The short-term initiative to simplify permitting processes at a national level holds the potential to create a more favourable environment for renewable energy development, offering a promising outlook for Norwegian competitiveness. The increased focus on onshore and offshore wind projects aligns with market opportunities for companies operating in these sectors, positioning them to benefit from the growing demand for renewable energy. In addition, Norway's self-sufficiency in renewable energy provides a significant advantage, allowing any production surplus can be exported, while other countries like Germany, may need to prioritise developing and transforming their own energy consumption needs with renewable energy before they can engage in exporting potential surplus.

Furthermore, the EU's policy support and smart investments can play a significant role in enhancing interconnection and infrastructure within the power market. This includes expanding the power grid and further integrating intermittent renewable sources into the power mix. Norwegian companies with expertise in these areas can exploit these opportunities. Nevertheless, it is important to consider the potential impact of increased competition and shifting market dynamics resulting from the accelerated deployment of RETs across the bloc.

Considering the definition of competitiveness, this is crucial as it can ensure access to energy at reliable and affordable prices. The planned expansion of wind energy in Norway can lead to a decrease in the average price of electricity, benefiting consumers. It is, however, essential to carefully evaluate the long-term effects of this expansion, considering that other countries are also looking to expand their renewable energy capacity. Norway, with its favourable starting point in the renewable energy sector, can capitalise on these opportunities but should remain aware of potential challenges and changing market dynamics.

5.1.4. Balancing the Energy Mix with Increasing Intermittent Power

Norway has a significant amount of hydropower, making it highly feasible to effectively offset fluctuations in wind power through hydropower utilisation. The variability of wind power leads to an increased demand for balancing power, subsequently impacting real-time market prices. Reservoirs enable hydropower producers to swiftly increase production, offering balancing power and the potential for additional profits. Consequently, enhanced planning tools hold considerable value for hydropower producers, granting them greater flexibility in their operations (Vardanyan et al., 2013).

The Nordic power flow is characterised by being divided into different price areas, where power is sold and purchased for each market area on the power exchange. For each spot area, bidding for purchases and sales of power will take place hourly. The price is determined by demand and supply, which is further reported to the power exchange. Higher prices are normally set higher in areas with shortage of energy, which will lead to lower power generation in these areas, while areas with a better power balance will produce beyond its own consumption. This excess power will flow from low-price areas to the high-price areas, which will lead to full transmission capacity utilisation. Making the high-price areas reduce consumption, this division of price areas also provides a reduction in risk of both local and regional power deficits (Statnett, n.d.).

The figure below is an aggregated representation of the power system in price area NO5, which is Bergen. The different icons represent wind power, small-scale hydro power plants, large-scale run-of-river plants, and reservoir hydroelectric power plants. HP represents the hydropower stations and WP represents the wind energy sites (Vogstad, 2000). For simplicity, the illustration focuses on the utilities within one region. The illustration showcases the various choices available for production, market exchange and contractual obligations. An expanded illustration can be found in Appendix G.

Hydro inflow is stochastic, meaning it is unpredictable and can vary over time. As mentioned earlier, Norway relies heavily on hydropower, with approximately 99% of energy generation being hydro based. The demand is classified into two categories: firm load, where a predetermined quantity of energy is sold at a fixed price, and price-dependent/dispatchable loads. The latter can be adjusted by consumers based on the spot price, such as flexible heating systems that switch between electricity and oil depending on the price. Incorporating wind power as an additional stochastic production source does not substantially alter the production scheduling challenge. The value of wind power relies on its complementary characteristics with the hydro inflow. Therefore, the primary focus of long-term production scheduling remains the effective management of water reservoirs, which plays a crucial role (Vogstad, 2000).

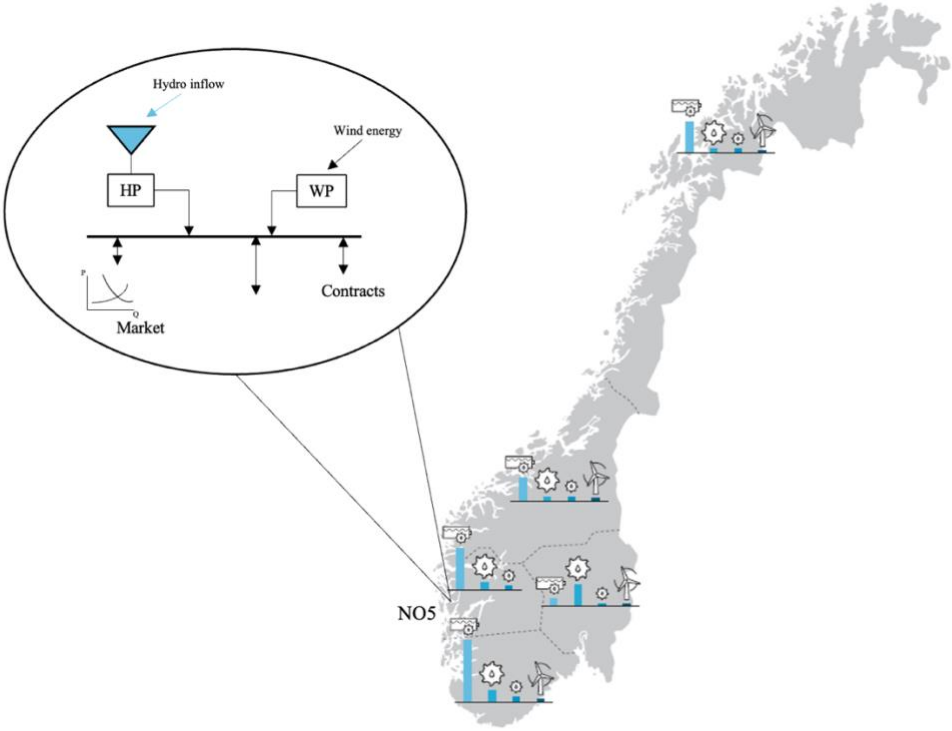


Figure 17: Representation of the Norwegian power market system with a close up of NO5, Bergen (Norwegian Ministry of Petroleum and Energy, n.d.; Vogstad, 2000).

5.1.4.1. The Uncertainty of Forecasted Wind Generation

Renewable electricity generation is creating new operational challenges for the system when displacing conventional generation with nonsynchronous sources. Wind cannot be forecasted with perfect accuracy as it is variable by nature (Lowery & O'Malley, 2012), which makes it difficult for meteorologists to conduct precise and reliable wind predictions. In a scenario where the winter season's wind power production falls short of its forecasted amount, the consequences ripple through various aspects, including the amount of water saved and its impact on prices. Initially, the "solution" revolves around determining the appropriate amount of water to conserve based on the forecasted wind power generation. However, when the wind blows less than anticipated, a significant shift occurs. With less wind power production than expected, there is less energy supply than what meets demand, which puts a strain on the power grid. In the short-term, if the hydropower producer must rely more on alternative sources of energy or purchase electricity from other sources to close the supply-demand gap, it may result in a production cost increase. Further, this could lead to an increase in electricity prices, as the producer may need to pass on these heightened costs to consumers. This is illustrated in figure 19, where we can see the effect on prices when wind power falls short to the forecasted amount.

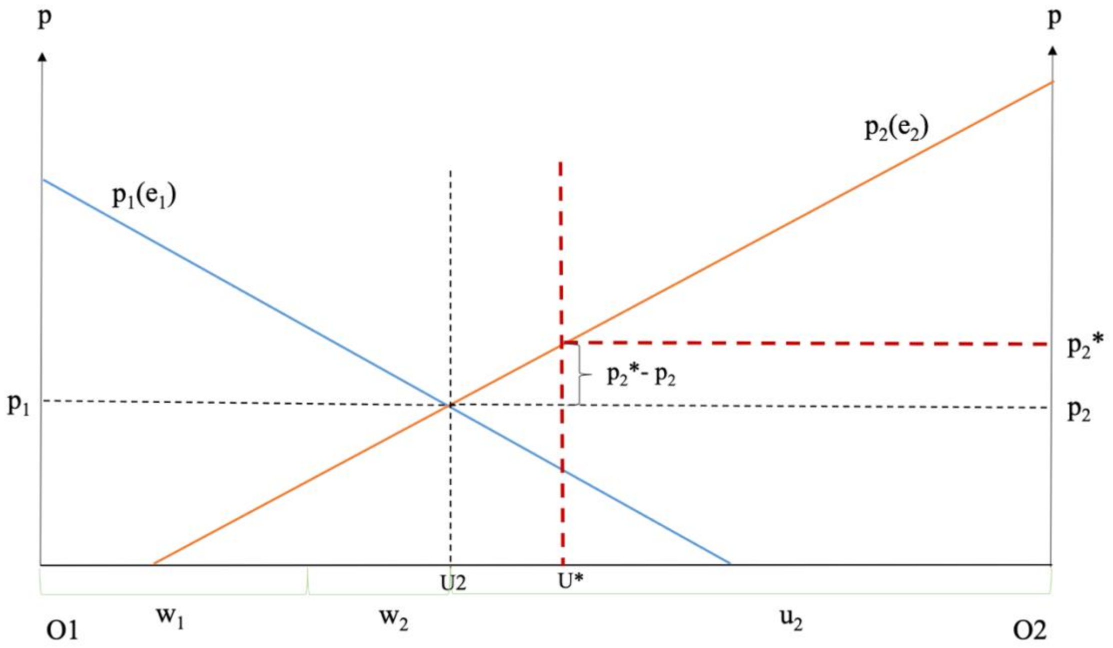


Figure 18: Illustration of the price effects caused by less wind in period 2 than forecasted.

For simplicity, we assume that there is no wind power in period 1 and we only expect a certain amount of wind power in period 2. The forecasted amount of wind is the distance between U2 and the right axis, while the actual amount of wind between U* and the right axis. As seen in the figure, this leads to a higher electricity price in period 2 as we saved an amount of water in the reservoir from period 1 based on the assumption of U2 wind power in period 2. As wind falls short, there is not enough water available to generate the desired amount of electricity in the corresponding period. This can result in reduced energy output or the need to use other sources of energy to meet demand, which can incur higher costs. However, the impact on electricity prices can potentially be mitigated if the shortfall in wind production is only temporary and the hydropower producer can replenish the water levels in the reservoir when the wind picks up. In this case, the producer may not need to rely as much on alternative sources of energy or purchase additional electricity, and the impact on electricity prices may be minimal.

There are a lot of factors that can affect a hydropower producers' decision on the amount of water to store in the reservoirs. Firstly, the price on power in the given price area will be essential in the decision-making which further depend on the weather and how wind and hydro power interacts in the market. Weather in form of floods and increased inflow will affect whether they must produce a lot, while still having high levels in the reservoirs. The wind conditions will also be important in terms of the fact that the price can be low when there is little wind power being generated. Another important element when looking at this case is the fact that we are comparing a regulated and unregulated form of energy. Hence, the value of the water level can therefore be strengthened by periods of low wind but weakened in periods of high wind.

5.1.4.2. Impacts of a Wind-Hydro System

Until today, the Norwegian domestic electricity supply has heavily relied on hydropower, which is regarded as one of the few sustainable electricity supply systems available today. However, the deployment of hydro schemes is becoming less attractive due to conflicting environmental concerns. As a result, exploring other sustainable alternatives becomes necessary, and among these, wind power stands out as one of the most promising. The two energy sources can on one level complement each other, but there are also some risks and shortcomings involved.

Integrating wind energy will have an impact on market prices, system costs, and reliability in electric power systems, and these factors can be significantly influenced by the availability of rapidly adjustable electricity sources. Hydropower plants with reservoirs are often considered an ideal solution for addressing the challenges posed by wind's intermittent and unpredictable nature, due to their ability to store energy, low marginal costs and adjustability (Kern et al., 2014). In this way, incorporating wind energy production into a hydro production scheduling model has been demonstrated to enhance the value of wind power. This increased value stems from improvement management of water reservoirs, resulting in reduced water spillage, and the complementary nature of wind and hydropower plays a significant role in achieving this outcome (Vogstad, 2000).

The share of wind power in the power system is undergoing substantial expansion even more so with the acceleration of permitting process and green transition (Vardanyan et al., 2013), making it important to mention that the volatility of wind power generation still poses considerable challenges in integrating it into the grid and maintaining a stable power supply. The existing wind power prediction methods can often fall short in accurately enough consider fluctuations in power generation, and the integration of wind on a large scale into the power system requires improvements to short-term planning models (Vardanyan & Amelin, 2011). To address the issue of providing stable supply, energy storage solutions like batteries, pumped hydro storage and hydrogen can be utilised to store excess wind power during periods of high wind speeds and release it during periods of low wind speeds.

To explore how these storage solutions can affect market dynamics, we use the pumped-storage power plant as an example. They operate by using excess wind power on the grid to drive electric motors pumping water into hydroelectric reservoirs, which allows for stabilising prices throughout the day and in dry periods (Belsnes & Habry, 2022). Considering the price differences that has characterised the electricity market lately, pumped power could be very profitable. However, they must be large and frequent enough in both a short- and long-term perspective as these power plants require large investments. According to Solvang et al. (2011), such a power plant will have an efficiency of 86% which means that if we pump water for 86 cents/KWh and sell the electricity for 1 EUR/KWh, it will break-even. Any amount above that will generate a positive profit, as a pumped-storage power plant allows for pumping water when electricity prices are low and sell it when they are high. It is important to mention that expanding existing facilities is not always easy and new facilities will have to get a permit to operate, as they have significant impact on the surrounding environment (Belsnes & Harby, 2022). Furthermore, implementing such storage systems comes with significant costs, further adding to the financial challenges associated with intermittent power generation.

5.1.4.3. Effects on Norwegian competitiveness

Integration of a wind-hydro energy system can have a positive impact on the competitiveness in the Norwegian renewable sector. Such a system can increase electricity production in Norway by combining the intermittent energy production from wind with the steady and more controllable production from hydroelectric plants. In general, diversifying energy sources can help reduce dependency on a single source of supply making a country less vulnerable to supply disruptions and price fluctuations in the global energy market. Further, the integration of Norwegian hydropower storage capacity into the European energy sector through interconnectors can enhance flexibility in the electricity market due to Norway's significant natural resources and geographic position.

The variability represented by IRES can create challenges for balancing energy supply and demand and may require the use of backup energy sources. This may entail increased costs for both producers and hence consumers and reduce the competitiveness of the wind-hydro energy system. When the actual wind production falls below the forecasted amount, it is highly probable that prices will rise as the shortfall likely will be compensated by employing costlier forms of electricity. As these types of energy systems expand at a greater scale, the probability of developing more advanced technology for short-term forecasting and planning increases. Moreover, with the growing capacity of wind power, there will be a heightened demand for alternative storage solutions, potentially accelerating investments in pumped-storage power plants.

By operating these power plants when price differences are high, these instalments can increase Norwegian competitiveness as they provide the ability to take advantage of differing prices between regions. Wind-hydro systems can also contribute to stabilising domestic electricity prices, as seasonal variations of wind and hydro power does not follow the same pattern. Subsequently, excess wind power generated during the winter months can be used to increase storages saved for high-price periods. According to Tande & Svendsen (2023), windy conditions in the northern and southern parts of Norway are not correlated which will increase the commercial value of domestic offshore wind. This finding is conditioned by wind capacity being allocated across large areas but highlights the potential value creation as well as it reduces the need for potential costly balancing measures.

REPowerEU emphasises the importance of supporting storage technologies, such as batteries and pumped hydro storage, as they play a crucial role in managing the intermittency of renewable energy sources (European Commission, 2022g). Increased investments in storage projects can enhance the flexibility and reliability of the Norwegian renewable energy sector, making it more competitive by ensuring a stable and secure energy supply.

5.2. Mid- to long-term perspective

In the mid- to long term, the plan puts forth a range of measures aimed at resolving the critical challenges concerning the EU's energy interdependence from Russia, ensuring a secure energy supply, and facilitating the widespread adoption of clean energy through significant cost reductions. The plan focuses on developing capital-intensive infrastructure, along with the deployment of additional solar photovoltaic (PV) and onshore and offshore wind systems, to enhance energy system integration. To ensure a reliable and secure energy supply, the plan calls for additional investments in the power grid and storage. Furthermore, the plan emphasises the need to adapt existing gas networks to bio-methane and renewable hydrogen, along with the construction of new LNG and gas pipeline infrastructure (European Commission, 2022d).

REPowerEU seeks to accelerate the deployment of renewable hydrogen production and hydrogen infrastructure in the longer term as a way of diversifying supply. This includes specific ambitions related to use of green hydrogen produced from renewable electricity, as well as the development of blue hydrogen produced from natural gas, while incorporating CCS technologies (European Commission, 2022d).

5.2.1. Hydrogen's Role in Flexibility and Diversification

The war has highlighted the importance of energy security and the need for greater cooperation among European countries. The EU has sought to address this by developing a common energy policy and investing in infrastructure such as interconnectors and storage facilities. In recent years, Norway has worked to increase its hydrogen production capacity and set ambitious targets for the deployment of hydrogen, especially green hydrogen that has the potential to provide the link between hard-to-abate sectors and the growing RE generation. The system-wide benefits of hydrogen include flexibility and storage, as well as energy security contribution and industrial competitiveness (IRENA, 2021).

REPowerEU presents a target of producing an additional 10 mt of renewable hydrogen by 2030, on top of the 5.6 mt already planned through the FF55 initiative. The plan highlights that this amount of renewable hydrogen has the potential to replace approximately 27 bcm of Russian gas imports by 2030, including 10 mt of imported hydrogen (European Commission, 2022c).

Compared to oil and gas reserves, renewable hydrogen production capacity is more evenly distributed worldwide thanks to the availability of global wind and solar resources. However, the development of this market still requires significant expansion of renewable production and water availability. To achieve its goal of importing 10 mt of hydrogen into the EU, the European Commission aims to establish hydrogen partnerships with reliable partner countries that ensure open and distorted trade and investment relations for renewable and low carbon fuels. It envisages three major hydrogen import corridors from the North Sea region, the Southern Mediterranean and Ukraine (European Commission, 2022c).

5.2.1.1. Cost Components and Estimates

Green hydrogen is the only shade of hydrogen that can ensure an entirely sustainable energy transition, but it also incurs significant energy losses though the whole value chain (IRENA, 2021). These energy losses entail costs for the producers, and the cost of producing hydrogen can vary widely depending on several factors. The cost of electricity, operation costs and cost related to distribution and storage, are three important components when setting the price on hydrogen.

The cost of renewable electricity used to power the electrolyser, when making green hydrogen, is the largest single cost component when produced on site. A necessary condition to produce competitive green hydrogen is therefore a low cost of electricity. Of the energy used to produce hydrogen, approximately 30-35% is lost through electrolysis (IRENA, 2021). As the cost of renewable energy continues to decrease and the technology for producing green hydrogen becomes more efficient, green hydrogen is expected to become more competitive with other forms of hydrogen production in the years to come.

The operating costs encompass the cost of the electrolysis facilities, which is the also the second largest cost component with great potential for reduction on investment costs. These are projected to be reduced by 40% in the short term and 80% in the long term (IRENA, 2021). Operational costs are the ongoing expenses associated with operating a hydrogen production facility and thus will impact the overall cost of production and the profitability of the facility. To meet the rising demand for renewable hydrogen, the installed capacity of electrolysers will need to be increased. Under the REPowerEU plan, the capacity is set to be increased from the previous FF55 plan target of 44 GW to 65 GW (European Commission, 2023c).

Cost related to storage and distribution of hydrogen varies greatly depending on the time perspective, as energy loss increases over time and entails costs for producers. A trade-off exists as hydrogen can be produced at a big, centralised plant or on-site near a refuelling station. Building a centralised electrolyser of a bigger size could reduce the cost of producing hydrogen but increase the cost of transportation (Rahil & Gammon, 2017). The three main forms of transporting hydrogen are compressed in trailers, liquified in tanker trucks and in hydrogen pipelines. To this day, hydrogen has been mostly produced close to where it has been used, due to limited transport infrastructure (IRENA, 2021). Further, transporting hydrogen requires energy inputs equivalent to approximately 10-12% of the energy the hydrogen contains itself.

Overall, the cost of producing green hydrogen tend to be higher than other forms of hydrogen, such as hydrogen produced from natural gas, due to the higher cost of renewable energy and the capital costs associated with electrolysis. The current gaps in the cost and performance of green hydrogen are expected to narrow down over time because of innovation and mass deployment of different electrolysis technologies (IRENA, 2021). Further, the final use of hydrogen is what will ultimately decide the total energy loss in the value chain. The calculation behind the cost estimates for green hydrogen can be found Appendix D.

Table 2: Cost estimates for green hydrogen in 2030, 2040 and 2050.

Year	**Cost estimate (EUR/kg)**
2030	2.63
2040	1.15
2050	0.89

5.2.1.2. Combining Hydropower and Green Hydrogen

The overall goal of the REPowerEU plan is to create a more resilient and sustainable energy system in Europe, by shifting away from fossil fuels and towards a healthy mix of RES. As mentioned earlier, the increased amount of IRES in the energy mix will have extensive implications and discovering flexible solutions for ensuring security of supply will be essential. As Norway becomes more integrated with the European electricity market, Norwegian hydropower will constitute a smaller part of the total market, making it necessary to explore alternative storage solutions. If there is a price difference between two periods that cannot be equalised with intermittent power or hydropower, it may be cost-effective to use the surplus intermittent power generated to produce and store hydrogen. Taking into consideration figure 9 presented in Chapter 3, it is important to note that the significance of the analysis extends beyond the immediate time frame. It remains relevant not only in the short term but also in the longer term, owing to the potential fluctuation of price disparities between different periods as time progresses.

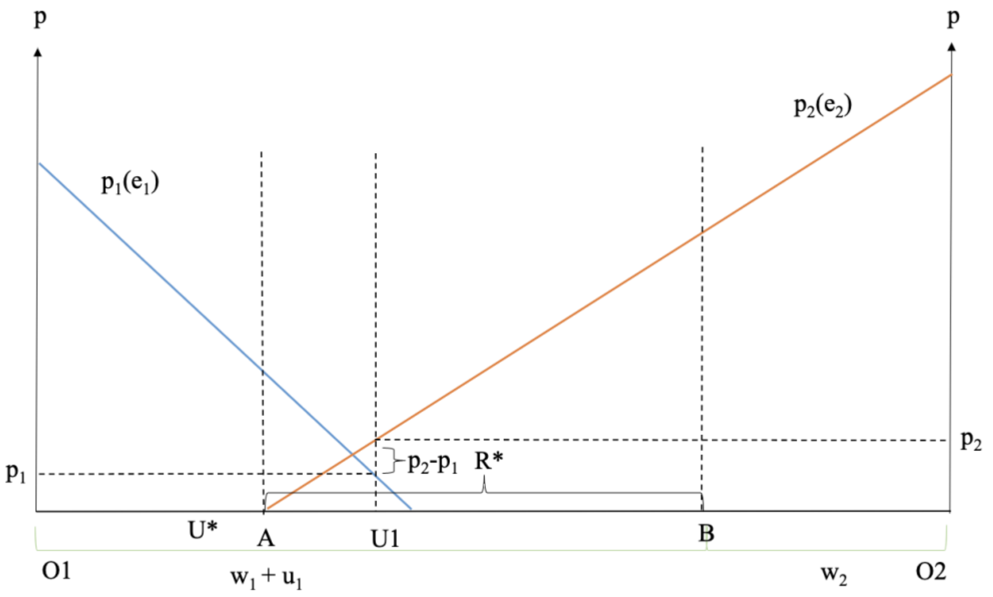


Figure 19: Illustration of how price difference between periods can make it profitable to store hydrogen.

To exemplify this scenario, we assume the wintertime to be period 1, which is characterised by high wind production and low price p_1. The summer months are respectively assumed to be period 2, with less wind power production, and hence characterised by high price p_2. The price difference between the two periods is shown in the figure as p_2-p_1, where the size of this price deviation will determine whether storing in green hydrogen is profitable. Building on the foundations from Chapter 3, we can delve further into the dynamic nature of energy prices and their correlation with the availability of wind or water resources. In scenarios where lower prices coincide with rich access to these RES, we can examine the phenomenon of fluctuating prices over time. Conversely, during periods with low wind or water availability, energy prices tend to be higher. For a hydropower producer, the assessment consists of whether to produce today or store water to be able to get a higher price at a later point it time. What makes it profitable to store water in short or longer periods, is the difference between the expected price and the actual price of the water (Norwegian Ministry of Petroleum and Energy, 2022a). When a significant price difference exists between the two periods, it presents a favourable situation for intermittently harnessing some of the energy for production of green hydrogen. Subsequently, this store energy can be utilised during the high price period, resulting in potential cost savings.

However, the decision to produce green hydrogen is influenced by various factors, including the cost associated with production and storage of hydrogen, the energy loss incurred during the conversion process of hydrogen production and retrieval, as well as the price differential observed between the two distinct periods. Although the model may not encompass the entirety of the topic, it adequately captures the underlying mechanisms to serve as a foundation for discussion and further exploration of related effects. The key takeaways remain intact. If the price difference between the two periods is large enough, there is potential value in producing green hydrogen and utilising it during period 2. In other words, the strategy of utilising energy during low-price periods for hydrogen production and subsequently using this stored hydrogen during high-price periods hinges on the magnitude of price differences. The decision to implement this approach effectively depends on whether the price differentials are significant enough to warrant the investment and potential benefits of such an energy management strategy.

This occurred during January and February 2021, when Europe experienced cold weather and reduced wind activity across significant regions. As a result, wind power generation was practically halted. In such circumstances, the necessity arises for storage methods capable of accommodating large capacities and storing electricity for extended durations. Currently, pumped power plants with sizable storage capabilities serve as the primary solution to address such scenarios. Although hydrogen storage presents an alternative, it is worth noting that the technology exhibits lower efficiency levels (EnergiAktuelt, 2023).

5.2.1.3. Effects on Norwegian competitiveness

The Commission aims to enter hydrogen partnerships with major corridors, including the North Sea region, which involves collaborating with Norway. This presents significant opportunities for Norway to export both blue and green hydrogen on a global scale. Hydrogen offers flexibility and secure supply options. Increased trade agreements and partnerships in the energy sector, especially for green hydrogen, is disponed to creating new market opportunities for Norwegian companies. Norway’s existing market presence and expertise in hydrogen production makes it well-suited to benefit from the growing demand in the EU. This can be seen in combination with its expertise in low-temperature water electrolysis that can give it a competitive advantage in supplying hydrogen to the EU.

However, the price and feasibility of green hydrogen rely on a variety of factors and potential challenges that may arise. The competitiveness of the renewable sector depends on various factors, including price, materials, skills, and access to markets. Changes in the energy landscape resulting from diversification efforts could introduce new market dynamics, competition, and pricing pressures which further will affect hydrogen's role in the energy transition. Further, the scale in which hydrogen will be deployed is even higher depending on technology related to transportation and infrastructure, and this will impact the size of market opportunities green hydrogen will create for Norway.

The green hydrogen industry is further somewhat determined by policies regarding wind power deployment as it is produced using renewable sources of energy. Therefore, they can complement each other in the years to come, but this is yet to be decided by the pace of capacity instalments of all sorts of wind power technologies. If this continues in its current pace, green hydrogen will not be competitive compared to the other shades and hence its value creation potential will not be realised.

It is important to mention the uncertainty of green hydrogen price estimates, as they are highly dependent on price on RE, electrolysis efficiency, competition from other sources of hydrogen, as well as prices on CO_2 quotas, which will further affect the future export values of green hydrogen for Norway and our competitiveness in the renewable sector. This expansion will require additional investments in electrolysers and the corresponding increase in renewable electricity generation from sources such as wind and solar power, consequently boosting the Norwegian renewable energy sector and enabling the production of renewable hydrogen.

5.2.2. Linking Energy and Trade

In recent years, there has been a significant shift in the global landscape of trade and investments with an increased focus on diversification and development to enhance security of supply (Amprion, n.d.). This shift encompasses multiple aspects, including improving interconnection and infrastructure, supporting storage projects and enhancing the flexibility of supply (A&L Goodbody, 2022).

Trade models serve as useful tools when analysing international trade patterns and assessing their welfare implications for society. By utilising these, it becomes possible to gain insights into the effects of accelerating the clean energy transition on supply in the EU and Norway in the mid- to long-term. A one-period, two-region trade model that incorporates transmission constraints can provide a framework to examine the interplay between energy production, consumption, and trade in these regions.

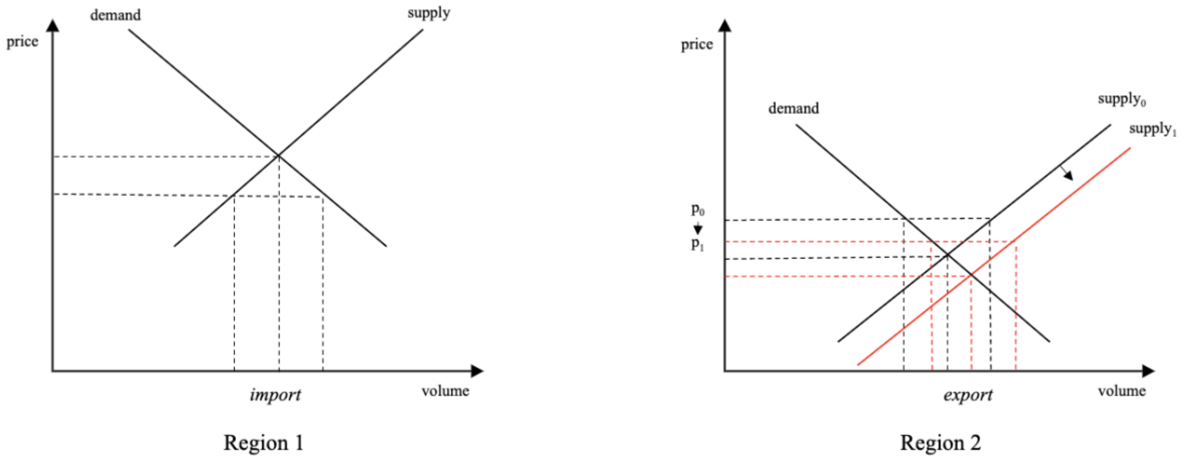
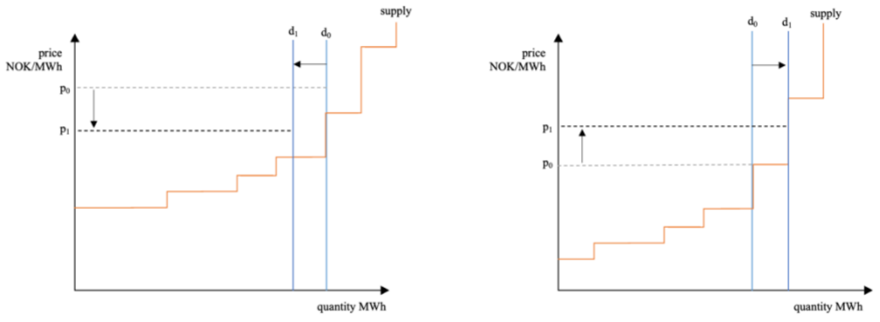


Figure 20: Illustration of trade with a transmission constraint.

In this trade model, we consider region 1 as the EU and region 2 as Norway. The trade of electricity between these regions occurs through interconnectors with a limited capacity. This reflects the current situation where Norway is a net exporter of electricity, with a total net export of 12.5 TWh in 2022 (NVE, 2023b). The Norwegian renewables policy support is expected to shift the supply curve outwards in figure 20 outwards from supply$_0$ to supply$_1$, increasing supply and lowering the electricity price from p_0 to p_1. This price drop will be further making Norwegian power an attractive option for linked countries and create a greater price difference between the two region (Farmer, 2021). By exporting electricity when prices are high in the EU, will also lead to some increased price in Norway due to the nature of the bidding mechanism. Within this model, the presence of transmission constraints means that the quantity and price of electricity traded between the EU and Norway are not solely determined by market equilibria. Instead, they depend on the capacity of the transmission lines or cables. When there is available cross-border capacity, the electricity dispatched first is determined by the lowest cost asset (Farmer, 2021). Consequently, the EU being the high-price region, tends to import electricity, while Norway as the low-price region, tends to export electricity. This trade dynamic is driven by the price disparities between the two regions and the availability of transmission capacity.

The capacity utilisation of a cross-border interconnector depends on a variety of factors such as the demand for electricity and the cost of importing or exporting electricity. In some cases, cross-border interconnectors may operate at full capacity during periods of high demand or when there is a shortage of generation capacity in one country. However, at other times, they may operate at lower capacities or not at all. Figure 21 provides an illustration of the outcomes of trade between two regions with different marginal generation costs, considering unrestricted dispatch. When transmission lines are developed or expanded without constraints, it represents an "extreme case" scenario (Jacottet, 2012).



Region 1

Region 2

Figure 21: An "extreme case" scenario with construction of additional transmission cables (Jacottet, 2012).

In the extreme case scenario, unrestricted trade through interconnectors results in equalised electricity prices between the two regions. In this scenario, the demand for electricity is perfectly inelastic, meaning that price changes have no impact on demand. Initially, electricity is sold at a lower price in region 2, but once the interconnector is established, region 2 starts exporting to region 1 as it can produce at a lower cost. Consequently, region 2 needs to produce more electricity, causing an increase in its marginal cost. Region 1 generates less electricity because it imports cheaper electricity from region 2, resulting in a lower marginal cost (Jacottet, 2012). Although not currently applicable to the wholesale electricity market, this scenario could arise with the expansion of trade and construction of additional transmission cables. The oil market serves as an example of a situation where such a scenario is relevant, as Norwegian oil prices are determined by the global market.

When examining this scenario, we base it upon a trade model without transmission constraints as shown in figure 11. This means that when the interconnectors' capacity is not fully utilised, the transmission constraint is not binding, and we will have more similar prices in the two regions. For Norway, this will entail a higher electricity price in contrast to the importing region who will experience a lower electricity price depending on its size. When looking at the EU as the importing region, this will typically not have a great influence on electricity price due to the size of the imported amount being relatively small in comparison to total consumption.

Historically, Norwegian electricity generation has been dominated by hydropower, which has a low marginal cost of production. In periods with a lot of rainfall, this has led to increased supply and export to our neighbouring countries. According to Farmer (2021), in the second half of 2020, the abundance of hydropower led Norway to become Europe's powerhouse. Intermittent production technologies naturally have low variable cost of production since the actual source of energy is free. This will allow power producers to generate renewable electricity even when the prices are barely above zero, which makes it attractive for high-cost regions to import Norwegian electricity (Norwegian Ministry of Petroleum and Energy, 2021). Once national demand has been met, this allows us to export the surplus at the transmission capacity. Trade across borders also puts Norway in a position where regional market developments can create benefits, without risking shortages of supply (IEA, 2022b).

5.2.2.1. Trade Volume and Overall Welfare

Increased supply will result in a substantial amount being transmitted abroad and increase export. Due to electricity demand growth, driven by the increasing prevalence of electric vehicles, heat pumps and hydrogen, demand is expected to rise by 25-30% in 2030 (IEA, 2022h). We can therefore safely assume that demand in the EU will rise due to structural changes, and that considerable parts of this gap will be met by importing from Norway.

Norwegian hydropower and wind power will directly contribute to the EU climate goals, as this can run down production of other high-emitting energy sources (Tellefsen et al., 2020). It also has the potential to reduce the expected demand gap, especially during high rainfall or windy years. With such whether conditions, there will be excess energy in Norwegian reservoirs and an energy surplus generated by windfarms. Moreover, this implies that a surplus of water is floating into Norwegian reservoirs and an excess of wind is passing through Norwegian wind turbines, surpassing the requirements to fulfil the nation's electricity demands (Tellefsen et al., 2020). It is clearly a better option to produce this electricity and export it through interconnectors. It must be taken into consideration that there are limits to the possibilities regarding the connections between Norway and continental Europe, and reservoir filling capacities. There are also possibilities, as the development of IRES is increasing the economic and environmental value of interconnectors (Tellefsen et al., 2020).

To ensure full utilisation of increased deployment of RE, it will require more interconnectors as well as strengthening of the Norwegian grid (Skar et al., 2018). Increased trade with large regions like the EU will affect Norwegian electricity prices, as they will converge more towards the prices in the region they are exporting to. The dominating trend is Norway being the exporting country due to large hydropower production and corresponding low electricity prices. Although the country overall will benefit from being a net exporter, typically the electricity producers will benefit, and consumers lose. Overall, it creates an economic benefit, but the consumers in the exporting countries will experience a fall in surplus as prices will increase. On the contrary, producer surplus will increase through exporting to high-price regions as well as rents for interconnector owners (Jacottet, 2012).

Although the construction of and trading electricity through interconnectors create winners and losers, they improve overall welfare. This potential for net welfare gains is why the European Commission are working towards greater investments in interconnectors within the EU. Beyond this, they also provide positive externalities as better security of supply and possible cross-border synergies. Each country in the EU has different degrees of renewable potential, and renewable generation is further determined to be sited where the resource is available. Where two countries have diverging renewable characteristics, interconnectors can allow for the resources to be exploited more effectively (Jacottet, 2012). This can be exemplified by NorNed that was commissioned in 2008 which interconnects the national grids of Norway and the Netherlands. Where the Dutch power system is dominated by thermal power plants useful for base load, the Norwegian system has plenty of hydropower which will generate cheap electricity during peak load. These characteristics complement each other and represents a complementary system through connecting renewables across borders.

5.2.2.2. Variations and Price Effects

Transitioning to a low-carbon society, will require the electricity sector to integrate an increasing amount of IRES. As the share of intermittent power production is increasing in the European power system, there is need for short-term flexibility in which Norwegian power plants are especially useful (Norwegian Ministry of Petroleum and Energy, 2021). The electricity generated by IRES is location specific and only possible to predict to a limited extent, and it will have a strong impact on future operation of the power system (Collins et al., 2017). When interconnecting European countries, the correlations between wind power generation are important to emphasise (Olauson & Bergkvist, 2016). The general pattern is that correlations are the lowest on short-term and highest in the long-term. Similar seasonal wind patterns in Europe, with a generally higher wind generation in wintertime, can explain this high long-term correlation. They are also determined by separation distance and can be reduced by the geographical area of the power system being expanded (Olauson & Bergkvist, 2016). Deviations from this correlation pattern do however exist, and variation in short-term correlation can have price effects.

A possible deviation on short-term might be a high correlation between wind power generation in Norway and the EU, where both regions experience windy conditions simultaneously. This will lead to lower electricity price in both regions, as wind power has close to zero in marginal costs of generation. Also closing the price gap, this will reduce the value creation for Norwegian renewable energy producers both in the national and international market. There may also occur a situation where windy conditions in the EU will shift the supply curve outwards, making Norway the importing region for this period. A closer integration of electricity grids through Europe, as well as the introduction of volatility dampening technologies, can diminish these price effects.

5.2.2.3. Effects on Norwegian competitiveness

Increased energy trade has the potential to significantly impact Norwegian competitiveness in the renewable energy sector. By exporting its abundant hydropower and growing wind power generation to the EU, Norway can contribute to the development of affordable, reliable, and accessible clean energy. This strengthens its capacity to compete in the global energy markets, aligning with the European Commission's definition of clean energy competitiveness.

Through increased trade, Norway can enhance its position in the European energy market, generating revenue and attracting investments. As more European countries seek to diversify their energy sources and reduce their dependence on fossil fuels, Norwegian suppliers of RES may benefit. The export of renewable energy can help meet the EU's climate goals and reduce reliance on high-emitting sources, further strengthening competitiveness. Furthermore, closer economic integration and cooperation with European countries could result in development of more cross-border infrastructure projects, enhancing the overall efficiency and reliability of the energy market. By engaging in cross-border trade and the development of interconnectors, Norway can ensure a resilient energy system that can mitigate challenges associated with price fluctuations and short-term variations.

A potential challenge lies in the possibility of increased competition from other energy-producing countries or regions as more European countries enhance their domestic energy production or establish new trade partnerships. This heightened competition could have implications for Norwegian energy exports, potentially impacting their market share. Moreover, Norwegian energy prices may be influenced by European market trends, affecting consumer affordability, and potentially hindering the competitiveness of the renewable energy sector.

5.2.3. Smart Investments for the Future

The urgent need to transition to clean energy has been magnified by the global economic disruption caused by war. Reliance on polluting fuels from a few major producers has highlighted the dangers of European dependency. Paradoxically, this situation has encouraged efforts to combat climate change. This is particularly present in developing nations, as local energy sources become more attractive due to the soaring profits of oil and gas companies (Hulac, 2023). Several of the EU’s objectives can be achieved by making smart investments in renewables and energy efficiency, beyond the FF55 proposals.

Encouraging investment in the scaling up of clean energy technology production at various policy levels is crucial. This approach would expedite the out-phasing of outdated coal and nuclear plants, reducing the need for further investment in these technologies (European Commission, 2022d). Consequently, the focus should shift to other sources of energy. DNV's Energy Transition Outlook predicts that by 2050, most of the world's energy supply will come from IRES, representing 70% of the global power system. Coal and gas are projected to constitute only 4% and 8% of the power mix, respectively. These fossil fuels will primarily serve as flexibility and backup sources for the power system (DNV, 2022b).

Smart investments in REPowerEU are crucial for driving effective actions across various sectors. This includes infrastructure, grid development, investing in renewables, energy storage and efficiency improvements, and these play a pivotal role in facilitating the clean energy transition. In the longer term, research, and development (R&D) investments are just as crucial. Literature widely suggests that involvement in R&D can assist companies and countries in fostering innovation, enhancing productivity, and facilitating the development of new products and markets. Consequently, these activities contribute to ensuring competitiveness and fostering sustainable growth (Moncada-Paternò-Castello & Grassano, 2014).

The development and implementation of low-emission technology typically follows extensive and extended development pathways. The deployment of new technology often entails a considerable time frame of 10 to 30 years, encompassing various stages such as research, pilot projects, and testing. The duration of this process depends on the complexity and scope of the specific project at hand, but generally there is widespread agreement that achieving a low-emission society demand a process of transformation that will affect every industry, not just those that have traditionally been considered “green” (Norwegian Ministry of Climate and Environment, 2021).

5.2.3.1. Long-term RE growth

The renewable energy sector has witnessed decreasing costs due to technological advancements at a larger scale, and this trend is expected to continue in the long run. Wind power capacity growth projections are significant, with onshore wind capacity expected to increase sevenfold and offshore wind capacity anticipated to increase by 56 times. Globally, wind capacity is predicted to grow ninefold between now and 2050. Additionally, substantial reductions in the LCOE are expected for both fixed and floating offshore wind, with projected decreases of 39% and 84% respectively. Onshore wind power costs are projected to decrease by over 50% by 2050 (DNV; 2022b; Shrestha et al., 2023). However, immediate challenges such as supply chain bottlenecks and commodity price inflation led to an average increase in LCOE for renewables and energy storage in 2022 (DNV, 2022b).

Currently, half of the technologies required for complete decarbonisation are ready for the market. R&D, as well as research and innovation (R&I) endeavours, aim to facilitate the transformation of both new and established technology solutions into market-ready entities (European Commission, 2022f). This plays a crucial role in driving innovation and technological advancements in the renewable energy sector, in particular for green hydrogen and solar energy. Without support or incentives to do so, many companies lack the motivation to engage in long-term R&D investments. However, being at the forefront of decarbonisation efforts can offer a competitive advantage, as the demand for clean solutions grows. Additionally, the development and sale of new technologies and solutions can create lucrative business opportunities (Damman et al., 2020).

REPowerEU highlights the need for long-term perspectives when considering renewable energy investments. Although renewable energy projects often require higher upfront costs, they often provide long-term revenue streams and exhibit lower production costs in comparison to traditional fossil fuels. This emphasises the significance of considering the complete lifecycle of renewable energy investments and recognising the potential cost benefits they can deliver in the long-term. Smart investments can have a significant impact on the LCOE of renewable energy technologies, influencing the overall cost of electricity generation. By strategically allocating resources, these investments optimise energy generation, leverage technological advancements, and provide policy support. Investments can contribute to cost reductions through economies of scale achieved by increasing the overall installed capacities of wind and solar power, resulting in improved efficiency and lower generation costs. Moreover, policy support and funding mechanisms like the RRF offer stability and financial resources for investors, influencing financing costs and making renewable energy projects more financially appealing.

Although LCOE is an important metric for comparing project competitiveness, it is a static indicator that does not consider all associated costs with actual financial decisions or interactions between generators in the market (IRENA, 2022). It oversimplifies interest rates and doesn't account for project risks or potential future technological developments that could further lower generation costs. Additionally, the impact of market design and regulatory frameworks on cost-effectiveness is not fully captured by LCOE calculations. Subsidies and other incentives may be necessary to support the deployment of RES in the short-term but may not be sustainable in the long term. It's critical to consider the market price of energy alongside LCOE when evaluating the cost-effectiveness of an energy technology. RETs may have a low LCOE but may not be profitable if the market price of electricity is too low.

Additionally, comparing LCOE can be misleading without considering several factors such as intermittency and grid balancing costs. LCOE alone does not account for the variability of some RES, such as wind and solar, compared to more dispatchable energy sources like natural gas or coal. It is therefore important to acknowledge the additional costs associated with balancing the grid and ensuring a reliable supply of electricity when comparing energy technologies. An example can be found in the offshore wind development of several countries, including Norway, Denmark, the UK, Germany, and the Netherlands. While high winds are favourable for wind energy production, the profitability of offshore wind farms can be affected by lower market prices, especially in areas with the same weather conditions. Moreover, wind correlation between different regions can result in the need for excess reserves, particularly during periods of low offshore wind production and high electricity demand. In Norway, hydropower serves as a reserve with storage, but other European countries rely on costly reserves like coal, gas and nuclear. This presents a dilemma for the LCOE since investors may charge higher prices for electricity due to the requirement for readily available reserve power plants, which only generate power during periods of low wind and high demand. Although this cost is not considered into LCOE calculations, it holds significance for wind energy, which exhibits a declining trend. Therefore, it is crucial to consider both LCOE and market price, along with the need for reserves, when evaluating the cost-effectiveness of an energy technology.

5.2.3.2. Effects on Norwegian competitiveness

In conclusion, Norway’s competitiveness in the renewable energy sector can be greatly influenced by the implementation of strategic investments. These measures have the potential to propel Norway further as a frontrunner in various industries, enticing investments and fostering innovation to support the transition towards clean energy. Not being a member state, there could be some uncertainty regarding Norway’s access to the EU’s funds for renewable energy projects. However, InvestEU is financed through the EU ETS, in which Norway is a part of. Followingly, this opens for Norwegian businesses to apply for financial support for projects leveraging emission reductions in line with the EU's climate targets (Enova, n.d.) In the REPowerEU plan, the European Commission proposes an extension of the fund's scope leading to even more opportunities (European Commission, 2022g).

The transition, however, goes beyond Norway and encompasses all EU countries and other markets. This broader adoption of smart investments in various sectors stimulates competition and boosts competitiveness in multiple regions. Consequently, Norwegian companies may encounter difficulties in competing with long-standing European renewable energy firms due to heightened competition. Additionally, if the EU enforces more stringent regulations and mandates regarding renewable energy generation and utilisation, Norwegian companies might need to allocate extra resources to meet these updated standards. The heightened competition may present challenges for Norwegian companies in securing contracts and maintaining market shares. The EU’s emphasis on developing its own renewable energy capacity through initiatives like REPowerEU may reduce reliance on energy imports, including those from Norway. This shift towards self-sufficiency within the EU may potentially lead to a decrease in demand for Norwegian renewable energy exports.

It is also important to highlight that increased investment in and deployment of RE generation in the EU may contribute to reduced cost of clean technologies globally. Using the theory of learning curves, the increased installed capacity may contribute to reducing the related costs, hence make them cheaper and more attractive as investment objects for Norwegian producers of RE. One example of this is the German energy initiative “Energiwende”, which is acknowledged to be a big part of the reason why previously expensive wind and solar technologies now has significant production capacity at a global scale (Morris, 2016). According to Gerarden (2017), the German energy transition policy has subsidised solar power at a lower cost for the rest of the world. This is due to the investment in innovation that these subsidies represent, which may create significant spillover effects. Moreover, the EU investing in numerous clean technologies, this may result in bringing cost down as well as increased cost competitiveness between substitute technologies that may further reduce cost and accelerate deployment.

5.3. Discussion of Results

The discussion section holds importance in every research study as it serves as a platform for interpreting and delving deeper into the results within the framework of the research questions. In this section, we aim to analyse several key findings of the research and shed light on other limitations that have been identified. Moreover, we will explore the concept of competitiveness and its interconnectedness with EU climate policy, emphasising the virtuous circle it creates. Finally, we will engage in a reflection of the term "transition" and its implications in the context of our study.

5.3.1. Key Findings and Observations

The REPowerEU initiative offers promising opportunities for Norwegian renewable energy companies by opening new avenues for growth and expansion. However, it may also result in heightened competition within the European energy market. The emphasis on technology neutrality within the initiative implies that Norwegian renewable energy technologies, such as hydropower, may face keen competition from alternative sources like wind and solar from other countries. The overall impact of the initiative will depend on future developments in the sector, the progress made by renewable energy industries in other regions, as well as the market dynamics in Europe. The REPowerEU package introduces a layer of complexity to EU regulation, as it introduces policies that partially overlap and may potentially contradict existing regulations and targets. This complexity has the potential to undermine the effectiveness of the initiative.

The successful integration of RETs into the power grid depends on three key factors: dispatchability, predictability and capacity. Hydropower with reservoirs provides extensive energy storage, meaning it can adjust output to meet fluctuating demand and stabilise the grid under variable conditions. Renewable technologies like solar PV and wind power lack storage capacity and must generate power in real-time based on resource availability. This unpredictability poses integration challenges, especially as their grid contribution increases (Skar et al., 2018).

Although certain countries may resort to the use of dirty fossil fuels like gas and coal in the short term to mitigate the economic impact of the evolving energy market, there remains optimism that the prevailing political climate could foster a lasting transition towards clean energy. By effectively integrating IRES in the long term with clean technologies like green hydrogen, pumped-storage power plants and geothermal energy storage, the stability and reliability of the renewable energy sector in Norway can be improved. The growing demand for renewable energy emphasises the need for energy storage in any energy system. There is always a mismatch between energy demand and its actual supply, making the incorporation of energy storage solutions crucial for maintaining a stable and reliable energy supply. This need becomes even more significant with the progressive integration of non-dispatchable renewable energy sources. Energy storage plays a pivotal role in accommodating the fluctuating nature of these sources, ensuring a more efficient and effective utilisation of renewable energy in the grid (Skar et al., 2018).

The actions presented in the REPowerEU package were analysed form a short-term to a mid- to long-term perspective, aligning with economic viewpoint. This approach allows for a comprehensive assessment of the actions' economic viability and sustainability over different time horizons. By considering the short-term implications and mid- to long-term implications, the study provides a more holistic understanding of the potential impacts of the initiatives.

Conclusions about how the REPowerEU initiative may affect competitiveness in the Norwegian renewable sector are specific to the Norwegian context and may not be directly applicable to the competitiveness of the renewable sector in other countries. It is important to recognise that each country has its unique set of circumstances, and the findings should therefore be interpreted with this in mind when trying to draw conclusions about the competitiveness of the renewable sector in other countries. The study adopted an energy economic perspective, which entails certain limitations and constraints. This perspective tends to overlook some non-economic factors, potentially impacting the comprehensiveness of the analysis. In addition, recognising the limitations about assumptions about human behaviour and market functioning is crucial for interpreting the findings accurately. To ensure relevance to the Norwegian context, the analysis focused on specific measures and initiatives within the REPowerEU that were deemed more applicable and relevant for the Norwegian energy landscape. This selection allowed for an evaluation of the actions with potential to directly impact the country and provided insights to address the research question effectively.

5.3.2. Unpacking competitiveness

While energy economic factors play a crucial role in determining competitiveness, there are additional considerations that come into play, particularly in the realm of renewable energy. Some would argue that competitiveness cannot be adequately defined solely through an economic lens, more specifically through a definition of "clean energy competitiveness".

One important aspect to consider is the influence of political uncertainties and long-term commitment on the competitive position of renewable energy. Investments in clean energy projects often require significant capital and long-term planning. When political uncertainties arise, investors may become hesitant about committing their resources, and this hesitancy can directly impact the competitiveness of RE. The financing gap remains substantial, underscoring the critical need to de-risk energy investments. Notably, global investment in the energy transition has experienced remarkable growth, surging over threefold in the past decade. However, it is important to recognise that this surge was facilitated by a decade of economic expansion, expansionary monetary policies, and historically low benchmark interest rates. Looking ahead, the prospect of higher interest rates aimed at curbing inflation, along with supply chain challenges and rising commodity prices, may potentially affect the cost-competitiveness of renewable energy projects relative to existing fossil fuel assets (Bocca & Singh, 2022).

The financing cost of capital-intensive renewable energy technologies are more affected by increases in interest rates compared to traditional fossil fuels. To ensure the continued cost-competitiveness of RES, it is important to address risks associated with operations, execution, and policies. Several measures can be taken to maintain a steady flow of investments in clean energy, and these include providing revenue stability, enhancing the creditworthiness of off takers, improving operational and infrastructure efficiency to minimise curtailments, and establishing clear demand signals that enable industries to secure financing based on their balance sheets. By implementing these strategies, the necessary investments in clean energy can be sustained, supporting the growth and development of renewable technologies (Bocca & Singh, 2022).

5.3.3. EGD, FF55 and REPowerEU: The European Virtuous Circle

This thesis aims to explore the influence of REPowerEU on Norway's renewable energy sector. REPowerEU is an integral part of the European Green Deal, which strives to expedite the transition towards a sustainable and carbon-neutral economy in Europe. Within the realm of climate and energy policy, the REPowerEU initiative complements and reinforces certain aspects highlighted in the FF55 package.

By combining the FF55 package and REPowerEU, a virtuous cycle can be set in motion, promoting the adoption of renewable energy sources throughout Europe, and reducing dependence on Russian fossil fuels. The full implementation of the FF55 package alone is projected to reduce EU gas consumption by 30% in 2030. However, with the inclusion of REPowerEU, the proposed targets for renewable energy and energy efficiency would be further amplified (KPMG, 2022). Appendix C contains a comparison between the heightened REPowerEU targets and current EU energy law. The FF55 package assumes a crucial role in the success of REPowerEU, and disentangling the specific effects attributable to REPowerEU becomes a complex task. In the context of Norway’s renewable energy sector, the changes brought about by the quota directive, the renewables directive, and the directive on energy efficiency will have significant implications for the profitability of hydropower and wind power.

The implementation of the REPowerEU plan involves various measures, such as incorporating high-priced gas alternatives like sustainable biomethane and renewable hydrogen, increasing the deployment or renewables, and implementing structural demand measures such as energy efficiency. These measures are anticipated to lead to a faster decline in gas demand within the EU compared to the projection under the FF55 package alone (European Commission, 2022g). By this we acknowledge that it may be difficult to fully isolate the effect of the REPowerEU plan on Norwegian competitiveness, as it builds upon and improves existing climate goals and strategies.

5.3.4. Feasibility of the initiative

The responsibility lies with the member states to take the REPowerEU actions into account and strengthen domestic policies to comply with the stated objectives in the proposal. When the EU adopts legislation, it is binding to all the member states in a wide range of policy areas (DeHavilland, 2013). Nonetheless, the process of monitoring and ensuring compliance proves to be both expensive and challenging, resulting in no assurance that all suggested policies will be effectively implemented. The achievement of REPowerEU goals is not guaranteed, as the EU has a history of somewhat deficient fulfilment of targets in the energy area. Furthermore, the targets are ambitious, especially considering the economic struggles of many European countries today.

Successful implementation of the REPowerEU measures, in combination with the FF55 proposals rely heavily on the rapid and determined adoption of fossil-free technologies. However, various bottlenecks could jeopardise both the deployment of these technologies and the attainment of energy security objectives. These encompass reliance on rare earths, supply chain constraints or limitations, shortages of skilled labour, and financing concerns.

To eliminate reliance on Russian fossil fuels, substantial growth in the shares of renewable energy is deemed necessary in the electricity, transport, and heating sectors. However, based on projections from the IEA, while renewable energy is projected to increase in all three sectors by 2027, none of them are anticipated to reach the levels stipulated in the REPowerEU plan (IEA, 2022d). Appendix F illustrates a comprehensive overview of renewable energy benchmarks in the plan compared to main case and accelerated forecast by the IEA.

If Norway is to achieve its 2030 goals, significant investments in new power production and grid infrastructure are necessary. Pareto Securities' analysis indicates that the investment requirement amounts to 420 billion NOK. Investments in energy efficiency, batteries, and hydrogen come in addition to this. New capacity will come from onshore wind, solar power, and hydropower. However, progress in offshore wind development has been slow, and it is not expected to contribute significantly to the energy mix until 2030. Since the added capacity will generate power intermittently, causing fluctuations, there is a greater need for investment in the grid infrastructure to effectively manage this variable supply (Øystese, 2023).

5.3.5. Understanding the clean energy transition

In context of REPowerEU and other strategies aiming to accelerate the energy transition, it is important to look at what this really entails. The word “transition” is not about stepping away from all types of fossil energy tomorrow, rather it is facilitating the structural changes needed in the energy system to limit global warming and reaching climate targets for all decades to come. Transitioning away from oil and gas towards a sustainable and affordable energy system is the only solution. Despite the IEA’s 2021 warning that the world must steer away from new oil and gas fields if it hopes to achieve net-zero emissions by 2050, Norway remains Europe's most fervent explorer in the field. In fact, between 2012 and 2022, Norway awarded as many exploration licenses as it had between 1965 (when it first began extracting oil) and 2011 (Bindman & Ferris, 2023). However, as renewable energy flourishes throughout Europe, the EU's demand for Norway's oil and gas is expected to decline in the approaching years. A recent report by think tank Oslo Economics confirms these concerns, indicating how the petroleum industry continues to impede the development of green industries by allocating more capital and skilled workers towards it. The authors suggest that Norway could face a shortfall of 100,000 skilled workers in key green industries by 2030. The country's cleantech sector is a promising start, more action is needed to avoid an economic downturn as nations move away from oil and gas (Bindman & Ferris, 2023).

Further, it’s important to note that the energy transition is in fact a process of changing, both on a micro and macro level. It demands individuals to change their behaviour and habits, and governments to create awareness and direct action towards relevant measures. When writing this thesis, we are completely aware that this is a transition and not a quick switch, which needs to be emphasised. Norway’s pace of transitioning is currently not fast enough, and argued to go in the wrong direction as the economy continues to be dominated by the oil and gas industry. The EU implementing initiatives like FF55 and REPowerEU will stimulate to action and potentially weaken Norway’s position as a competitor in the renewable market. Therefore, we acknowledge this action plan to be an opportunity to shifting priorities by transitioning and investing in a green future.

6. Conclusion

Europe's energy dependency demands immediate attention and carries a twofold urgency. Firstly, the climate crisis has been further exacerbated by Russia's invasion of Ukraine, emphasising the need to reduce reliance on fossil fuels and transition to cleaner energy sources. Secondly, the EU's dependence on fossil fuels, which Russia exploits as an economic and political weapon, poses a significant threat to energy security. The ongoing crisis in Europe raises the central question of whether it will act as a catalyst for expediting energy transitions or if short-term policy choices and economic upheaval will hinder progress.

6.1. Essential Takeaways

REPowerEU was introduced as a rapid response to accelerate the transition and reduce dependency on Russian fossil fuels, in response to the invasion of Ukraine. This comprehensive package includes measures targeted at energy conservation, promoting clean energy production, and diversifying energy suppliers withing Europe. Furthermore, it offers financial and legal support to facilitate the establishment of new energy infrastructure and systems. On one hand, the high prices of fossil fuels and alarming emission levels provide compelling incentives to shift away from reliance on these fuels or enhance their efficient utilisation. On the other hand, concerns regarding energy security may lead to renewed investments in the supply and infrastructure of fossil fuels (IEA, 2022h). Balancing these factors is crucial in navigating Europe’s energy landscape and determining the trajectory of its energy transitions.

As more RES are integrated to the grid, the power market is poised to become more decentralised, allowing smaller-scale producers to play a greater role in the energy system. This shift could foster increased competition and potentially result in lower prices, as RETs become more cost-competitive with traditional fossil fuels. Additionally, incentivising investments in renewable projects could lead to job creation and economic growth. REPowerEU holds the potential to accelerate the shift towards clean energy by providing additional funding and support for renewable energy projects. To fully capitalise on the package’s potential, it is vital to promptly finalise it along with other legislative proposals, adopting a market-driven and technology-neutral approach.

Through an analysis of the short-, mid-, and long-term effects of REPowerEU, this research explores the potential implications for Norway's competitiveness in the renewable energy sector. By considering factors such as market dynamics, policy frameworks, and technological advancements, a comprehensive understanding of the potential effects. In the short term, Norway's position within the energy industry can be enhanced by combining hydropower with gas. This strategic integration has the potential to effectively address the challenges posed by fluctuating renewable energy sources and provide a reliable and accessible energy supply. By leveraging the abundant reservoirs for hydropower storage and the flexibility of gas, Norway can better manage the fluctuations in energy supply and demand. This approach not only ensures a more stable and resilient energy system but also contributes to Norway's overall position within the industry.

Furthermore, it is worth noting that Norway's energy sector, thanks to its ample reservoirs, does not heavily rely on additional backup power beyond hydropower. Consequently, the significance of gas as a backup source is relatively limited within the Norwegian context. However, in countries where reliance on emission-intensive production methods like coal or oil is more significant, gas can offer a viable and comparatively less carbon-intensive alternative for backup power, especially when integrating IRES. By further enhancing the security of supply, affordability, and reliability of energy while concurrently strengthening competitiveness, Norway can position itself favourably within the global energy industry. Additionally, the implementation of energy efficiency measures without demand rebounding can contribute making Norwegian industries more competitive and generate spillover effects.

EU climate policy plays a significant role in Norwegian competitiveness in the mid- to long term. It can create opportunities for Norwegian businesses and industries while enabling Norway to contribute to the climate objectives of the EU and other regions. Sustainable utilisation of Norwegian natural resources is crucial for future value creation, job opportunities, and regional development. Promising potentials are discovered for Norway to expand deployment of green hydrogen production, if facilitating policies are implemented, as it is an important part of REPowerEU diversification efforts. Building the necessary infrastructure for transporting hydrogen, as well as for transmitting RE, holds prominent possibilities for future Norwegian value creation and competitiveness. Achieving the goals and targets set forth by the initiative requires smart investments to be integrated into all proposed actions. To achieve the target of reducing emissions by 55% by 2030 and reaching carbon neutrality by 2050, it is imperative to prioritise green investments over fossil fuel investments. This is the opportune moment to shift our focus towards sustainability.

By identifying areas where Norway possesses unique strengths, such as expertise in specific RETs or access to abundant renewable resources, this research highlights the potential for Norway to play a pivotal role in Europe's clean energy transformation. In the short term, Norway serves as a key actor in the EU’s gas diversification measures and contributing to the complete independency of Russia. Looking beyond, Norway is poised to play a crucial role in the efforts of EU extending their energy mix. Nevertheless, the clean energy transition also presents some difficulties. The increasing electrification of society will drive up power demand and potentially result in labour shortages. Skill gaps are already apparent in several sectors, highlighting the need for efficient workforce utilisation. Rapid technological advancements can enhance productivity and mitigate these challenges. Given the rapidly evolving conditions aimed at promoting the green transition, evaluations of profitable endeavours can swiftly alter. Additionally, the reductions in global emissions expected within the next decade will shape future climates. Therefore, it is justifiable for governments to support accelerated global technological advancements and the adoption of new solutions. Although the initial expenses associated with early transformation may be higher due to nascent technologies, the comprehensive evaluation must also consider the indirect costs of inaction.

6.2. Recommendations for Future Research

There are several areas of interest that warrant further research regarding the REPowerEU initiative and EU climate policy’s impact on energy markets, energy sectors and competitiveness. To ensure a comprehensive assessment of the long-term viability of the actions proposed in the plan, further research should focus on the following aspects.

Firstly, conducting in-depth research of the analysis of the financial and legal support provided for the establishment of new renewable infrastructure is essential. This should evaluate the effectiveness of financial instruments, such as subsidies, grants, and tax incentives, in promoting the development of renewable energy. Additionally, it should examine the legal frameworks that facilitate the development and operation of renewable energy facilities. Research has shown that implementing several types of policies simultaneously can result in undesirable results, which highlights the need for evaluation.

Another important area of interest pertains to the challenges and potential conflicts that may arise from accelerating the transition and permitting process, particularly in relation to the Permitting Recommendation. It is crucial to investigate the implications of these processes on the broader climate and nature context, including the potential loss of ecosystems to mitigate negative externalities. Seen as these technologies often intervene with the natural environment, it is important that fast-tracking these projects does not compromise on this.

Furthermore, it is essential to explore the social and environmental implications of the REPowerEU plan, both for member states and for countries that currently serve as alternative suppliers for fossil fuels in the short-term. This research should encompass a comprehensive assessment of the socioeconomic impacts, such as job creation and displacement, as well as the environmental consequences associated with the proposed actions. Identifying potential trade-offs and formulating strategies to maximise positive outcomes while minimising adverse effects will be vital for the long-term success of REPowerEU. Further analysing the potential cross-border synergies of complementary RES can be at interest, as these may accelerate the transition at an even faster page.

Lastly, given that the REPowerEU initiative is an ongoing process, continuous monitoring and assessment is perceived as necessary. Researchers and policymakers should continue regular evaluation of the progress and effectiveness of the proposed actions, while also identifying and addressing any emerging challenges or opportunities. The implementation of political and economic measures may also bring along some unforeseen consequences, and assessing these continuously is viewed as important.

By conducting research in these areas, policymakers and stakeholders can significantly enhance their understanding of climate policy pertaining to energy markets and competitiveness. Increased knowledge will empower them to make well-informed decisions and develop effective strategies for achieving sustainable energy systems. Moreover, such research endeavours will enable policymakers and stakeholders to proactively address potential challenges and optimise positive outcomes in the pursuit for a greener future.

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Appendix A

Scenario trajectories and CO_2 emissions in the World Energy Outlook, 2000-2050

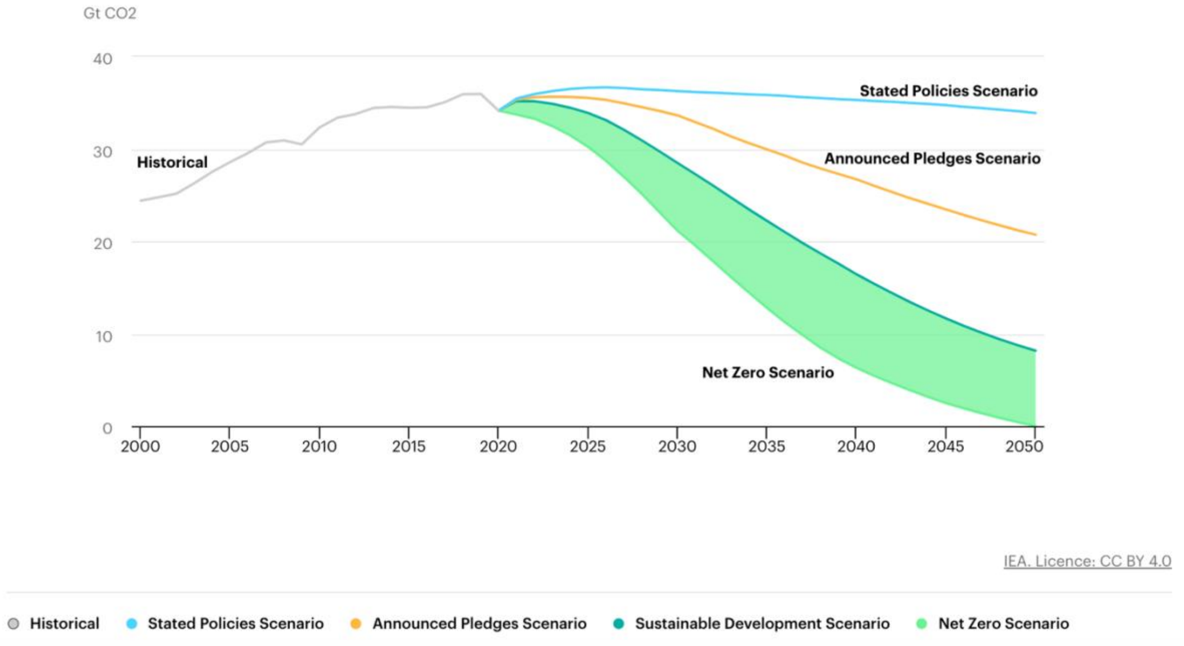

Figure 22: CO_2 emissions in the World Energy Outlook, 2000-2050 (IEA, n.d.-d.)

Appendix B

The EU's diversification away from Russian gas, 2019-2022

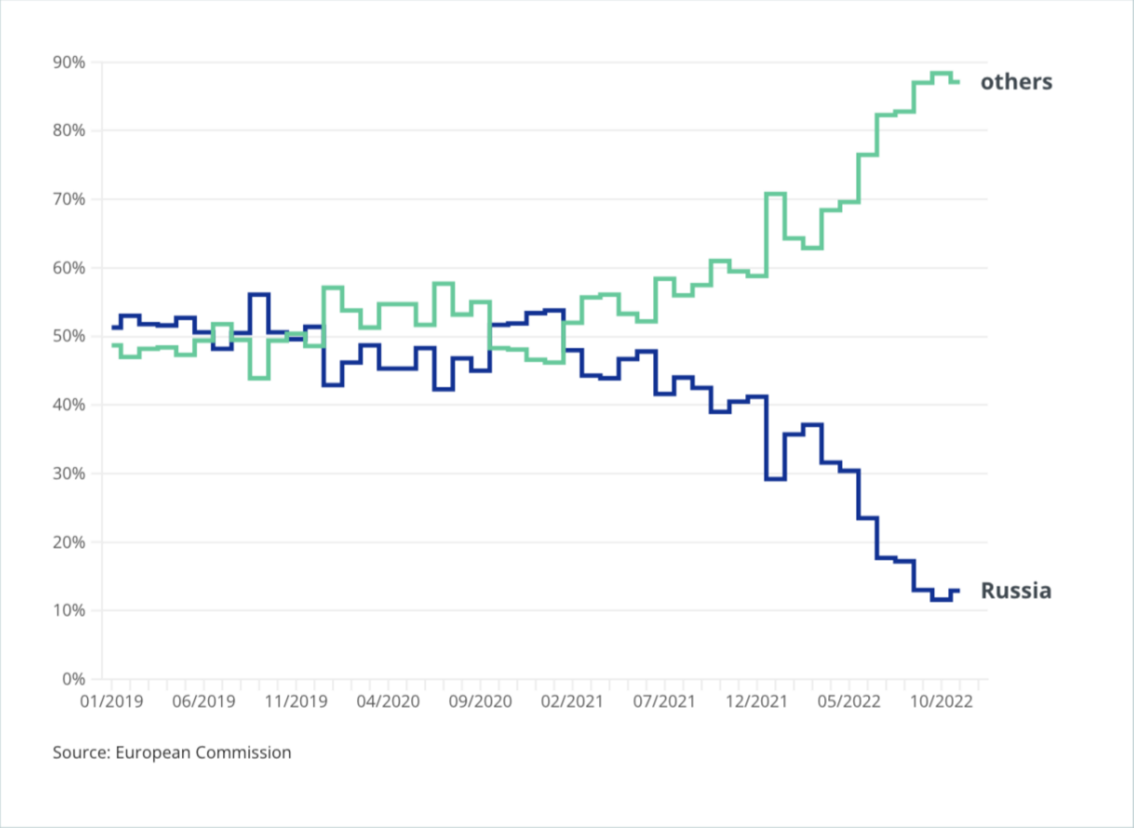

Figure 23: The European Union's diversification away from Russian gas, 2019-2022 (European Commission, 2023d)

The chart shows the monthly share of gas delivered to the EU by Russia compared with other countries between January 2019 and November 2022. From January 2019 to the second half of 2021, Russia maintained a dominant position in the EU gas market, with its share hovering around 50%. However, a notable shift occurred thereafter, leading to a rapid decline in Russia's gas share and the emergence of other suppliers. This trend accelerated throughout 2022 (European Commission, 2023d).

By June 2022, Russia's share of EU gas imports dropped below 20%, and by November of the same year, it reached a mere 12.9%. During the period spanning January to November 2022, Russia, inclusive of pipeline gas and LNG imports, accounted for less than a quarter of the EU's gas imports. Approximately an equal proportion originated from Norway, while Algeria contributed 11.6%. Additionally, LNG imports, excluding Russia, primarily sourced from the United States, Qatar, and Nigeria, represented 25.7% of the EU's gas imports (European Commission, 2023d).

Appendix C

REPowerEU in comparison to EU energy law

Table 3: REPowerEU in comparison to EU energy law (Arthur Cox, 2022).

	Current law under the Clean Energy Package	**FF55 Proposals**	**REPowerEU Proposals**
2030 Renewable Electricity Target (% of gross final energy consumption being met by RE sources)	At least 32%	At least 40%	At least 45%
2030 Energy Efficiency Target (Reduction in energy consumption)	At least 23.5% reduction in both primary and final energy consumption relative to the 2007 Reference Scenario	At least 39% and 36% reduction for primary and final energy consumption respectively relative to the 2007 Reference Scenario*	At least 41.5% and 39% reduction for primary and final energy consumption respectively relative the 2007 Reference Scenario**

**Equivalent to* at least 9% reduction in energy consumption compared to the new 2020 Reference Scenario.

***Equivalent to* at least 13% reduction in energy consumption compared to the 2020 Reference Scenario.

Appendix D

Cost estimates for green hydrogen in 2030, 2040 and 2050

There are various studies that estimate the cost of green hydrogen, and to create our estimates table in chapter 5.2.2, we have used different sources in order to give the most precise depiction.

The estimate for 2030 is based on IEA's (2022y) report "Global Hydrogen Review 2022" and presents a cost raging from 1.18 to 4.08 EUR/kg. This gives an average of 2.63 EUR/kg for green hydrogen.

There are fewer studies providing cost estimates for 2040, but a study by Wood Mackenzie (n.d.) conducted in 2020 expects cost of green hydrogen to drop by up to 64% compared to 2020 prices. We have used two sources to give a price estimate for 2020, which is IEA (2021c) estimating a range from 3.10 to 6.65 EUR/kg and the European Commission (2020a) estimating a range from 2.50 to 5.50 EUR/kg. Taking an average of the 2020 estimated and deducting the 64% reduction in cost, the estimated cost for 2040 is 1.15 EUR/kg.

The estimate for 2050 is by two studies we have found, projected to be below 0.89 EUR/kg (IEA, 2022c; Bloomberg NEF, 2020) in locations where there is potential for RE sources. To be conservative, we have used a cost estimate equal to 0.89 EUR/kg for this time frame.

Appendix E

Investment by 2030 for reaching the REPowerEU objectives

Table 4: Investment by 2030 for reaching the REPowerEU objectives (European Commission, 2022d)

Investment areas	**REPowerEU**	**FF55**	**Difference**
Installed wind capacity (GW)	510	469	41
Installed solar PV capacity (GW)	592	530	62
Net imports of hydrogen (Mt)	6.16	0.05	6.11

Appendix F

Summary of renewable energy benchmarks in REPowerEU plans and main and accelerated cases from the IEA

Table 5: Summary of renewable energy benchmarks in REPowerEU plans and main / accelerated cases from the IEA (IEA, 2022d)

Segment	REPowerEU benchmarks, 2030*	Main case/ accelerated case benchmarks, 2027*
Electricity**	69%	54% / n/a
Solar capacity (GW)	592	396 / 471
Wind capacity (GW)	510	291 /316
Transport***	32%	16% / 20%
Heating and cooling		
Share of renewable energy in heating and cooling	2.3-percentage-point average annual increase to 2030	0.9-percentage-point average annual increase to 2030****
Share of renewable energy in industry	1.9-percentage-point average annual increase to 2030	0.9-percentage-point average annual increase to 2030 ****
Share of renewable energy in buildings sector final energy consumption	60%	32%****

* REPowerEU targets 45% renewable energy share, in combination with numerous other objectives and commitments. EC modelled the package to determine renewable energy shares likely necessary in electricity, transport and heating

** Electricity and transport shares are not REPowerEU targets, but estimates of shares needed to achieve goals in REPowerEU

*** Including RED II multipliers

**** Excluding ambient heat harnessed by heat pumps

Appendix G

Expanded representation of the Norwegian power market system with focus on NO5, Bergen

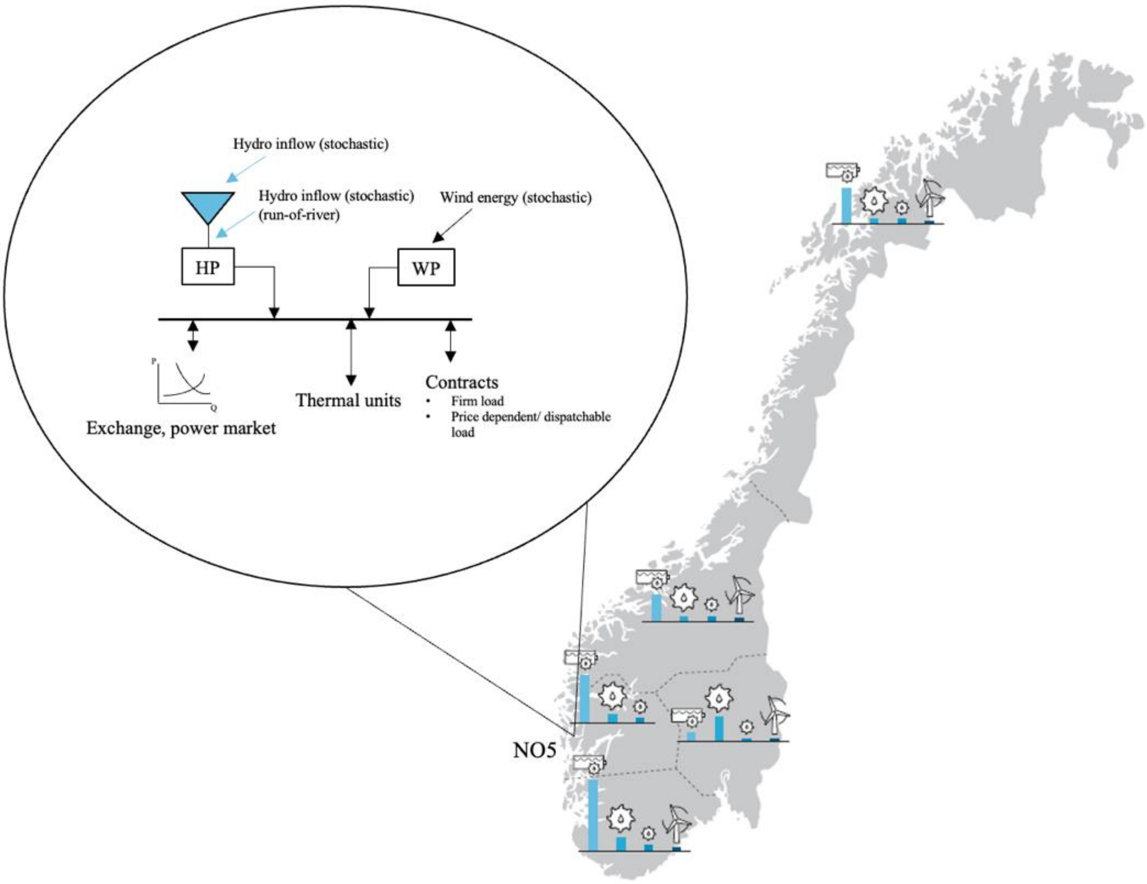

Figure 24: Expanded representation of the Norwegian power market systems with focus on the NO5 area, Bergen (Norwegian Ministry of Petroleum and Energy, n.d.; Vogstad, 2000)