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Abstract

This research paper investigates the impact of energy policies on the energy market in Norway and assesses the possibility of achieving CO2 targets set by Norwegian Ministry of Climate and Environment in the "Norway's Climate Action Plan 2021-2030" using the TIMES (The Integrated MARKAL-EFOM System) model. The TIMES model is a bottom-up framework that minimizes the total discounted cost of the energy system to match the energy services demand at least cost for the area over the definite period. The specific energy policies such as carbon tax increase, EU-ETS price increase, and wind subsidies increase are considered. Our research helps to understand the relationship between energy policies and energy market mechanisms, and CO2 targets.

Our findings show that the CO2 targets set are not attainable under the examined energy policies. According to the most effective policy mix scenario, CO2 emissions will reach 36 million tonnes CO2 equivalents, which is only 32% reduction from the CO2 emissions level of 1990. This implies that further efforts and more effective strategies may be required to achieve desired environmental results.

However, it is important to recognize that there are some limitations in the TIMES model and our research such as the requirement of extensive data inputs, rationality of agents, perfect market conditions, complexity of energy systems and absence of uncertainties. These limitations should be taken into consideration for further studies and analysis to provide more accurate and comprehensive insights.

1 Introduction

1.1. Overview

In this research we evaluate the effectiveness of energy policies that are mentioned in Norway's Climate Action Plan 2021-2030, developed by Norwegian Ministry of Climate and Environment, such as EU-ETS (European Union Emissions Trading System), carbon tax and wind subsidies. The primary reason for the assessment is to understand whether Norway is able to achieve its environmental targets. We will analyze the effects of these policies on the energy market, taking specifically the following vital energy and environmental variables, i.e. energy use, electricity production and CO2 emissions.

In our analysis, we use the TIMES model, which is a modeling framework for energy systems that is used to assess energy technologies and policy scenarios. It is an optimization model that incorporates the whole energy sector and its interactions with the rest of the economy, as well as the trading partners (Loulou et al., 2005).

The TIMES model includes a set of energy technologies, energy sources and energy carriers. This complex model takes into consideration all aspects of the energy market such as energy demand, energy supply, energy conversion process, infrastructure and CO2 emissions caused by the energy sector. With the help of the model it is possible to evaluate the effect of different policy scenarios on the energy system (Loulou et al., 2005).

In our research we will use the VEDA (Visual Environment for Dynamic Analysis) interface in order to run the TIMES model. VEDA is a tool which is used to solve complex economic models for managing data input and generating the results as the model output.

1.2. Motivation

The climate change topic has been playing a vital role in people's lives. The main objective stays the same throughout the years, which is to prevent catastrophic environmental damage and protect the well-being of future generations. According to the Paris Agreement, Norway has ensured to reduce greenhouse gas emissions by at least 50% and towards 55% by 2030 compared to 1990 levels. There are many doubts and concerns from local people related to this target. Questions such as "Is it achievable?" and "Is it within the realm of possibility" and "what are the consequences?" have been under discussion a lot. Hence, it is important to analyze and assess the possibility of achieving this target. This thesis is a contribution to these discussions.

According to Statistics Norway (2022), there has only been a negative change of 4,7% in CO2 emissions from 1990 to 2022. In Norway there are 48.9 and 51.1 million tonnes of CO2 equivalents in 2022 and 1990 respectively. The target of at least 50% by 2030 is equivalent to 25.5 million tonnes of CO2 equivalents in 2030.

It is clear that Norway needs to adopt further policies in order to meet its updated target by 2030. Energy policy and regulation play a crucial role in shaping how energy markets are structured and operate. Norway, a small country abundant in resources, has an extensive history of investing in energy production, including both fossil fuels and renewable sources, and engaging in global energy trade. Norwegian energy policies and regulations have had a significant impact on shaping the energy market, both domestically and globally.

1.3. The research questions

In order to reach the climate targets, the Norwegian government has implemented a number of policies and regulations aimed at supporting the development and deployment of renewable energy sources, adopting energy efficiency measures and reducing national greenhouse gas emissions.

Our research questions are:

- How do the policies and regulations governing the energy market in Norway impact the electricity production, energy use and CO_2 emissions?
- How do these policies potentially achieve environmental targets set in the "Norway's Climate Action Plan for 2021-2030"?

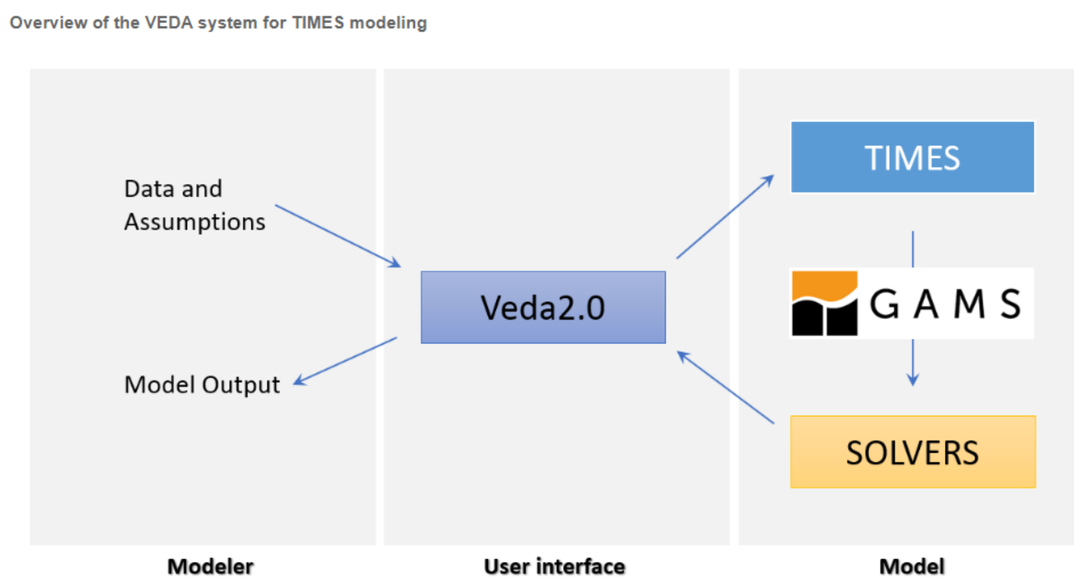
In our research, we examine the ways in which the energy policies and regulations have impacted the energy market in Norway, and discuss the implications for the country's energy mix, economic and environmental development.

To do so, we firstly describe context and framework for conducting the analysis in chapter 2. Then, in chapter 3, we explore the literature on various energy policies and regulations that have been implemented both in Norway and other countries and assess their effectiveness and impact on the energy market. In chapter 4, we introduce methodology and design where we describe the structure, context and mechanics of the TIMES model and depict the assumptions linked to the model. Thereafter, in chapter 5, we go through the economic mechanisms and relevant theories. In chapter 6, we present the model input and design where we explain in detail the model structure and its components. In chapter 7, we show our findings, where we made a split into our scenarios used in the analysis. In chapter 8, we discuss our results through application of various economic theories and concepts. We end the thesis by explaining the limitations of the TIMES model and our research and concluding our notes in chapters 9 and 10.

1.4. The research methodology

As part of our methodology, we use a long-term bottom-up optimization model of the energy system in Norway. This computational model is a detailed techno-economic description of resources, energy carriers, conversion technologies and energy demand estimated to map Norway. The model is called the TIMES modeling framework in the VEDA interface. An overview of the VEDA system for TIMES modeling is shown in Figure 1 below.

Figure 1. Overview of the VEDA system



Source: Amit (2023)

The data and assumptions are entered into VEDA that generates input to the TIMES code.VEDA receives input from many different excel files that contain various structures linked to data intensive models. The TIMES code operates in the GAMS (General Algebraic Modeling System) space and creates the text results. VEDA transfers this into numerical and graphical results. The TIMES model is described in detail in chapter 4 and Appendix 1.

2. Framing the analysis - Essential background

2.1. Introduction

The goal of this master thesis is to evaluate the effectiveness of Norway's Climate Action Plan for 2021 - 2030 through analyzing the effects of three different policy measures on three main output variables: (i) electricity production, (ii) energy use and (iii) CO_2 emissions reduction.

There are a number of energy policies and regulations that have been implemented with the explicit objective of decreasing emissions. After carefully reviewing the report "Norway's Climate Action Plan for 2021-2030" conducted by the Norwegian Ministry of Climate and Environment (2021), the following energy policies are chosen for assessment in our research: (i) a higher price on the European Emission Allowances (EUA's) in the EU-ETS (ii) a higher national carbon tax and (iii) an increase in the wind energy subsidies. The EU-ETS and the national carbon tax policies cover 85% of the total CO_2 emissions in Norway (Norwegian Ministry of Climate and Environment, 2021).

In our research we will analyze the following five different scenarios:

1. **Baseline scenario:** the projection of the electricity production, energy use and CO_2 emissions under the current policy, i.e. 590 NOK per tonne CO_2 in non-ETS sectors and 1130 NOK (590 NOK per tonne is carbon tax plus 540 NOK per tonne in ETS sector (Norwegian Petroleum, 2022), where the baseline year is 2021;
2. **Hike in the national carbon tax:** An increase in the national carbon tax from 590 NOK per tonne to 2000 NOK per tonne in all sectors and its effects on electricity production, energy use and CO_2 emissions;

3. **Hike in the EU-ETS price:** The increase of EU-ETS price from 540 NOK per tonne to 1500 NOK per tonne in the EU-ETS sectors and its effects on electricity production, energy use and CO_2 emissions;
4. **Policy Mix:** The policy mix of scenario (2) and (3);
5. **Subsidize renewable energy:** The wind subsidy is assumed to increase by average of 20% by 2030, its effect on electricity production, energy use and CO_2 emissions, according to our analysis which are based on historical values and assumptions used in NVE (2020);

2.2. Carbon pricing and taxation in Norway

The industry in Norway is divided in four categories in terms of their type of tax obligation:

(i) Sectors that are subject both to CO_2 tax and EU-ETS (petroleum sector);

(ii) Sectors that are subject to just CO_2 tax (transport sector, agriculture*(explained below), construction);

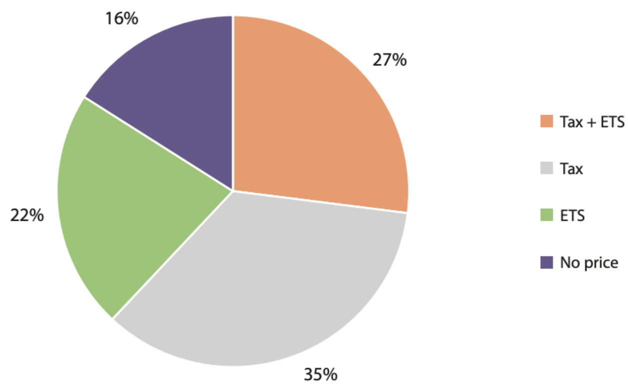
(iii) Sectors that are subject to just EU-ETS (metal industry and international air);

(iv) Sectors that do not pay any carbon price at all (15% of Norwegian emissions, will not be considered in our analysis);

In the Figure 2 below, the proportion of sectors which are covered by different instrument types is presented in the pie chart.

Figure 2. Emissions covered by economic measure by instrument type.

Figure 4.1 Emissions covered by economic measures by instrument type.



Source: Norwegian Ministry of Climate and Environment (2022)

As can be seen, cross-sectoral economic policies such as emission trading and carbon taxes form the basis of the Norwegian climate policy. The emissions trading scheme or GHG taxes cover almost 85% of Norwegian greenhouse gas emissions (Norwegian Ministry of Climate and Environment, 2022).

(i) Mineral oil, petrol and emissions from petroleum extraction and domestic aviation are subject to both a national CO2 tax and are also included in the EU-ETS scheme. The total price on the carbon for these sectors sum to 1130 NOK per tonne in 2021 (Norwegian Ministry of Climate and Environment, 2021). In the scope of our analysis, we will include the petroleum industry.
(ii) In Norway, the tax for non - EU ETS sectors in 2021 is 590 NOK per ton CO2, and it is imposed on uses of mineral oil, petrol, diesel and natural gas. Agriculture is not part of the EU-ETS, and also exempt from taxes for the emission of methane and nitrous oxide. However, the agriculture sector still pays the national carbon tax on their use of mineral oil (Norwegian Ministry of Climate and Environment, 2022). In the scope of our analysis, we will look at the road transport sector, agriculture and construction.

(iii) Fishing in distant waters, chemical reduction or electrolysis, metallurgical and mineralogical processes and international shipping and aviation, as of 2022, are the sectors that are only subject to EU-ETS carbon pricing scheme (Norwegian Ministry of Climate and Environment, 2022). In the scope of our analysis, we will look at the international aviation industry.

(iv) In 2019 Emissions of around 8.8 million ton CO2-equivalent, almost one third of non-ETS emissions were not included in the scope of national taxes on GHG emissions nor in the EU-ETS scheme. Mostly those emissions stemmed from the methane and nitrous oxide emissions in the agriculture sector (Norwegian Ministry of Climate and Environment, 2019). These emissions are not included in our analysis..

As an overview, we present the Norwegian taxes on emissions of greenhouse gasses in 2022 presented in the Table 1 below. The standard tax of 766 NOK per ton of CO2 was set for petrol, mineral oil, natural gas, LPG, HFC and PFC. In addition, there are additional tax implemented for both ETS and non-ETS sectors which vary according to their activities.

Table 1. Norwegian taxes on emissions of greenhouse gasses in 2022

Table 4.1 Norwegian taxes on emissions of greenhouse gases in 2022.

	NOK. per l/Sm³/kg/ ton	NOK. per ton CO_2
CO_2-tax on mineral products		
Petrol	1.78	766
Mineral oil		
Standard rate	2.05	766
Domestic aviation (non-ETS)	1.96	766
Domestic aviation (ETS)[1]	1.61	631
Natural gas		
Standard rate	1.52	766
Use covered by the ETS[1]	0.066	33
Greenhouse industry	0.15	77
LPG		
Standard rate	2.30	766
Use covered by the ETS[1]	0.00	0
Greenhouse industry	0.23	77
Tax on waste incineration		
Non-ETS emissions	106	192
ETS emissions[1]	106	192
Tax on HFC and PFC	-	766
CO_2-tax for offshore petroleum		
Mineral oil[1]	1.65	620
Natural gas[1]	1.65	705
Natural gas emitted to the atmosphere	10.66	766

[1]These emissions are also subject to the EU ETS.

Source: Norwegian Ministry of Climate and Environment (2022)

2.3. The EU-carbon price from the EU-ETS

Around half of the total Norwegian greenhouse emissions are covered by ETS, in 2019 the total ETS emissions amounted to 25.6 million tonnes CO2 equivalent, which mainly comes from oil and gas production and industrial processes (Norwegian Ministry of Climate and Environment, 2021).

The EU-ETS was introduced in 2005, as a tool to commit to the Kyoto Protocol (1997). EU-ETS operates as a cap-and-trade system, with the primary goal of achieving a set reduction target for total CO2 emissions. It is a policy instrument that allows industries to have the option to buy or sell these carbon emission allowances as they see fit, making this mechanism more flexible and cost-effective compared to straightforward emission regulations or standards. As an overview, Figure3 shows the trend for EU-ETS for all the time until June

2023. According to the figure, the EU-ETS price increases dramatically starting from early 2018.

Figure 3. The EU-ETS trend

Source: Eu Carbon Permits (2023).

Similar to the EU-ETS, there was an oversupply of emission allowances compared to the demand in the early stages, leading to a very low price of allowances, close to zero. Nevertheless, this endeavor provided valuable insights and knowledge in terms of allocating, monitoring, reporting, and verifying emissions. Norway started a domestic trading scheme in 2005. Since 2008, Norway has been integrated in the EU-ETS, encompassing approximately 110 to 120 facilities and accounting for around 40% of Norway's total emissions (Hood, 2010). As a member of the European Economic Area, Norway has the opportunity to engage in the European market by incorporating the EU-ETS Directive into its domestic legislation, while also making certain negotiated modifications to accommodate its specific needs.

2.4. The national carbon tax

According to Norway's Action Plan, the Norwegian government targets to gradually increase the CO2 tax from 590 NOK per tonne in 2021 to 2000 NOK per tonne in the non-EU-ETS sector in 2030 (Norwegian Ministry of Climate and Environment, 2021). The ETS applies to petroleum, aviation and industrial production sectors. The Norwegian government aims to increase the total tax for the EU-ETS sectors from 1100 NOK per tonne to 2000 NOK towards 2030.

A CO2 policy instrument is aimed to decrease CO2 emissions by implementing a financial burden on climate change activities. There are several effects on electricity production, energy use and CO2 emissions.

The CO2 tax policy encourages electricity producers to shift towards cleaner energy sources, such as renewable energy. This shift is explained by the intention to avoid increased tax payments linked to electricity production.

The CO2 tax incentivizes both households and industries to reduce their energy consumption or embrace energy-efficient methods and technologies. The increased energy costs caused by the tax policy leads consumers to use energy in an efficient way by modifying the habit to minimize the energy consumption or investing in technologies.

By imposing a financial burden on activities that generate significant amounts of CO2, the CO2 tax policy establishes an economic incentive for energy producers to reduce their CO2 emissions.

2.5. Subsidies to renewable energy

Wind energy subsidies policy instruments provide incentives to adopt wind generation systems and technologies which leads to more electricity production from wind power sources.

Subsidies can increase the development of wind farms which lead to more wind electricity production. This helps in diversifying the energy mix and reducing the dependence on fossil fuels for generating electricity.

Energy costs reduce over time due to wind energy that takes a larger part of the energy mix. In addition, there are relatively low operational costs that can benefit consumers and industry as well.

Wind energy is an environmentally friendly and sustainable energy that produces minimum emissions during electricity generation. Hence, by increasing wind electricity production, subsidies play a vital role in significant reduction of CO_2 emissions.

3. Literature Review: The energy market

3.1. An introduction

Climate change is a global problem that sets up substantial challenges to economies and ecosystems. As the climate continues to incur changes, countries including Norway are implementing climate change mitigation policies aimed at pushing the economy into a green energy transition. To understand how climate policies affect electricity production, energy use and CO_2 emissions , a broader introduction to the energy market in Norway is needed. In this section we go through relevant literature that has studied the energy market in Norway (chapter 3.2), energy policies in general (chapter 3.3) and energy policies in Norway (chapter 3.4).

3.2. Energy market in Norway

Norway has a diverse energy mix, with significant contributions from hydropower, oil and gas, wind and solar. Due to its abundance of oil and natural gas resources and a relatively small population, Norway is able to export a significant portion of its energy production. In 2020, the country exported 87% of the energy it produced (IEA,2022). The vast majority (93%) of Norway's domestic energy production came from natural gas and oil. The total energy production for that year was 208 million tonnes of oil equivalent

(Mtoe), which was 7% more than in 2019, but in line with the average production over the last decade. It is slightly lower than the production in 2010 (IEA,2022). Norway's energy production far exceeded its domestic consumption; domestic production was seven times greater than the total energy consumed domestically. That year, the country produced 10 times more oil and 21 times more natural gas than it needed domestically, and this trend has been increasing over the past two decades (Azizbekov & Kaliyeva, 2023).

Hydropower has long been a major source of energy in Norway, with the country's extensive network of rivers and fjords providing an ideal resource for harnessing the power of water. Oil and gas have also been important sources of energy in Norway, with the country being a significant oil and gas producer and exporter (Azizbekov & Kaliyeva, 2023). In recent years, however, there has been a growing focus on the development of renewable energy sources in Norway, with wind and solar becoming increasingly important contributors to the country's energy mix (Boasson&Jevnaker, (2022).

Energy policies and regulations have played a significant role in shaping this energy mix. The Norwegian government has implemented a range of policies and regulations designed to support the development and deployment of renewable energy sources, including subsidies (named ENØK) and other financial incentives (Azizbekov & Kaliyeva, 2023). These policies have helped to make renewable energy sources more cost-competitive with fossil fuels and have contributed to the growth of the renewable energy sector in Norway (Boasson&Jevnaker, 2022).

In addition to subsidies, the Norwegian government has also implemented a number of regulations designed to adopt and develop energy efficiency and reduce greenhouse gas emissions (Azizbekov & Kaliyeva,2023). These regulations have included building codes, appliance standards, and fuel efficiency standards for vehicles, among others. By setting and imposing penalties for non-compliance, these regulations have helped to reduce energy consumption and emissions in the country.(Boasson&Jevnaker, (2022).

The impact of energy policies and regulations on the energy market in Norway has not been limited to the production of energy. These policies and regulations have also had an impact on the consumption of energy, as they have affected the prices of different energy sources and the behavior of consumers. According to the Norwegian Ministry of Climate and Environment (2021), the implementation of carbon pricing mechanisms, such as a carbon tax or a cap-and-trade system, can increase the price of fossil fuels and make renewable energy sources more competitive. This can lead to a shift in demand towards renewable energy sources and away from fossil fuels, as consumers seek out more cost-effective options (Azizbekov & Kaliyeva, 2023).

By promoting the development and use of renewable energy sources, increasing energy efficiency, and reducing greenhouse gas emissions, the policies and regulations on energy have contributed to the country's energy mix, energy security, and economic development (Azizbekov & Kaliyeva, 2023).

Energy is vital for welfare and prosperity, but at the same time some energy sources have the potential to seriously pollute the environment and alter the climate system. Excessive fossil fuel use depletes natural resources and steadily raises carbon dioxide emissions, which are thought to be the cause of rising world average temperatures. Despite the increasing use of renewable energy sources in many countries due to government subsidies, traditional energy sources and fossil fuels still dominate the electricity generation market, holding about 75% of the market share in the European Union (EU) (A European Green Deal,2019). Hence, the EU strongly decided to lead global efforts to combat climate change. It unveiled the "European Green Deal" in December 2019 which intends to address the growing climate catastrophe by having the EU achieve net-zero greenhouse gas (GHG) emissions by 2050 (Eu, 2019).

According to Azizbekov & Kaliyeva (2023), governments and concerned members of civil society are therefore working to put effective laws and regulations into place in order to prevent such a temperature spike and face the challenges of rising energy demand and environmental damage.

In this research the focus is on the Norwegian economy. Norway is not part of the EU, but the energy policy is closely linked to the EU through the EEA Agreement (Azizbekov & Kaliyeva, 2023).

3.3. Energy policies across countries

In the US and many EU countries, according to Goldthau (2006), a wide range of policy instruments, including feed-in tariffs for the production of renewable energy and tradable emission rights, taxes, and subsidies, have been adopted. The secret to facilitating adequate private finance flowing into clean energy investment is how policy frameworks are properly established. Therefore it is important to understand how efficient frameworks for investing in clean energy are built, as well as the corresponding risk-return structure (Azizbekov & Kaliyeva, 2023).

The need for a sustainable energy policy is motivated by the reduction of carbon emissions (Azizbekov & Kaliyeva, 2023).Many researchers including Goldthau (2006) and Lund (2009) identify three key technological changes that move the country towards sustainable energy development: reducing energy consumption, increasing energy production efficiency, and replacing fossil fuels with various forms of renewable energy. They highlight that many governments adopt and develop policies around these technological changes.

Some previous research workings on energy policy have mostly concentrated on the evolution of a particular energy policy in many nations or the laws and policies governing renewable energy in a particular nation (Azizbekov & Kaliyeva, 2023). Maya-Drysdale et al. (2020) highlight that to provide direction for creating appropriate and efficient energy policies for other countries, it is important to comprehend the evolution of those successive sustainable energy policies in various countries.

Lu et al. (2020) present an overview of sustainable energy policy with a focus on promoting the use of renewable energy by discussing the historical development of energy policy in the United States, Germany, the United Kingdom, Denmark, and China.

The US as an industrial country achieved the peak of increasing emission in 2009 and took the second place among other countries around the world (Mendonca et al.,2009). This led to an increase of penalties from organizations and indignations from society. In order to address these issues, energy policies were developed to regulate the energy sector. The country enacted the Energy Independence and Security Act (EISA) and the Energy Policy Act (EPAct). They passed in the early 2000s and aimed to address the problem by proposing regulations centered on energy conservation and efficiency. The conservation and efficiency measures outlined in the EPAct05 and EISA were divided into four main categories: 1. Provisions aimed at improving energy conservation and efficiency in transportation, 2. Provisions aimed at improving energy conservation and efficiency in buildings, 3. Provisions aimed at improving energy conservation and efficiency in industry, 4. Provisions aimed at improving energy conservation and efficiency in the electric power sector (Lu et al.,2020).

In 2011, the German government implemented the "Energiewende" plan, which aimed to significantly reduce the country's dependence on fossil fuels from 80% to 20% of its energy supply by 2050 (Lu et al.,2020). The plan's main elements include phasing out nuclear energy, decreasing the use of fossil fuels, and significantly increasing energy efficiency (Azizbekov & Kaliyeva, 2023).

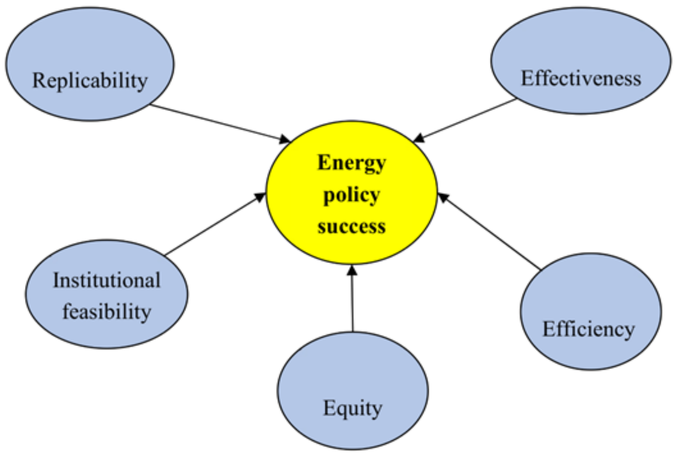
According to Lu et al., (2020), in the UK, in recent years, a number of policy measures have been implemented and revised to promote energy efficiency, such as strengthened building regulations, mandatory energy labeling through certificates like Energy Performance Certificates (EPC) and Display Energy Certificates, and a diverse set of financial incentives and penalties like the Green Deal, Feed-in Tariffs, Energy Efficiency Opportunities Scheme, and Climate Change Levy.

Lu et.al. (2020) state that in Denmark, the way electricity is generated has undergone a change, shifting away from using large, centralized thermal power plants towards using renewable energy sources. The is a pioneer in the development of wind power generation, dating back to Poul la Cour who built a wind turbine for electricity production, effectively kickstarting the modern wind power industry. In 2001, wind power accounted for nearly 12% of the total electricity consumption and by 2005, it was responsible for generating 18.2% of all electricity produced (Mendonca et al.,2009).

Lu et.al. (2020) highlight that building energy consumption has been identified as a major challenge for sustainable development globally and it is predicted to keep rising in the coming years. China has been working on addressing this by implementing systematic design standards for buildings in different climate zones, starting in 1986. These standards include guidelines for the design, construction and acceptance of both residential and public buildings. In addition, the authors imply that in 2017, The National Development and Reform Commission of China released the 13th Five Year Plan for energy development which serves as the foundation for China's energy policy from 2016 to 2020. This plan includes the breakdown of electricity generation from various sources such as coal, natural gas, wind, and solar power. The main focus of this energy policy is to address the imbalance between energy supply and demand, and aims to correct the problem of previous renewable energy policies which focused primarily on building facilities without adequate consideration for usage.(Azizbekov & Kaliyeva, 2023).

Gungah et.al. (2019) highlight that designing and creating an appropriate energy policy scheme is essential as it can have a big impact on economic, environmental, and technological development. The authors also listed five common criteria (see Figure 4) in evaluating the success of a renewable energy policy that have been identified as a benchmark: Effectiveness, Efficiency, Equity, Institutional feasibility and Replicability.

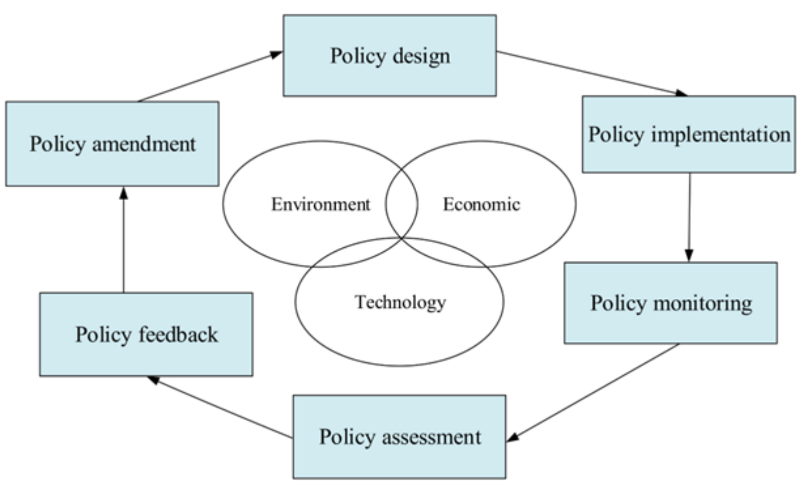
Figure 4. Success criteria of the policy



Source: Gungah et.al. (2019)

They also indicate that a well-crafted policy generally involves a cycle of six major steps: policy design, policy implementation, policy monitoring, policy assessment, policy feedback and policy amendment (see Figure5).

Figure 5. The policy design cycle



Source: Gungah et.al. (2019)

Lu et.al. (2020) state that developing an energy policy requires a thorough examination of the complexity of incorporating new technologies into the system. To design an effective policy, it is crucial to understand the interactions between the various variables that influence decision-making and the potential alternatives. Qudrat-Ullah (2015) presented simulation studies that consist of major modeling methodologies, they are linear programming, econometric methods, partial equilibrium, optimisation, scenario analysis and agent-based. Developing an effective sustainable energy policy requires thorough modeling as it is considered to be a crucial aspect of policy creation (Azizbekov & Kaliyeva, 2023).

Table 2. Major modeling methodologies

Modelling Methodology	Major Themes	Source
Linear programming and dynamic programing	Capacity expansion and energy-economy analysis	WASP model [64], and MARKAL model [65]
A mixed-integer linear program	Distributed energy resource system	MILP model [66]
Econometric methods	Annual energy outlook and the role of carbon capture and storage	NEMS model [67] and SGM model [68]
Partial equilibrium model	Develop the US Climate Action Plan	IDEAS model [69]
Optimisation	Energy-economy interactions and the options for SO_2 control	Meier and Mubayi's model [70] and Islas and Grande' s model [71]
Scenario analysis	Energy policies	Munasinghe and Meier's model [72]
Agent-based	Quantitative support for climate policy formulation and evaluation	ENGAGE model [73]

Source: Qudrat-Ullah (2015).

Many research studies have found that governments and other stakeholders need to take active measures to increase the use of renewable energy and implement effective policy measures, such as incentives and regulations, in order to lower CO2 emissions in their respective countries and regions. (Azizbekov & Kaliyeva, 2023). Maya-Drysdale et al. (2020), by using an analytical framework of crucial components of Strategic Energy Planning for 100% renewable systems, assessed the vision strategy in the EU New Green Deal for the energy planning of eight European cities. Despite their intentions, the cities are not doing a very good job of implementing the vision strategy.

Energy planning is still constrained by the paradigm and traditions of urban planning, which hinders strategic planning and does not work well with the vision strategy (Maya-Drysdale et al.,2020).

One of the renewable energy sources that might have a great renewable energy growth potential is wind energy. Nguyen & Chou(2018) examine the economic aspect of offshore wind energy systems, and analyzes the different government subsidies in order to find out the most effective policy mix in Taiwan, while taking into consideration the investor expectations (The research has found out that the currently applied subsidies in Taiwan, i.e. capital cost subsidy which covers 50% of the capital expenditures is not effective since it is not attractive enough for the investors. Furthermore, the FIT (feed-in-tariffs) in Taiwan are uniformly applied across the country, which in turns leads to a higher profitability for the regions that are highly feasible for the wind turbine systems, and leaves the low feasible regions underprivileged. That implies that imposing the FIT uniformly across all regions is not optimal, and doesn't incentivise the low feasible regions in investing into wind turbines (Nguyen & Chou, 2018).
The authors suggest addressing these deficiencies by introducing the VAT decrease of 10%, which was found to be more attractive for the investors, resulting in a higher IRR (Internal Rate of Return) than the investor expectations. Moreover, they propose to introduce the regional FIT subsidies which would take into account the feasibility of the region, i.e. lower FIT tariffs for the medium and high feasible regions, and higher tariffs for the low-feasibility regions. According to this research, such a policy mix would substantially reduce the installation cost and therefore would make investing in renewable energy more attractive (Nguyen & Chou, 2018).

In another paper "Effect of government subsidies on renewable energy investments: The threshold effect", Yang et al. (2019) analyzed the effect of the government subsidies on the 92 energy listed enterprises in China over the period of 2007-2016. Compared to the study made by Nguyen Thi Anh Tuyet and Shuo-Yan Chou, this study emphasizes that government subsidies play a significant role in promoting renewable energy investments. However, they discuss the threshold effect of the government subsidies, that is the effectiveness of the policy depends on a certain threshold of different economic variables. (Yang et al., 2019)

Subsidies are effective when the energy consumption and the bank credit exceed a certain threshold, as well as when the economic development is below a threshold. Furthermore, tax incentives are more efficient in promoting renewable energy investment compared to the government subsidies when the energy consumption intensity surpasses the certain threshold. The government subsidy has a large effect on the large enterprises when the bank credits exceed the threshold, the effect on the medium and small enterprises is significant regardless of any threshold level (Yang et al., 2019).

The research suggests the main policy implications, the government subsidies should be largely used to promote renewable energy investments. One of the policy implications is consistent with the research by Nguyen Thi Anh Tuyet and Shuo-Yan Chou, and suggests tailored subsidy policies based on regions, i.e. implementing higher subsidies for the regions where there is higher energy conversion costs, higher energy consumption intensity and lower economic development. Such tailored subsidies will promote renewable energy investments with the lower feasible regions. Additionally, the research paper encourages governments to focus on enterprises of all sizes, including large, medium, and micro enterprises in order to promote renewable energy investments (Yang et al., 2019).

3.4. Energy policies in Norway

3.4.1. The effect of the EU-ETS in the literature

Skjærseth & Wettestad (2009) qualitatively assessed the consequences of implementation of EU-ETS. They found out that it can be explained by considering the decentralized nature of the system and its growing connections to the Kyoto Protocol. Issues such as excessive allocation of CO2 emission allowances and uncertainty regarding the environmental goals of the system within the EU region have emerged. However, the EU has made efforts to address these challenges by progressively enhancing harmonization, reducing proposed national allocation plans, and introducing a revised directive for the period 2012-2020 in a 2008 Commission proposal. A crucial aspect of this proposal is establishing a total cap at the EU level to ensure a limited supply of allowances in the market and a higher level of environmental ambition. In addition, the authors highlight that if the crisis persists and leads to a prolonged economic downturn that consistently drives down carbon prices, it could significantly undermine the incentive impact of the EU-ETS climate policy.

3.4.2. The reduction of energy use and applicable policies

Simonsen et al. (2022) in their recent paper analyzed the energy use of households in Norway, they attempted to explain the patterns of energy use in the period from 1990 to 2019, and gave suggestions of policies to reduce households' energy use. Norway aims at reducing the energy use in existing buildings by 10 TWh by 2030 compared to 2016 levels, the goal which was presented by the Norwegian Parliament. This paper gives a valuable insight into possible policies that could be implemented in order to decrease households' energy use, and investigates whether it is possible to achieve the goal given Norwegian realities (Azizbekov& Kaliyeva, 2023).

Although Norway has an advantage of benefitting from renewable energy sources, reducing energy use and increasing energy efficiency still brings about other advantages (Azizbekov & Kaliyeva, 2023). The potential reduction of 10 TWh can cover the whole Norwegian passenger car fleet, a large contributor of GHG in Norway, emitting 4,4 MT CO2 gasses and accounting for 8,6 % of the total emissions in Norway. (Simonsen et al.,2022). Apart from that, the saved energy can also be used in the Norwegian industry or can be exported to substitute CO2 intensive fossil fuels in other countries (Simonsen et al., 2022).

Authors, therefore, argue that energy efficiency in Norway is highly relevant in terms of contributing to a greener future both domestically and internationally.

Norwegian household stationary energy use from 1970 to 1990 indicates quite high growth (2,4%) compared to the growth level between 1990 to 2019 (0,15%), actual outcome in 2019 being 45.9 TWh, almost 2 times less energy use outcome than if we projected the steady growth rate since 1970 (Simonsen et al., 2022). Authors of the paper attempt to explain such drop in growth of the energy use in the past three decades, and their findings showed that main reasons are lower growth in dwelling area, which in turn can be explained by rises in real estate prices, the non-western immigration inflow and smaller household sizes (Azizbekov & Kaliyeva, 2023).

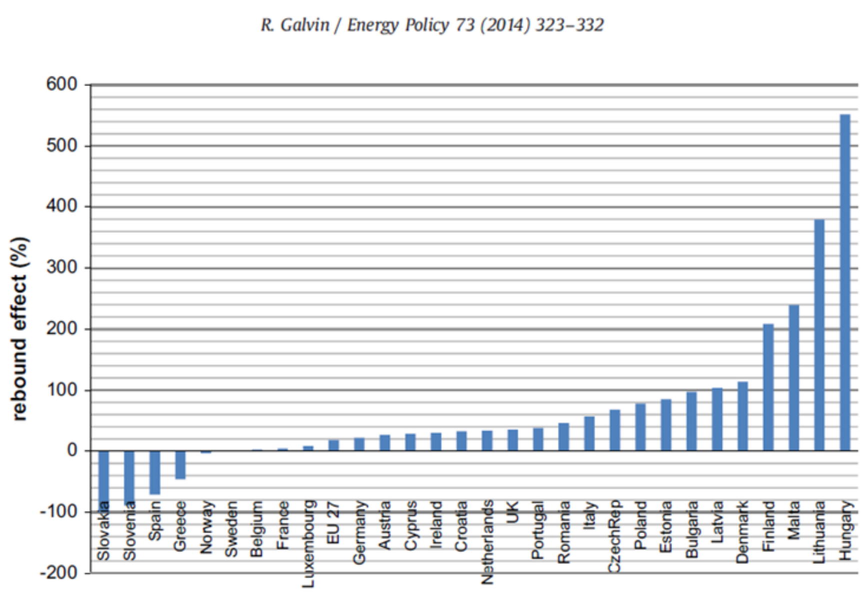
Authors looked at different scenarios of energy policies that could lead to the highest reductions in the energy use. They concluded that it should be a mix of policies, among which the reallocation of dwelling areas from detached houses to flats play a major role (Simonsen et al., 2022). Another suggestion for the policy based on authors' findings is the requirement to reduce heating demand by 1.5% annually through renovation, which will lead to 1.9 TWh reduction in energy use by 2030. However, by 2028 it is projected that in Norway 95% of car coverage will be electric cars and 5% plug-in hybrids, which will result in an increase of energy use by 5.7 TWh (Simonsen et al., 2022). Therefore, authors argue that the reduction of energy use induced through the introduction of policies will be offset by higher energy use related to electric cars (Azizbekov & Kaliyeva, 2023).

Even though, energy efficiency measures in most of the cases imply that that it will lead to a lower energy consumption levels, Galvin (2014),in his paper "Estimating broad-brush rebound effects for household energy consumption in the EU 28 countries and Norway: some policy implications of Odyssee data", argues the contrary, and tests whether there is a rebound effect from the energy efficiency measures. Many EU countries set the goal to increase energy efficiency in the residential buildings to achieve their long-term goals of net-zero emissions. However, findings in this current paper show that the consequences of such measures are not straightforward (Galvin, 2014). Galvin investigated the energy efficiency and energy consumption of 28 EU countries and Norway from Odyssey database from 2000 to 2011 to find out the correlation between the two. It is of particular interest for us to look to which extent energy efficiency policies are effective in Norway, and to determine whether it is exposed to rebound effect.(Azizbekov & Kaliyeva, 2023).

3.4.2.1. The rebound effect of the energy efficiency measures

Rebound effect in the paper was defined as "the energy efficiency elasticity of energy services", and is given as a ratio of percentage change of energy services consumption and percentage change in energy efficiency. The assumption in the paper is that the energy efficiency measures encourage households to use even more energy, i.e. "exploit" the energy efficiency, which results in the rebound effect (Azizbekov & Kaliyeva, 2023).

Figure 6 . The rebound effect of the energy efficiency measures



Source: (Galvin, 2014).

Findings, indeed, indicate that for some EU countries the rebound effect is quite high, reaching 550%, which was the case in Hungary. However, Norway and Sweden, as well as Belgium, France and Luxembourg exhibit a very low rebound effect. In fact, for Norway the rebound effect is negative (-3,5%), which suggests that the energy efficiency measures are somewhat effective, and lead to a reduction in energy consumption. (Galvin, 2014). The results can be seen in Figure 6 . The rebound effect of the energy efficiency measures.

3.4.3. The effect of policies on the renewable energy production

Following the energy efficiency flow of discussion, Rosenberg et al. (2013) investigates how the projections of future energy demand can affect the renewable energy production in Norway. Furthermore, based on the TIMES-model authors attempt to suggest the most cost-optimal energy system for Norway taking into account increased energy demand (Azizbekov & Kaliyeva, 2023).

Since the future energy demand is uncertain, authors made forecasts of the future renewable energy production based on different scenarios of the long-term energy demand. TIMES-model, which was developed as part of the implementation of IEA(International Energy Agency) agreement, was used in order to find the response of the renewable sector to the changes in the electricity demand (Rosenberg et al., 2013). The model is the cost-optimization model that predicts the optimal energy system to meet the future demand (Azizbekov & Kaliyeva, 2023). The model incorporates in itself energy efficiency measures such as better insulation in new buildings and others.

Authors concluded that decreased energy demand leads to a higher renewable energy fraction, whereas increased energy demand leads to higher renewable energy production. Therefore Rosenberg et al. (2013) suggest that in order to achieve a higher renewable energy fraction the demand for energy services should be reduced and energy efficiency should be increased.

Furthermore, for Norway achieving renewable energy targets have several implications such as higher investments in the wind power sector and an increase of electricity export (Rosenberg et al., 2013). However, electricity export depends on the electricity prices in the countries that Norway trades with, which is not taken into account in this model (Azizbekov & Kaliyeva, 2023).

3.4.4. The effect of the carbon tax in the literature

One of the widely used energy policy tools in Norway is a CO2 tax. In the research paper "Greenhouse gas emissions in Norway: do carbon taxes work?" Annegrete Bruvoll and Bodil Merethe Larsen attempted to investigate the effect of the increased carbon taxes in Norway from 1990 to 1999 on the carbon emissions. Norway is one of the leading advocates of the carbon taxes, and has one of the highest tax rates for the carbon emissions, in the period from 1990 to 1999 the highest tax level was 51 USD per tonne. Despite the common perception that the carbon taxes is an effective tool, the current study established that the effect of the carbon taxes on the emissions reduction during 1990 -1999 was quite modest, resulting in a 2.3 percent reduction of national CO2 emissions (Bruvoll and Merethe Larsen, 2004).

Over this period average emissions per unit GDP has decreased by 14 percent, the main factors that led to such a decrease were more efficient use of energy and shift from the fossil fuels to less carbon-intensive energy. The effect of the carbon tax on the emissions reduction is primarily due to the oil and gas sector, which contributed to 1.5 percent of CO2 reduction. The main reasons for the limited effect of the taxes on the CO2 emissions reduction was the exemption of the high carbon intensive industries from the carbon tax. The process industries are exempt from the carbon taxes, hence, there is almost zero effect of the carbon taxes on the process related CO2 emissions. The metal and industrial chemicals sector are carbon tax exempt primarily due to the fact that otherwise they would be unprofitable. Authors suggest that the uniform taxation for all GHG sources, and the mix of different regulations would lead to a larger reduction of the CO2 emissions. With regards to the tax on gasoline, it is quite high, 13 percent of the purchase price. However, authors argue that the substitution possibility from the gasoline run cars to more energy efficient cars for the households is quite limited, which can be explained by different factors, including the availability and the affordability of the alternatives. (Bruvoll and Merethe Larsen, 2004)

Statistics Norway conducted the analysis of the impact of the increased CO2 taxes on the emissions and the Norwegian economy. R. Kaushal and Yonezawa (2022) analyze how a CO2 tax increase to NOK 2000 per tonne CO2 in 2030 in the non-ETS sector affects the leisure/labor supply, private consumption and welfare compared to the reference scenario where the CO2 tax remains unchanged since the 2022 level. A few counterfactual scenarios were examined, one of them is that the revenue from the CO2 taxes is returned to households as a lump sum, the second scenario is the carbon tax would be "recycled", and would lead to a reduction in the labor tax. The third scenario is exempting the road sector by 50% of the carbon tax, i.e. the road sector is charged only NOK 1000. Such an increase of the taxes towards 2030 led to the CO2 reduction of more than 9% compared to the reference scenario. This paper in comparison to the paper by Annegrete Bruvoll and Bodil Merethe Larsen demonstrates a higher effectiveness of the carbon taxes. Furthermore, the current paper in comparison to the previous paper also emphasizes that the level of gasoline and diesel consumption would lead to a high reduction in the CO2 emissions, precisely by 17%. It might be because the report estimates the hypothetical forecast, and didn't take into the account that the agents are not that flexible between choosing the gasoline run cars and the green alternatives. According to the report, the most effective policy is achieved through recycling the CO2 carbon taxes into the lower labor income tax, which has a positive effect on the economy overall (R. Kaushal and Yonezawa, 2022).

3.4.5. Other decarbonization policies in Norway

Whereas most papers discuss how to achieve Renewable energy targets through introduction of new technologies, this paper gives an useful insight into how they can be achieved if we include the future energy demand in the model. Furthermore, authors suggest that the model can be developed further to include the impact of different precipitation and climate change on the production of electricity from hydropower, which is highly relevant for the case of Norway. (Azizbekov & Kaliyeva, 2023).

As Norway updated its Nationally Determined Contribution (NDC) to cut GHG gases by at least 50% compared to 1990 levels by 2030 and set a goal to reach carbon-neutrality by 2050, it is vital for Norway to assess different decarbonization policies both in transportation sector and industries which are the most effective. Zhou et al. (2022) analyzes the energy system that is most optimal for the largest mainland island in Norway, Hinnøya under 5 different scenarios.

Government has already introduced some decarbonization policies such as CO2 taxes on fossil fuels, and incentives for electric vehicles. These policies lay a fundament for a baseline scenario, i.e., current policies will persist for the coming years. The second scenario includes an additional policy instrument, which is the ban for fossil fuel cars from 2025. Third scenario suggests the increase of carbon tax from 545 NOK to 2000 NOK per ton CO2 by 2030. The most rigid scenario is the combination of the second and third scenarios, implying both the ban for fossil fuel cars and the ICT (incremental carbon tax) increase. The fifth scenario is the reduction of electricity imports by 50% by 2050 compared to the baseline scenario (Zhou et al., 2022).

Results from the studies show that the baseline model exhibits the largest energy supply growth with an average annual rate of 0.6%. The best results in terms of the least energy supply growth is achieved through the fourth scenario, that is the combination of all the climate policies, giving the result of an average annual growth of energy supply of 0.4%. The latter policy leads to a higher electrification in both transportation and offshore industries (Zhou et al., 2022).

Findings of the current paper also demonstrate that keeping the current policies will result in 30% CO2 reduction by 2050, whereas the rigid policies such forbidding fossil fuel cars in 2025 will result in 28% reduction of CO2 emissions already by 2030, and 80 % decrease by 2050. Therefore, authors suggest that for Norway to reach its carbon-neutrality targets by 2050 that more stringent policy instruments have to be introduced (Zhou et al., 2022).

Norway has already achieved high results in increasing EV's share thanks to strong incentives and low electricity prices. However, electrification of heavy-transport sectors and industries is still a challenging task, since it is correlated with the high battery costs. Hence, the overarching decarbonization pathway in the transportation sector should include technological advancement in the production of batteries, as well as considering alternative technologies such as hydrogen-based routes (Zhou et al., 2022).

The authors also suggest that to provide energy supply security, Norwegian islands should reduce their reliance on the mainland electricity sources, and develop their local renewable energy sources.

4. Research Methodology and Design

4.1. The contents and mechanics of the TIMES model

The TIMES model is a modeling framework for energy systems that is used to assess energy technologies and policy scenarios. It is an optimization model that incorporates the whole energy sector and its interactions with the rest of the economy, as well as the trading partners (Loulou et al., 2005).

The TIMES model includes a set of energy technologies, energy sources and energy carriers. This complex model takes into consideration all aspects of the energy market such as energy demand, energy supply, energy conversion process, infrastructure and CO2 emissions caused by the energy sector. With the help of the model it is possible to evaluate the effect of different policy scenarios on the energy system (Loulou et al., 2005).

TIMES is a "bottom-up" model, which means that it is *technology explicit*, and focuses on the different aspects of the energy system of the economy. In "the bottom-up" model each technology used in the energy system is described by several characteristics including its inputs, outputs, unit costs and several other technical and economic characteristics.

The TIMES energy economy consists of four types of inputs, (i) energy service demands, (ii)primary resource potentials, (iii) a policy setting, and (iv) description of a set of technologies.

4.1.1 The Demand component of a TIMES model

The Demand drivers such as GDP, population, family units, etc. in TIMES are derived externally from other models. The reference demand scenario is constructed by computing the demands of a set of energy service demands over a time horizon. In order to do so, every energy service demand is determined as a function of elasticities of demand to the respective drivers.

$$Demand = Driver^{Elasticity}$$

The demands have to be determined only for the reference scenario. TIMES is able to estimate the response of demands subject to counterfactual scenarios. In order to do that, another set of inputs should be identified, that is the elasticities of the demands to its own price. In conclusion, the demand component of the TIMES model is determined by the externally obtained demand drivers, and by the elasticities of demand to those drivers and their own prices.

4.1.2. The Supply component of a TIMES model

The supply component of the TIMES model consists of supply curves of different primary resources (oil, coal, etc.), and they are modeled in TIMES as the potential of resources available at a certain price, sometimes they can be modeled as the cumulative potential of the resource over a time horizon (e.g. reserve of crude oil, gas, etc.).

4.1.3. The Policy component of a TIMES model

The policy scenario component is the integral part of the TIMES model as long as the policy affects the energy system. Due to the fact that the TIMES model is a technology rich model, the policy scenarios can be micro based, (e.g. targeted subsidies to groups of technologies), or they can be broad policies (carbon tax, or permit trading system). Other examples of the policy scenarios that can be incorporated are the tax levy on fuels, or industrial subsidies.

4.1.4. The Techno-economic component of TIMES model

The last component of the TIMES model is the technical and economic parameters of the technologies necessary for the conversion of primary resources into energy services. TIMES is a technology rich model, which means there are various technologies available for the model to choose, and each technology is described in detail, for example their efficiency levels, capacities and so on. Such a comprehensive description of the technologies is one of the main features of Bottom-up models such as TIMES.

4.2. The basic structure of the TIMES model

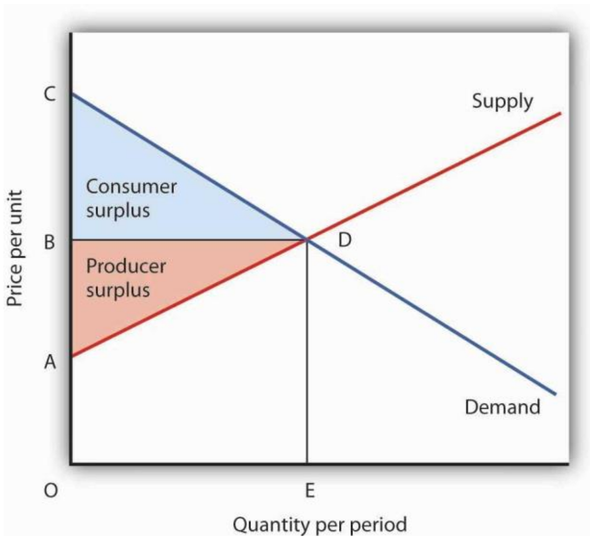
The TIMES energy economy consists from the producers and consumers of commodities:

- Energy carriers, i.e. electricity, coal, natural gas, petroleum products, biomass, hydrogen, etc.
- Materials

- Energy services, i.e. lighting , heating, transportation, industrial processes, etc.
- Emissions

The TIMES model finds the supply-demand equilibrium which maximizes the total surplus (the producers' surplus + consumers' surplus), while satisfying various constraints, see Figure 7.

Figure 7. The equilibrium where consumers' and producers' surplus is maximized.



Source: University of Minnesota Libraries Publishing (2016)

4.2.1. The Reference Energy System (RES)

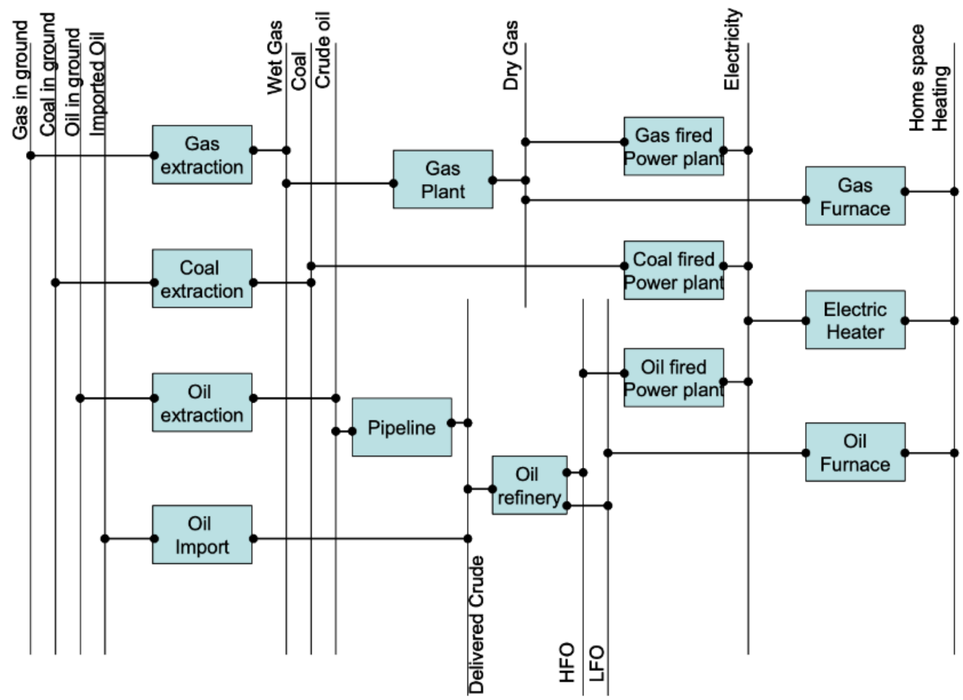
The TIMES energy economy includes three types of entities:

- *Technologies (or processes)* are the physical devices that are able to transform commodities from one form into another. Examples of such technologies can be mining, import processes, or conversion technologies such as plants that produce electricity, refineries, end-use demand devices such as heating systems, transport, etc.
- *Commodities* are everything that is included in the energy system such as energy carriers, energy services, emissions, materials. These commodities can be consumed by certain processes, and can be produced by certain other processes.

- *Commodity flows* are the bridge between commodities and the technologies. They are certain commodities that are attached to a specific technology, and serve either as an input or as an output for that technology.

The example of such a Reference Energy System for residential space heating can be seen in the *Figure 8* below.

Figure 8. RES for a residential space heating



Source: Loulou et al. (2016)

The processes are represented in the blue boxes, the commodities used in the heating energy service are represented as the vertical lines (electricity, wet gas, coal, crude oil, etc.). The commodity flows are the links between process boxes and commodity lines.

4.3. Economic interpretation of the TIMES model

4.3.1. Introduction

TIMES is a partial equilibrium model. At the core it maximizes total surplus (sum of producers' and consumers' surpluses) in one market. In our context that single market is the energy market, assuming the rest of the economy is fixed. A common feature of partial equilibrium models is that it configures at the same time the production and consumption of commodities (i.e. fuels, materials, and energy services) and their prices. The cost of producing the commodity will affect the demand for the commodity, whereas changes in demand for the commodity can affect the price for it. The market is at equilibrium at price p* and quantity q*, where consumers don’t wish to buy more, and producers don't wish to produce more.

This equilibrium concept is applied at every stage of the energy system, i.e. primary energy resources, secondary energy forms, and energy services.
The mathematical properties, and the underlying simplifying assumptions, of the TIMES model is as follows:

1. Output of a process/ technology are the linear functions of its inputs (4.4.2);
2. Total surplus is maximized over the whole time horizon (4.4.3);
3. Energy markets are competitive, and there is perfect foresight (4.4.4);
4. The market price of a commodity equals its marginal value (4.4.5);
5. Each economic agent, i.e. producer and consumer, maximizes its profit and utility respectively (4.4.6).

4.3.2. Input-to-output relationship

Inputs of the technology can be any commodity that can be converted into another commodity, and the linearity of the input-to-output relationship means that the technology within the energy system can be implemented at any capacity, and there will be no *economies of scale*[1] or diseconomies of scale.

Due to such a linearity feature of the TIMES equilibrium the optimization problem can be solved by using the Linear Programming techniques.

[1] Economies of scale is the concept in economics which refers to when the businesses produce more, the more cost-effective it becomes to produce.

However, it is important to note that even though the equations in the TIMES are linear, production functions don't necessarily behave in the linear fashion. The linearity assumption is a crucial simplification.

4.3.3. Total economic surplus maximization: Equivalence principle

The total surplus is the sum of the consumers' and producers' surpluses. The supplier is an economic agent that produces an energy commodity such as energy form, a material, an emission permit, and energy services. A consumer is a buyer of commodities. In the TIMES model we can regard the consumers and producers as the *technologies* that produce and consume *commodities.*
In microeconomics the set of suppliers of commodities are represented by the *inverse production function*, where the marginal production cost of a commodity (vertical axis) is given as a function of the quantity supplied (horizontal axis). As can be seen in *Figure 9* the supply (inverse production) function is the step-wise constant and rising as the Q increases.
The intuition behind the stepwise supply and demand curves:
In the context of TIMES model such a pattern can be explained as follows: As the quantity of the commodity increases, the depletion of one or more resource components in the mix, whether due to limited technological potential or resource availability, results in higher costs associated with deploying alternative technologies to meet the growing energy demand. Each step in the supply function is a new set of technology/energy production methods. The technologies are sorted related to costs because the market will deploy the cheapest production methods first. Therefore, as the quantity is increasing, we observe a higher unit cost. The width of the step is determined by the extent/amount of the technological potential or resource availability.

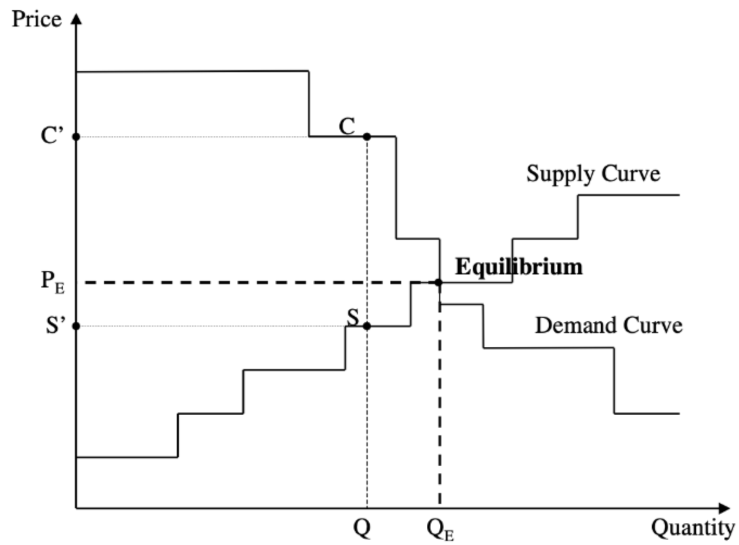
The demands in the TIMES model can be divided into two categories: (i) the stepwise demand for the *energy carriers* is constructed implicitly within the model endogenously, see *Figure 9* (ii) the continuous demand for the *energy service* is defined by the user by determining the price elasticity of the energy service to its own price, see *Figure 10*. The supply-demand equilibrium is at the intersection of supply and demand curves at the point P(E) and Q(E), equilibrium price and equilibrium quantity. As can be seen from the figure 9, the consumers' and producers' surpluses are maximized when the supply-demand equilibrium is satisfied. That is the definition of the Equivalence Theorem in the context of TIMES.(Loulou et al., 2016).

4.3.4. Stepwise representation of supply and demand curves in TIMES model

In TIMES model the representation of the supply and demand curves for the energy carriers and energy services is stepwise in order to increase the computational efficiency and at the same time depict the general behavior of energy markets. The supply and demand curves for the energy carriers are discretized into a finite number of points or steps rather than being continuously variable, and each step is the representation of different production methods/technologies required to produce the certain energy carrier. Apart from the computational efficiency, the stepwise supply and demand curves provide a fairly good approximation of the energy market dynamics without having to model every small fluctuation or price point. It incorporates the overall trends and the main features of how the supply and demand curves respond to changes in the energy market.

The difference between the demand curves for the energy carriers and the energy services is a specific feature of the TIMES model due to the fact that the demand for the energy carriers is computed endogenously and the demand for the energy services is defined by the user.

Figure 9. Supply and demand curves in TIMES with demand for energy carriers.



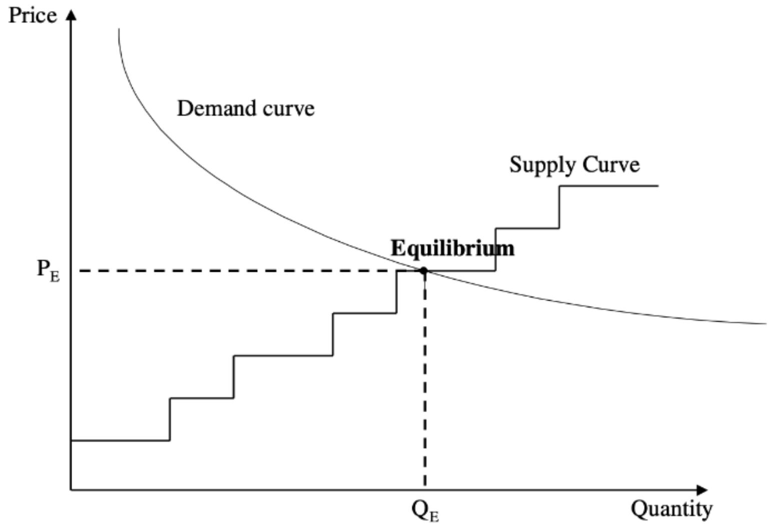
Source: Loulou et al. (2016)

For the energy services the user explicitly defines in the demand function the price elasticity.

$$D/D_0 = (P/P_0)^E$$

$\{D_0, P_o\}$ is the reference demand and price values for the energy service, and E is the negative own price elasticity of demand of that energy service. This pair is calculated by solving the equilibrium for the reference scenario.

Figure 10. Supply and demand curves in TIMES with demand for energy service.



Source: Loulou et al. (2016)

4.3.5. Competitive energy markets

In the TIMES model all economic agents, both consumers and producers, are competitive with perfect information, meaning that they don’t have a power to affect the market price. This is a simplification, as there are several actors within the fossil fuel market that have the market power to affect the price. We do not consider the implications of market power in our analysis.

According to the foundational microeconomics theory, in the competitive market the market price equals marginal cost (marginal value in case of the TIMES model).
All the economic agents have a complete knowledge of the market, in the present and in the future. Therefore, the total surplus is solved for all periods at once, and such an equilibrium is called intertemporal equilibrium or *clairvoyant equilibrium* (Loulou et al., 2016).

4.3.6. Commodity price - marginal value pricing

As we have already established, there is an equilibrium at the intersection of supply and demand curves in the TIMES model, where the equilibrium price is equal to the marginal value of a commodity. In the case of TIMES model it is more relevant to call such pricing as marginal value pricing rather than marginal cost pricing. See *Figure 10*, the price is determined by demand rather than supply, and the equilibrium price is not equal to the marginal supply cost. Furthermore, such marginal value pricing does not mean that firms make zero profits, and the profit is equal to the producers' surplus (Loulou et. al, 2016).

4.3.7. Profit maximization

In the TIMES model, not only is there a maximization of total surplus but also every economic agent maximizes its own profit and utility, which is consistent with rational agents and the "Invisible hand" property of the competitive markets. This is only valid when the market is competitive, and none of the economic agents can affect the market price, in other words, they are price takers. In real life, however, that is not always the case, as for example large oil producers can affect the oil prices. Sometimes, some monopolies can be price takers if there is a state regulation for the price, for example electricity producers.

4.4. Assumptions in the TIMES model

It is essential to mention that the TIMES model includes some simplifications and assumptions for the computational efficiency. However, they don't necessarily reflect all the complexity of the energy systems in the real world. Some of the assumptions are listed below:

1. Perfect foresight - all the economic agents in the TIMES model have complete information about the future developments, and therefore take the most optimal decisions. In reality, there is a lot of uncertainty and incomplete information in decision-making, and future events are difficult to predict.
2. Perfect competition - the TIMES model assumes that there is a perfect competition, and all the economic agents are the price takers. The model ignores the possible market distortions, monopolies, and other factors that impact the energy market dynamics in the real world.

3. Linear relationships - in the TIMES model there is typically the linear relationship between inputs and outputs, for example there is a linear relationship between the investment in a certain technology and its generation.
4. Static technology characteristics - TIMES model assumes that the technology parameters such as costs, efficiencies and performance parameters don’t change over time. This is not realistic, since over time the technologies advance and they become more efficient.
5. Homogenous market, all the energy carriers are substitutes as long as they contribute to meet the certain demand for energy services. However, they might not be the perfect substitutes since the cost of producing one energy carrier can be greater than producing another one. Therefore, the TIMES model chooses the most cost optimal energy mix to meet the demand.

5. Relevant economic theory

5.1. Carbon taxes

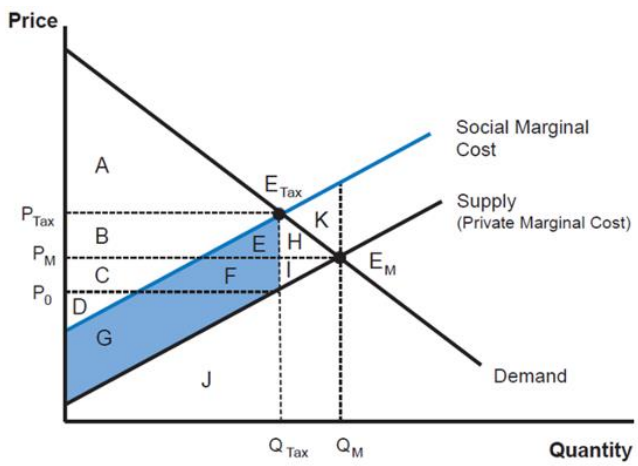
In economic theory carbon emissions are a negative externality. This is a market failure that implies that the first welfare theorem does not hold. Hence, the unregulated market will not provide an optimal allocation of resources. In economics market failure is when the goods and services are inefficiently distributed due to the fact that the individual incentives of the economic agents do not lead to the most socially efficient outcomes. In order to reach the socially optimal allocation of the resources, such markets have to be regulated.

According to the Arthur Pigouvian tax theory, a carbon tax can address the market inefficiency brought on by the negative externalities brought on by carbon emissions. The theory contends that by taxing carbon emissions, the market price of goods and services with a high carbon footprint will rise, resulting in decreased demand for and production of those goods and services.

The tax encourages the adoption of greener, more energy-efficient technologies by providing incentives for people and businesses to internalize the costs associated with their carbon emissions.

Goodwin et al. (2018) in their book, precisely show the effect of Pigouvian Tax within the welfare analysis of negative externalities. In *Figure 11* they show the scenario with Pigouvian Tax, where quantity falls to Qtax and price increases to Ptax, with the externality damage reduced to the shaded region.

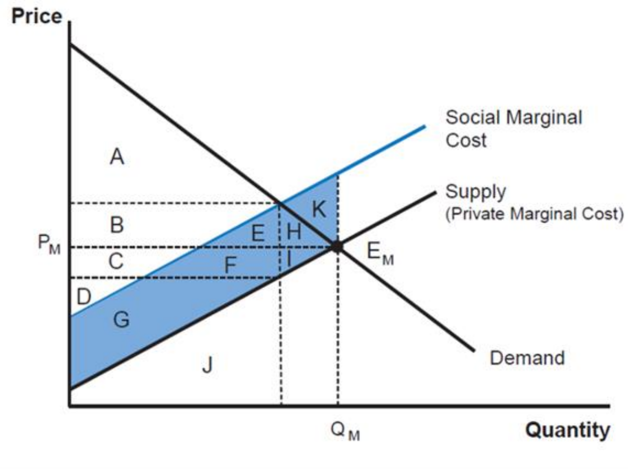
Figure 11. Welfare Analysis of a negative externality with Pigouvian Tax



Goodwin et al. (2018)

In Figure 12 the authors show the scenario without Pigouvian Tax, where quantity will be Qm and price will be Pm, with the externality damage equal to the shaded region.

Figure 12. Welfare Analysis of a negative externality without Pigouvian Tax



Goodwin et al. (2018)

By comparing both cases, it can be seen that the externality damage is less in the welfare analysis of a negative externality with Pigouvian Tax.

5.1.1 Price Elasticity of Demand

Understanding how carbon taxes affect energy use and electricity production requires an understanding of the concept of price elasticity of demand. Measured by price elasticity of demand, quantity demanded is responsive to price changes. A carbon tax could result in a significant decrease in consumption and production as consumers and producers switch to less carbon-intensive alternatives if energy and electricity have a high price elasticity of demand. In contrast, the tax's effects might be minimal if demand's price elasticity is low.

5.1.2 Substitution Effect

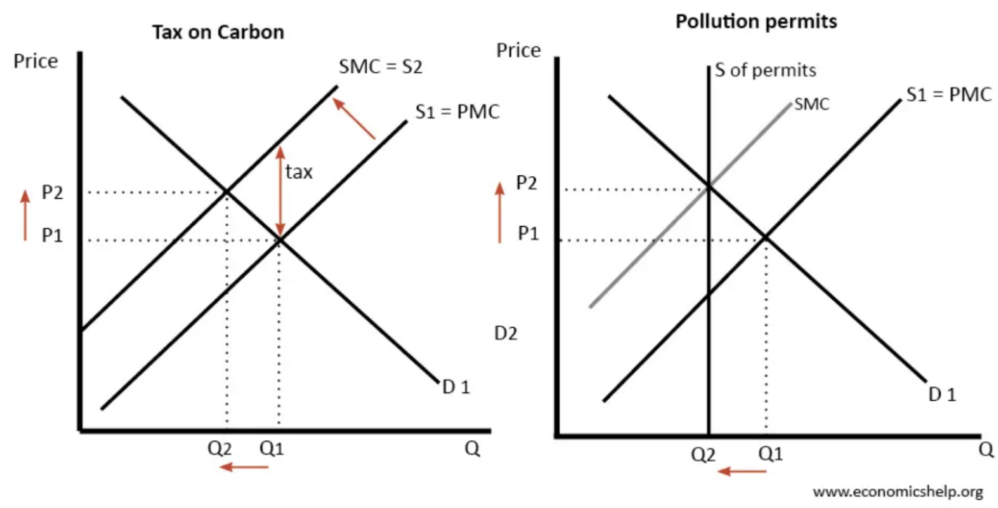
Consumers and producers may be encouraged by carbon taxes to switch from carbon-intensive energy sources to cleaner ones. The substitution effect is what is meant by this. People and businesses may switch to renewable energy sources, energy-efficient technologies, or other lower-carbon options as the price of carbon-intensive energy rises as a result of the tax. The substitution effect can encourage the development of greener technologies and encourage investment in renewable energy sources.

5.2. Cap-and-trade system

The second policy that we analyzed is EU-ETS price increase which has similar effects as the carbon tax by increasing the cost of producing carbon emissions and providing incentives to decrease the production of those negative externalities. When there is a negative externality, the social marginal cost of the polluting industry is higher than the private marginal cost. Imposing a carbon cap incentivizes the industry to reduce the quantity of the carbon emissions that they produce so that the price of producing the carbon emissions equals the social marginal cost.

In *Figure 13*, the graphs demonstrate the similarities of the economic implications of the carbon taxes and carbon prices:

Figure 13: the effects of the carbon tax and carbon price



Source: Pettinger, T. (2019)

As can be seen in the diagram both policies shift the supply curve to the left, meaning that both measures push the industries to produce less carbon emissions.

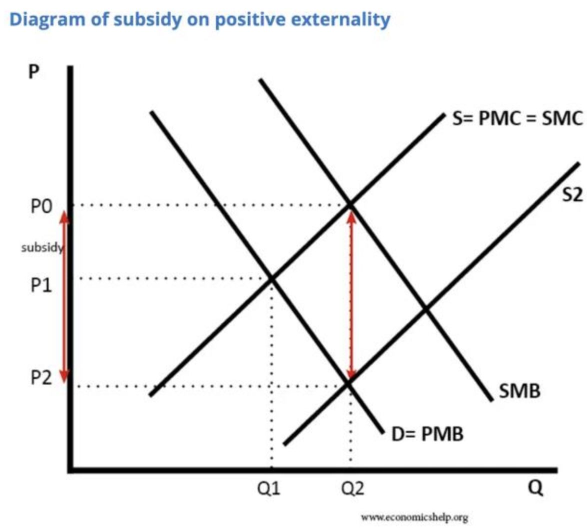
5.2.1. The challenges in the cap-and-trade system

One of the main challenges in ensuring the effectiveness of the cap and trade system is that the rich countries or rich industries (such as the oil industry) are able to buy permits from other countries if they exceed the cap without necessarily feeling the financial burden of paying the carbon price. Therefore, the policy might not lead to a reduction in the carbon emissions, but rather shift the pollution from one country to other countries. Furthermore, if the demand for carbon permits is inelastic (which can be the case in the oil industry), then that would mean the industry will be slow to act on it and will keep buying as many carbon permits even at a higher price.

5.3. Subsidies

On the other hand, subsidizing renewable energy production incentivizes the production of renewable energy which entails positive externalities to society in the form of a reduction of CO_2 emissions. When there is a positive externality, the social marginal benefit of producing renewable energy exceeds the private marginal benefit, therefore for the renewable energy companies to produce higher quantities the government can subsidize the production. In *Figure 14,* the effect of the subsidy is illustrated.

Figure 14. The effect of subsidy on positive externality.



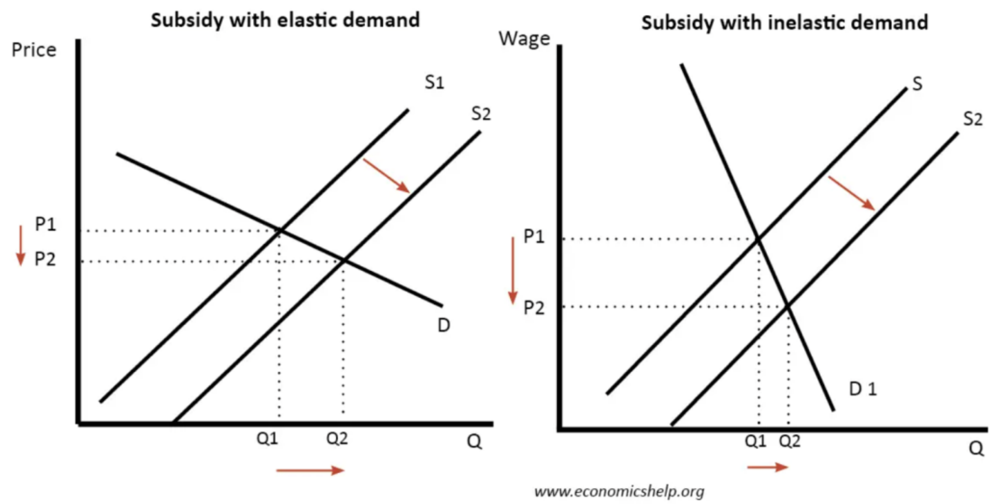
Source: Pettinger, T. (2019)

The subsidy will shift the supply curve rightward, pushing the price from P0 to P2 (the difference is the subsidy amount), as a result the quantity produced (Q2) equals the socially optimal levels.

5.3.1. The effect of the subsidy in case of different elasticities of demand

Depending on the elasticity of demand for renewable energy the government subsidies can have different effects. As can be seen in *Figure 15* the when the demand for renewable energy is elastic, a small decrease in price leads to a greater increase in the quantity demanded. However, when it is inelastic, an even higher fall in price leads to much smaller increase in the quantity demanded.

Figure 15. The effect of the subsidy in case of different elasticities of demand



Source: Pettinger, T. (2019)

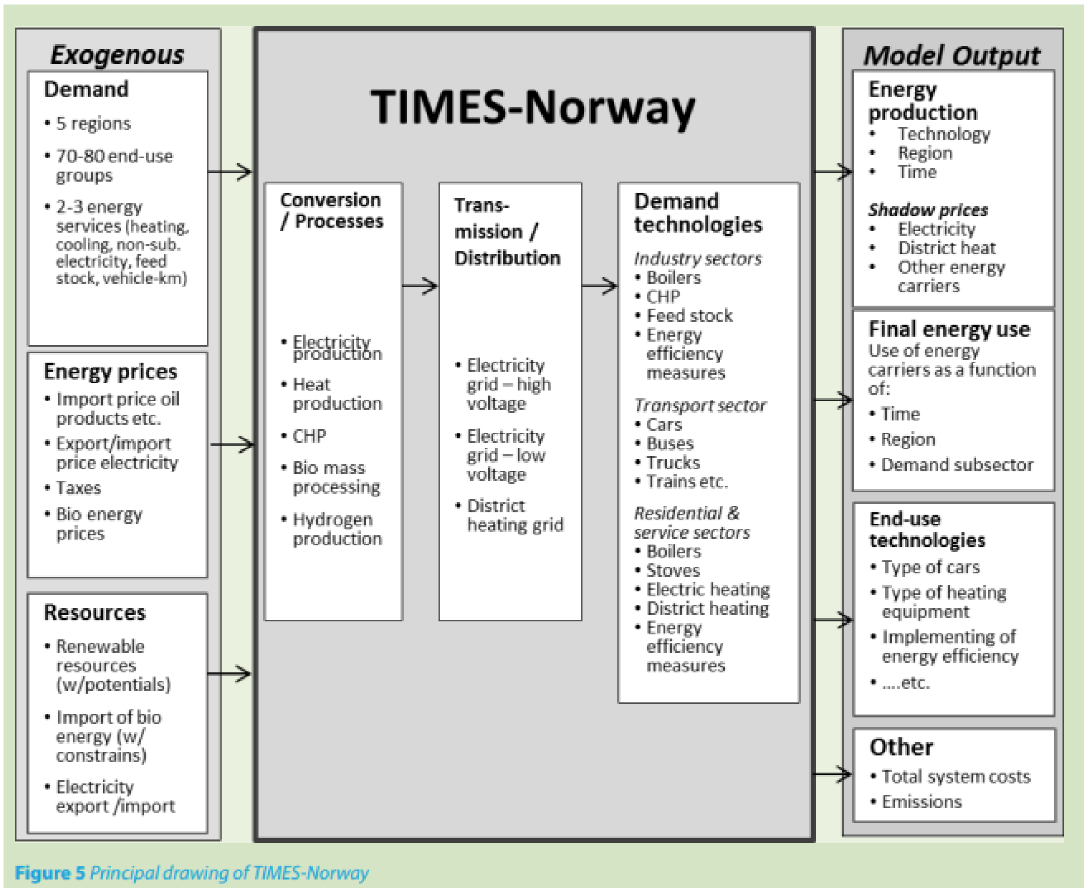
6. Data input and Assumptions

The TIMES model consists of generic variables and equations created from sets and parameter values characterizing the energy system. To create a TIMES model, we first transformed all the data defined by our research problem into a special internal data structure representing the TIMES matrix coefficients set to every variable which is used in every equation. After solving the model, the matrix generation, reporting write and control files are written in GAMS (the General Algebraic Modelling System), a powerful language designed to ease the process of building large optimization models. GAMS achieves this by relying on concepts of sets, composite index parameters, dynamic loop and conditional control, variables and equations. Then it translates the TIMES database into the Linear Programming (LP) matrix. The results files are generated once this LP is supplied to an optimizer. There are two different user faces to choose from, which are VEDA and Answer. We use the VEDA user interface for our model which is developed and supported by KanOrs. KanOrs is the organization that has an expertise in mathematical and economic modeling of energy and environment systems, based on the analysis of local, national and global policies in the domain of energy and the environment.

6.1. Model input and design

The model structure was taken from the TIMES-Norway model developed by Institute for Energy Technology (IFE) in 2008. Figure 16 shows the TIMES-Norway model flow and structure.

Figure 16. TIMES-Norway model structure



Source: NTNU (2021).

It is important to emphasize that variables, equations and model output are somewhat different in our model compared to TIMES-Norway, as they are aligned in accordance to our research objectives.

The modeling framework can be either stochastic or deterministic. The stochastic modeling framework takes into consideration short-term and long-term uncertainty, while the deterministic model simulates systems based on known inputs (Loulou, 2016). In our analysis, we use deterministic modeling, without consideration of uncertainty. The model input and design are constructed in several excel files. Each model file with its content and data inputs are shown in Table 3 and are described in detail below.

Table 3. Content of model files.

Model files	**Content**
SysSetings	Time periods, starting year, time slices, discount rate, units etc.
Power	Production technologies, production potenentials and restrictions
Trade	Paramaters of trade
Fuels	Commodities, prices, potentials
	Delivery costs related to technology specification CO2 emissions
Indusry	Annual demand, demand technologies with their potentials and limitations
Scen_Base_Profiles	TimeSlice profiles of demand and resources
Scen_BASE_Assumptio	Norwegian energy balance, electricty prices including trade
SubRES_CCS	New technologies
Scen_carbon price Scen_Taxes Scen_Mix Scen_subsidies	Different scenario files

6.1.1. Model file: SysSettings

The general model characteristics are described in Table 4. All five major geographical regions of Norway were included and named as NO1, NO2, NO3, NO4, and NO5. The specifications of the region were retrieved from the TIMES-Norway model. The start year for all data in the analysis was chosen to be 2021 taking into consideration the availability and scope of all data. The model horizon is split yearly, where each year consists of four seasons (fall, spring, summer, and autumn), and each season comprises months and days (24 hours per day). The discount rate was taken as 4%, that is according to TIMES-Norway. The discount rate is the rate used to compute the present value of future costs and benefits. The currency is set to be Norwegian krone (NOK), that is because our research objectives are related to Norway only. In addition, major share of data presented as costs are based on NOK. Both activity and commodity units are presented in Gigawatt hours (GWh), that is according to available data from Norway Statistics. The same reason applies to capacity unit measure, which is presented in Megawatts (MW).

Table 4 . Model characteristics and settings

Parameters	Settings	Source
Regions	Five regions: NO1, NO2, NO3,NO4,NO5	*Danenbergs et al. (2021)*
Start year	2021	*According to available data and assumptions*
Time slices	Four seasons: Fall, Spring, Summer, Autumn. 24 hours per day	*Danenbergs et al. (2021)*
Discount rate	4 %	*Danenbergs et al. (2021)*
Currency	NOK	*According to our research objective*
Activity unit	GWh	*Norway Statistics (2022)*
Commodity unit	GWh	*Norway Statistics (2022)*
Capacity unit	MW	*Norway Statistics (2022)*

6.1.2. Model file: Power

6.1.2.1. Production technologies and potentials

Energy Sources

The data on energy sources was retrieved from Norway Statistics (2022). The produced commodities are electricity, district heat[2], and biofuels. The electricity commodities are defined in the power files, while district heating in a separate file and biofuels in fuel files. Some products can be both produced and imported. The exogenous prices for them are placed in. These energy prices adjust according to scenario files.
There are several assumptions used to facilitate the conversion and transmission processes in the model. The grid losses are assumed to be 4% for both high and low voltage grids, that is based on historical calculation of grid losses. The grid fee is assumed to be equal to 284 NOK/MWh, according to historical calculation of fees. The tax for electricity and VAT were included in the "Base assumptions file", and were set equal to Norwegian taxes level of 2021.

Technology types

The actual capacities and generation in a base year for Hydro power and Wind power are retrieved from Norway Statistics (2022). Table 5 displays the actual electricity production from hydro and wind powers in the form of MW of

[2] District heat - production of district heat. District heat is a system that distributes heat to multiple buildings from a centralized source. The centralized source is based on renewable energy in Norway.

output. The thermal power was excluded from the analysis since it has a minor share of total output, which is around 3% of total output.

Several assumptions were implemented in our basic scenario for next year until 2030. According to NVE (2019), the current hydropower plants are assumed to increase by at least 100 MW each year up to 2040 due to additional capacity and investment. The current wind power plants are aimed to increase by at least 10% due to increased capacity. Also according to NVE (2017), the operating and maintenance expenses are going to decrease by 31% by 2025.

Table 5. Actual electricity, power stations

Output (MW)	2021	2022
All types of power	39 124	39 331
Hydro power	34 075	34 269
Wind power	5 049	5 062

Source: Norway Statistics (2022)

Technological parameters

The technical characteristics for hydro power and wind power such as technology, capacity, efficiency, operating and capital costs, lifetime, emissions were included in the model. The data were taken both from Norway Statistics (2022) and NVE (2020), Tables 6 and 7 show the breakdown of hydro and wind power parameters, respectively, and their settings linked to the source of data.

There are several assumptions used for capital costs, emissions, resource availability and potential constraints. The main reason for using them is because of no availability of reliable data. These assumptions are in accordance with our qualitative overview of the research papers related to these topics, including Norway's Climate Action plan. No precise figures were set in the settings, that is, no emissions and high resource availability were set for both hydro and wind powers. The grid connection and land requirements was chosen as an assumption for wind power potential constraints, whereas we assumed no potential constraint for hydro power.

Table 6. Technological parameters for Hydro power

Hydro power

Parameters	Settings	Source
Efficiency	90 %	*NVE (2020)*
Average lifetime	50 years	*NVE (2020)*
Operating costs	LOW	*NVE (2020)*
Capital costs	LOW	*Assumption*
Emissions	NONE	*Assumption*
Resource availability	HIGH	*Assumption*
Potential constraints	NONE	*Assumption*

Table 7. Technological parameters for Wind power

Wind power

Parameters	Settings	Source
Efficiency	50% both for offshore and onshore	*NVE (2020)*
Average lifetime	25 years	*NVE (2020)*
Operating costs	LOW	*NVE (2020)*
Capital costs	LOW	*Assumption*
Emissions	NONE	*Assumption*
Resource availability	HIGH	*Assumption*
Potential constraints	Grid connection and land requirements	*Assumption*

Norway is a water rich country that has many rivers and lakes (Norwegian Ministry of Climate and Environment, 2021). Hence, the resource availability for hydro power was designed to be high. In addition, Norway has wind resources which are located in the coastlines and mountain regions (Norwegian Ministry of Climate and Environment, 2021). Hence, the resource availability for wind power was designed to be high.

6.1.2.2. Restrictions

Regulations

The Renewable energy support schemes such as financial incentives and tax benefits were determined in the model both for hydro and wind powers. The effects of these schemes are set up within our assumptions.

Other environmental regulations such as water management regulations and grid connection were not included in the model due to less availability of clear data and information.

Policies

The policies of increase in carbon tax, EU-ETS price, mix effect and wind subsidies were included in the model. They are splitted and described separately in four scenario files. The results on production of energy from hydro and wind powers will differ in each policy scenario.

6.1.3. Model file: Trade

Trade parameters of the electricity are set in the Trade excel files.

The model requires exogenous input of electricity prices for countries which have transmission mechanisms with Norway. Set of prices were retrieved from the NordPool (2022). The future prices were taken from the forecast analysis done by NVE (2020).

Table 7. Average power trade prices

Year	UK	Germany	Denamrk	Finalnd	Sweden	The Netherlands
2022	55	43	36	35	38	45
2025	57	48	44	41	43	48
2030	49	46	45	35	38	46
2040	52	45	44	41	42	48

Source: Nordpool (2022) and NVE (2020).

6.1.4. Model file: Fuels

The commodities such as natural gas, oil and oil products, coal and coal products and biofuels were included in the fuel files. Their prices were taken from Norway Statistic (2022) and their potentials were determined according to our qualitative overview of research.

There are different bioenergy goods that can be produced from raw materials and be imported in Norway. In our model, we focus on biofuels which play a vital role to reduce greenhouse gas emissions. Norway actively contributes the production and use of biofuels as part of the strategy to soften climate change and achieve environmental targets. In the base scenario, we used an assumption of an increase in the level consumption of biofuels by at least 10% every year by 2030, according to the projection analysis made by Andersen & Weinbach (2010).

Oil and oil products and coal are assumed to increase by 8% every year, that is according to historical assessment of consumption.

6.1.4.1. Environmental, Policy and Regulatory data

The data on EU-ETS price, carbon tax and wind subsidies were retrieved from Norway Statistic (2022) and NVE (2020). The increased level of these were set in accordance with the Norwegian Climate Action Plan.

6.1.5. Model file: Industry

In our model, the industry sector are divided into the following sectors:

- Petroleum industry
- Agriculture
- Construction
- Road Transport
- International air transport
- Metal industry

Each industry has a demand for electricity and raw/or raw materials. The demand is set in the energy balance of 2021 which was retrieved from Norway Statistics (2022). The assumption of constant energy demand was used within our model in the base scenario.

All sectors can use fossil fuel based energy or electricity for production. The data on technology such as investment costs, efficiencies etc. were retrieved from the NVE (2017).

6.1.6. Model file: Base scenario profiles and assumptions

“Base profiles” scenario file consists of compiled profiles. It contains profiles of wind and hydro power, demand and charging of resources.

“Base assumptions” scenario file comprises Norwegian energy balance for 2021 and includes assumptions that are used in the base scenario. It contains carbon tax, EU-ETS price, subsidies for wind generation and electricity trade prices.

6.1.7. Model file: Scenario files

There are four scenario files that were created and developed by changing the parameters, optimization settings, assumptions and mechanism specifications. The target for the increase was defined for each scenario. In addition, the input parameters were located and the impact on the energy system variables (energy use, electricity production) and environmental variables (CO2 emissions) was assessed. These scenario files were named as:

1. EU-ETS price increase
2. Carbon tax increase
3. Mix of EU-ETS price and carbon tax increase scenarios
4. Increase in subsidies

6.1.8. More assumptions

Energy services are set to have relatively inelastic demand, so changes in price lead to insignificant impact on the quantity demanded. The supporting factor for this assumption is that even though Norway has been supporting renewable energy production, the energy consumption is still influenced by the oil and gas resources.

7. Results

7.1. Main findings

Our main findings suggest that energy consumption (the same as energy use) in the coming years will increase. In the baseline scenario energy consumption over time increases by 56% from 2021 to 2030, whereas in the policy mix scenario energy consumption increases by 171%. The excess increase in the policy mix scenario (scenario 4: increased carbon tax in all sectors, and the increased EU-ETS price (carbon price)) happens due to the fact that the electricity consumption increases by 136% compared to 30 % increase in the case of the baseline scenario. Energy consumption will increase since higher prices on carbon-based energy will electrify the economy, making it more energy-intensive.

Furthermore, under the baseline scenario energy consumption of oil and oil products keep growing with the 3 % rate every year. This implies that with the current policies the growth of the economy will still be carbon based. In comparison, in the case of scenario 4 we find 1% decrease every year. This implies that stricter policy on a broad set of sectors is necessary.

Electricity production in the baseline scenario increases by 23% (excluding thermal power) from 2021 to 2030, from which wind power increases by 115% over this period. In the case of the policy mix the electricity production increases by 69%, from which hydropower increases by 49% and wind power by 207%. In the case of a wind subsidy, the electricity production increases by 43% from 2021 to 2030, mainly through the increase in the wind production, 331 % increase over the period. Moreover, the wind subsidies lead to a change in the energy mix, where the portion of the wind power production increases by more than in any of the scenarios, and the hydro power production becomes less compared to the baseline scenario.

CO2 emissions in the baseline scenario are increasing by 4% over the period from 2021 to 2030. In the policy mix scenario the CO2 emissions fall by 29% from 2021 to 2030, that is 32% decrease from 1990 levels. Since the target is 50-55% decrease from the 1990 levels, the policy mix will not achieve the target. When there is an increase in wind subsidies, CO2 emissions decrease by 19% from 2021 to 2030.

Overall, we see that the policy mix leads to the most CO2 emissions reduction, however, it doesn’t meet the target set by Norway's Climate Plan. The policy mix also results in the highest energy consumption and electricity production over the period from 2021 to 2030.

7.2. Scenario 1: Baseline

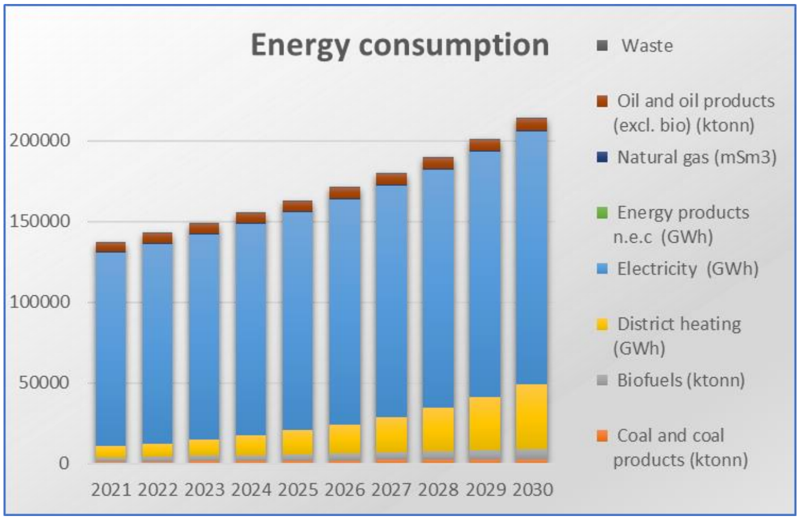
Baseline scenario: *the projection of the electricity production, energy use and CO2 emissions under the current policy where the baseline year is 2021.*

The baseline scenario is the scenario under no policy change since 2021.
In this scenario we made projections of the electricity production, energy use and CO2 emissions if there was no policy change since 2021, that is 590 NOK per tonne CO2 up to 2030 in the non-ETS sectors, and 1130 NOK per tonne CO2 in the ETS-sectors.

Energy consumption

Figure 17 shows the overall energy consumption in the baseline scenario increasing gradually and reaching a 56% increase from 2021 to 2030. The main drivers are electricity, district heating and biofuels which rise by 30%, 499%, and 117%, respectively. The consumption for these will increase since the relatively high prices for carbon-based energy will still have an effect despite their lower level in comparison with carbon tax and EU-ETS price increase scenarios. In addition, there will be an impact of higher population and business activities. Other drivers are carbon-based energy products such as oil, coal and natural gas, the consumption for these will increase by 28%, 107%, and 59%, respectively. They increase at a lower level in comparison with renewable energy products due to relatively higher prices set in 2021.

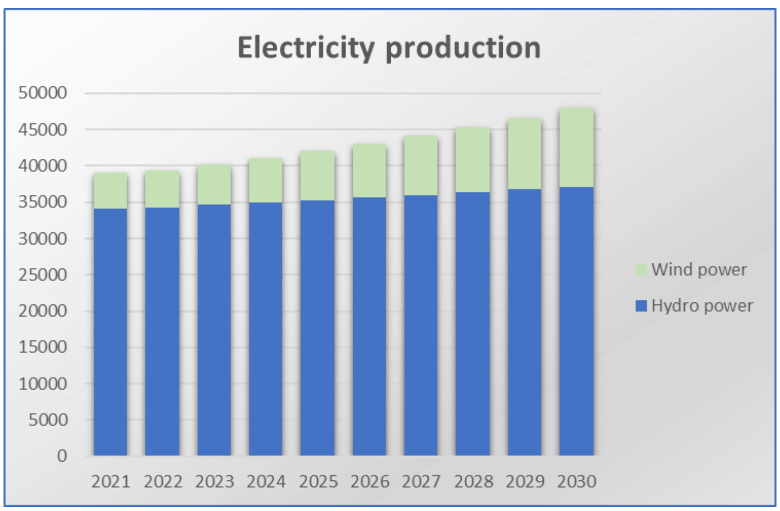
Figure 17. Energy consumption in the base scenario



Electricity production

Figure 18 shows that if the policy in 2021 keeps unchanged, the electricity production from hydropower and wind power will increase by 9% and 115% respectively, from 2021 to 2030. The relatively sharp increase of wind power production is due to historical average governmental support of wind power. This assumption was used for baseline scenario to reflect policies used in 2021.

Figure 18. Electricity production in the base scenario

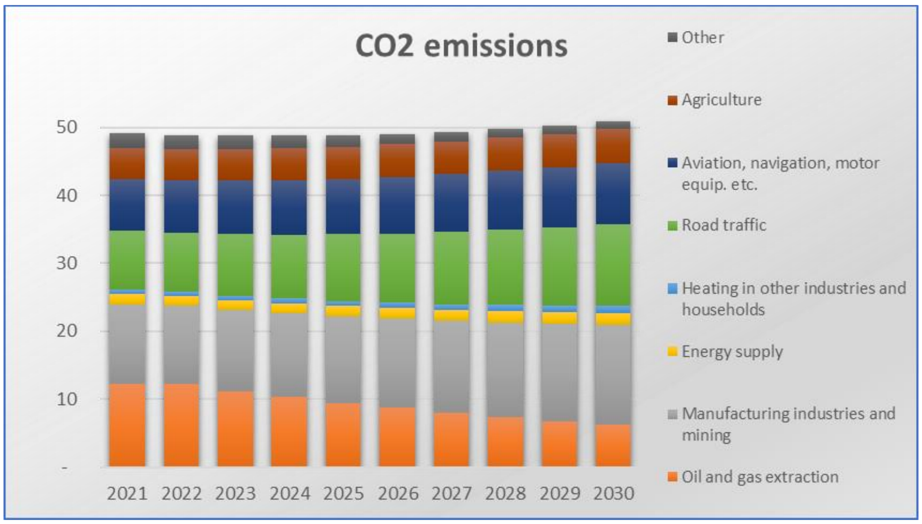


CO2 emissions increase

Figure 19 displays the CO2 emissions slightly increasing from 2021 to 2030 in the no policy change scenario. The level of CO2 emissions will increase by 4% in total and will reach 51 million tonnes CO2 equivalents in 2030. The main drivers are heating in other industries and households, road traffic and manufacturing and mining industries. These sources are projected to increase by 101%, 37% and 26%, respectively. There are several explanations for this effect. Despite Norway's progress in promoting electric vehicles, traditional ones still dominate the market. In addition, the country has energy intensive industries that often use fossil fuels.

However, it is important to mention that the oil and gas extraction source will decrease by 49% from 2021 to 2030 due to the presence of energy policies in 2021.

Figure 19.CO2 emissions in the base scenario



7.3. Scenario 2: Hike in the national carbon tax

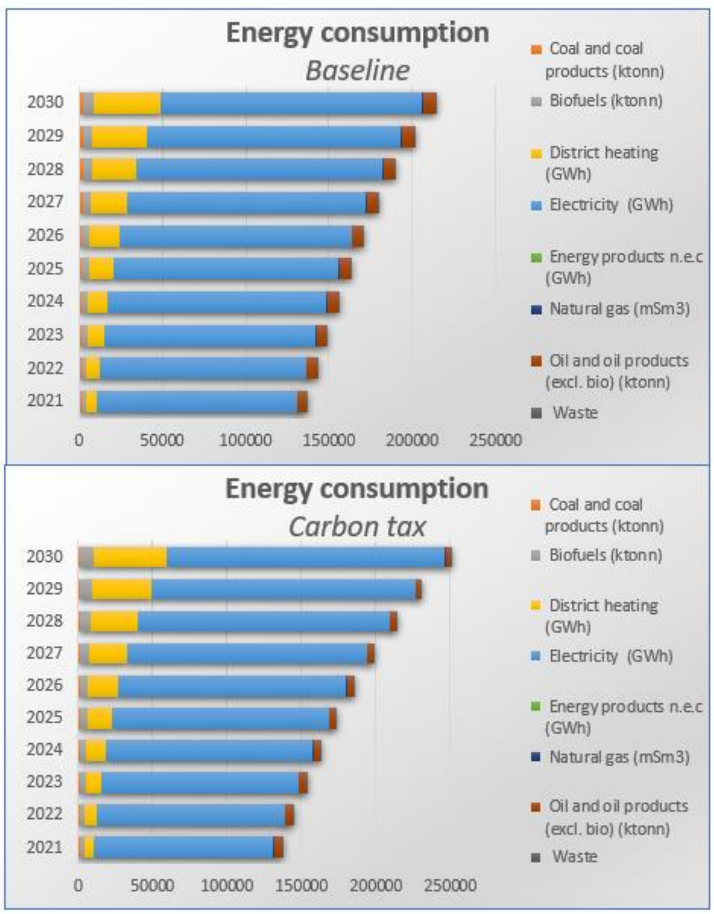
Scenario 2: Hike in the national carbon tax: *An increase in the national carbon tax from 590 NOK to 2000 NOK per tonne in all sectors and its effects on electricity production, energy use and CO2 emissions;*

Energy consumption

The energy consumption increases by 82% from 2021 to 2030 compared to 56% in the baseline scenario, where electricity consumption will increase by 55%, which is at a higher rate than in a baseline scenario (30%). This implies that electricity consumption is the main driver for the increase in total energy consumption. Second driver of the increase is district heating which will increase by 146% more in comparison with the baseline scenario from 2021 to 2030. The main reason is that the main source of district heating is based on renewable energy.

In contrast, consumption of oil and oil products will decrease by 43% compared to 30% increase in a baseline scenario. Less fossil fuel based energy needs to be replaced by other cleaner sources of energy, causing an increase in overall energy use. See Figure 20 for a detailed timeline of energy consumption sorted into different sources of energy use.

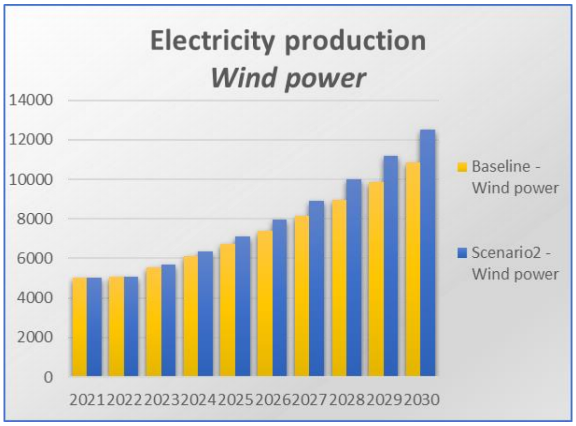
Figure 20. Energy consumption in the carbon tax increase scenario relative to the base scenario

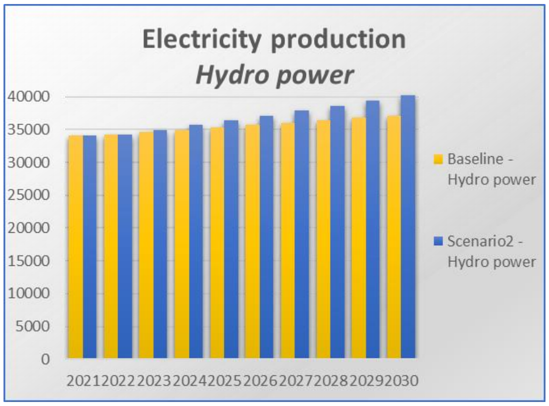


Electricity production

The increased CO2 tax in all sectors will lead to higher electricity production, which will increase more by 12% in comparison with the baseline scenario.The hydro power and wind power will increase by 18% and 148%, respectively from 2021 to 2030 and will reach 52 685 MW of total output. The increase in electricity production can be explained by a shift from the use of fossil fuels to electricity. See Figure 21 for a detailed timeline of electricity production sorted into wind power and hydro power.

Figure 21: Electricity production from hydro and wind power in the carbon tax increase scenario relative to the base scenario



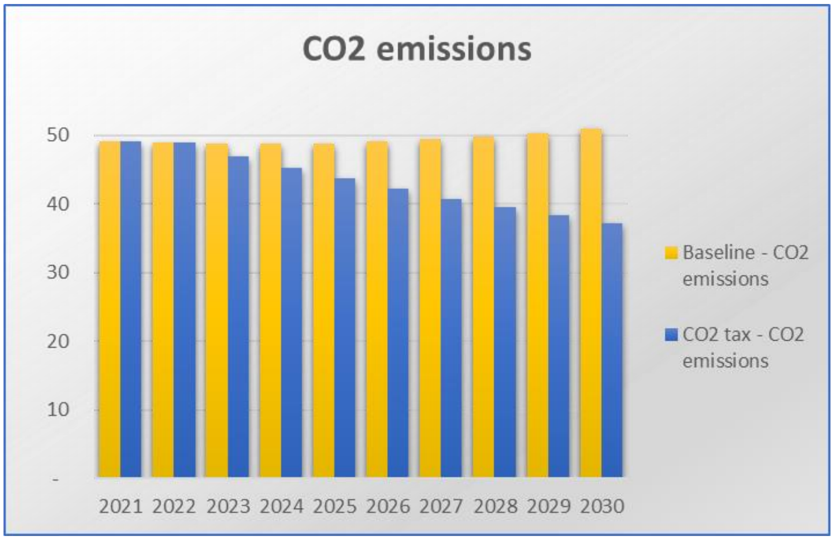


CO2 emissions reduction

Figure 22 demonstrates that when there is an increased carbon tax, total CO2 emissions fall from 49 million tonnes to 37 million tonnes CO2 equivalents, meaning 24% decrease from 2021 to 2030. The main driver is oil and gas extraction and manufacturing and mining sectors which fall by 57% and 22%, respectively, from 2021 to 2030. The oil and gas extraction decreases by 8% more than in the baseline scenario due to higher level of tax.

In contrast, the manufacturing and mining sectors were increasing in the baseline scenario whereas the higher level of CO2 tax changed the pattern in this scenario.

Figure 22: CO2 emissions in the carbon tax increase scenario relative to the base scenario



7.4. Scenario 3: Hike in the price of EU-ETS

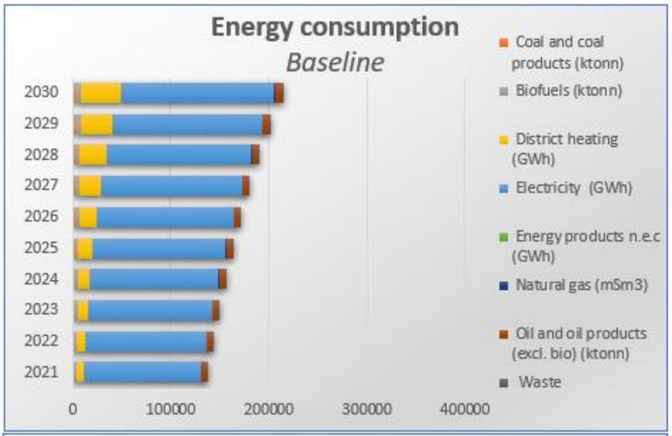
Hike in the price of EU-ETS: *The increase of EU-ETS price from 540 NOK to 1500 NOK in the EU-ETS sectors and its effects on electricity production, energy use and CO2 emissions;*

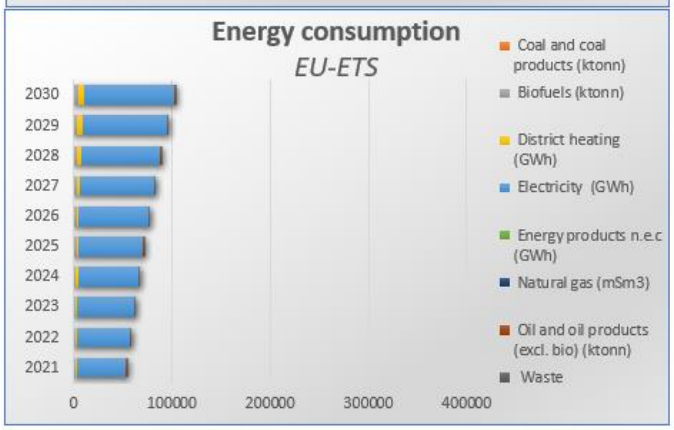
Energy consumption

Figure 23 displays the effect of the increase of the EU-ETS price up to 1500 NOK per tonne in the ETS sector only. This scenario has similar effects to scenario 2 .The total energy consumption will increase by 90% from 2021 to 2030, where the main driver is electricity consumption.

Electricity consumption will increase by 84% from 2021 to 2030, this is 29% more in comparison with Scenario2. The opposite effect has consumption of oil and oil products, which will decrease by 10% more than in scenario 2. This can be explained by the basis of our analysis, where only ETS sectors were included into the scope. One of the main sectors that includes the ETS sectors are energy intensive heavy industries which will switch from carbon based energy sources to renewable energy ones.

Figure 23: Energy consumption in the EU-ETS price increase scenario relative to the base scenario



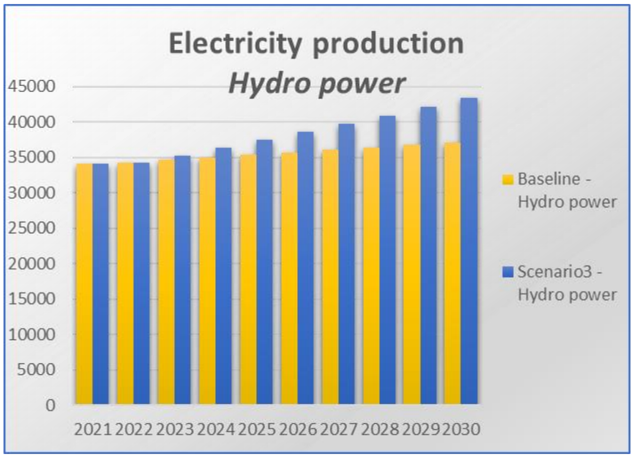


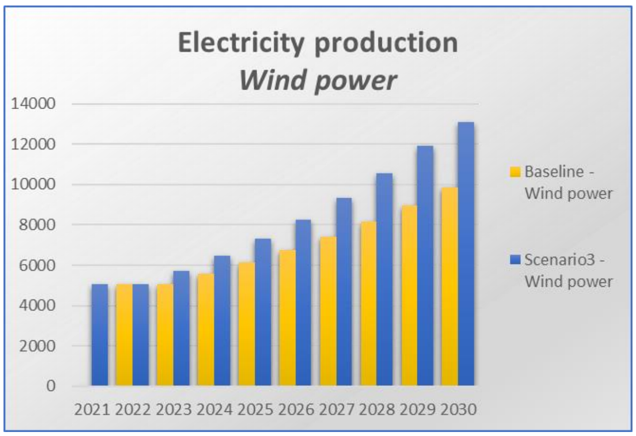
Electricity production

Figure 24 displays the total electricity production increasing by 44% from 2021 to 2030 and reaching 52 685 MW in 2030. The hydro and wind powers will increase by 27% and 159%, respectively.

There is a stronger increasing effect in comparison with scenario 2 due to transition of the share of industries into production of renewable energy based powers.

Figure 24: Electricity production from hydro and wind powers in the EU-ETS price increase scenario relative to the base scenario

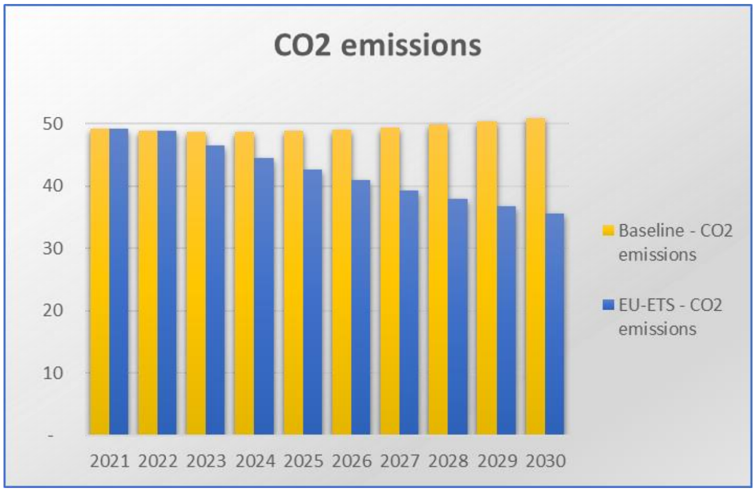




CO2 emissions reduction

Figure 25 shows the impact of EU-ETS price increase on CO2 emissions in the ETS sectors. We observe a 27% reduction in the total CO2 emissions by 2030, the highest reductions occurring in the sectors affected by the increased EU-ETS price. The CO2 emissions in oil and gas extraction sectors fall by 64% from 2021 to 2030, the effect of decrease is higher than scenario 2 by 7% and by 15% than in the baseline scenario. This effect is explained by our concentration solely on the EU-ETS sector in our analysis.

Figure 25: CO2 emissions in the EU-ETS price increase scenario relative to the base scenario

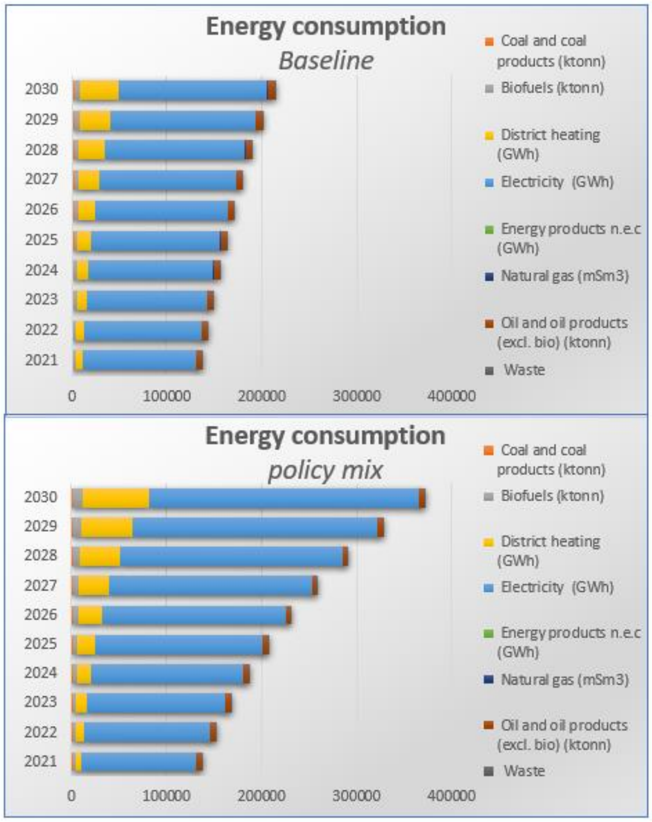


7.5. Scenario 4: The policy mix scenario

The effect of both scenario 2 and scenario 3 on the electricity production, energy use and CO_2 emissions is shown in Figure 26.

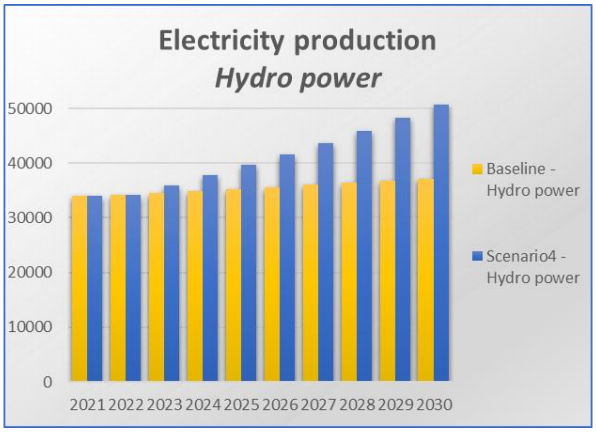
According to the results, the most significant effects occur when there is a policy mix, the energy consumption increases by 171% (higher than baseline scenario by115%), from which electricity consumption increases by 136% (higher than baseline scenario by 106%) and oil and oil products consumption decreases by 59% (it was increasing by 30% in the baseline scenario) from 2021 to 2030. The total energy consumption rises dramatically due to the double effect of policies where all sectors including energy-intensive industries face both carbon tax and EU-ETS price increase and decide to switch from carbon based energy to renewable based.

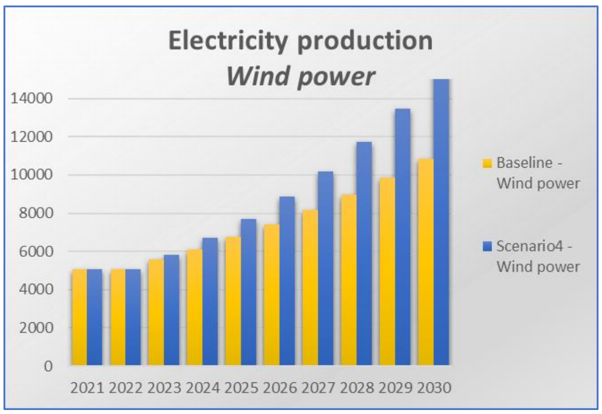
Figure 26: Energy consumption in the mix scenario relative to the base scenario



Moreover, according to Figure 27, overall electricity production increases by 69% and reaches 66 116 MW of output under the policy mix (higher than baseline scenario by 46%), where hydro power increases by 49% (higher than baseline scenario by 40%) and wind power increases by 207% (higher than baseline scenario by 92%) from 2021 to 2030. The effect can be explained by the double effect of policies.

Figure 27: Electricity production from hydro and wind powers in the mix scenario relative to the base scenario



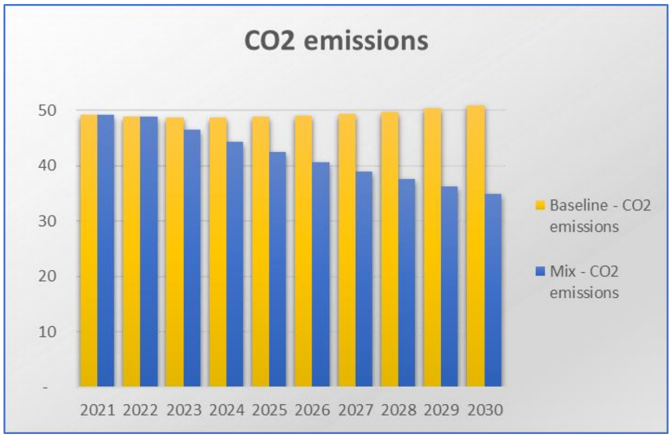


CO2 emissions reduction

Figure 28 displays the policy mix results in the most significant effects, leading to CO2 reductions by 29% from 2021 to 2030 and reaching 36 million tonnes CO2 equivalents. However, this is only a reduction of 32% from the CO2 emissions level of 1990.

The main drivers are oil and gas extraction, manufacturing and mining industries and road traffic, the emissions falling by 64%, 34% and 15%, respectively. The effect of both policies have the strongest effect towards CO2 emissions reduction.

Figure 28: CO2 emissions in the mix scenario relative to the base scenario



7.6. Scenario 5: Subsidize renewable energy

Subsidize renewable energy: *The effect of the increased wind subsidy on electricity production, energy use and CO2 emissions;*

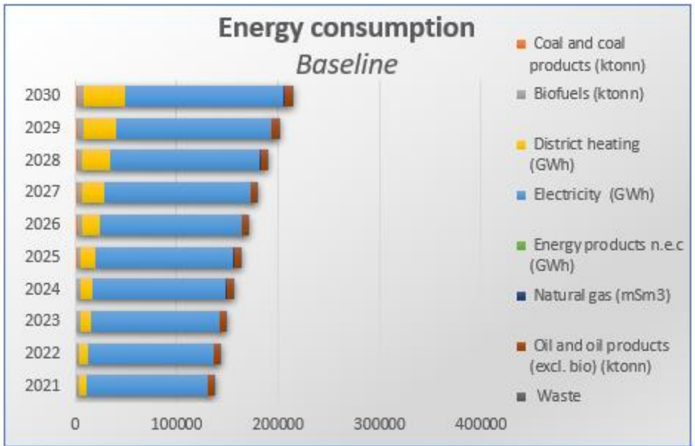
In this scenario, we made projections of the electricity production, energy use and CO2 emissions if there was government support in the form of wind subsidies.

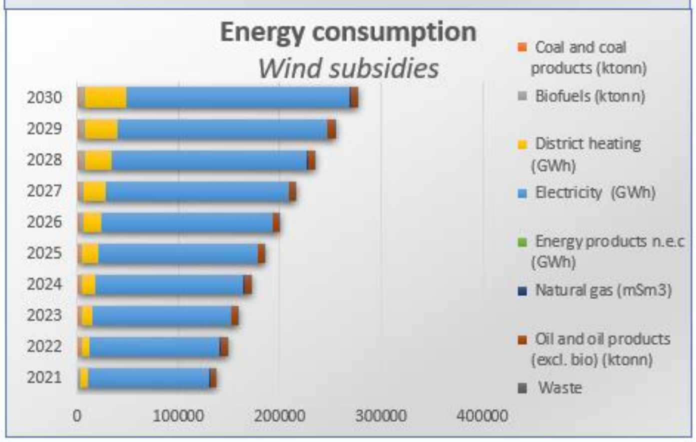
Energy consumption

Figure 29 shows the increased presence of wind generated farms leading to higher usage of this renewable energy in different sectors.

The overall energy consumption will increase by 102% from 2021 to 2030, which will have a higher effect than in the baseline scenario (56%). The energy products that drive the increase are electricity consumption (84%), biofuels (117%) and district heating (499%). In contrast, the consumption of coal and coal products slightly decreases by 84 %, and the same pattern has oil and oil products (-20%) and natural gas (-42%) from 2021 to 2030. The effect is explained by availability of more renewable energy which is affected by the wind subsidies.

Figure 29: Energy consumption in the wind subsidies increase scenario relative to the base scenario

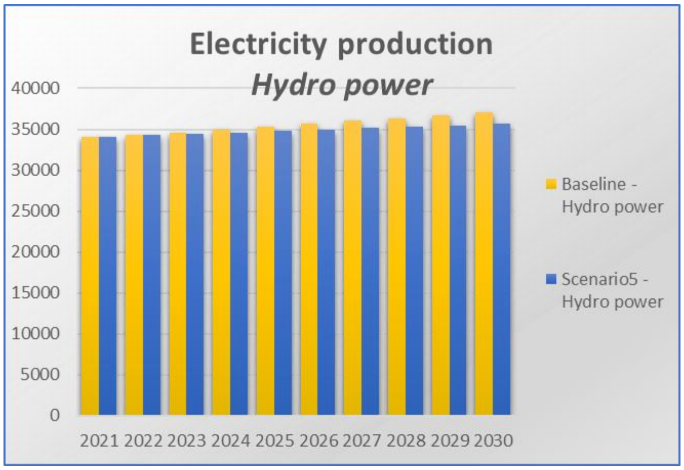


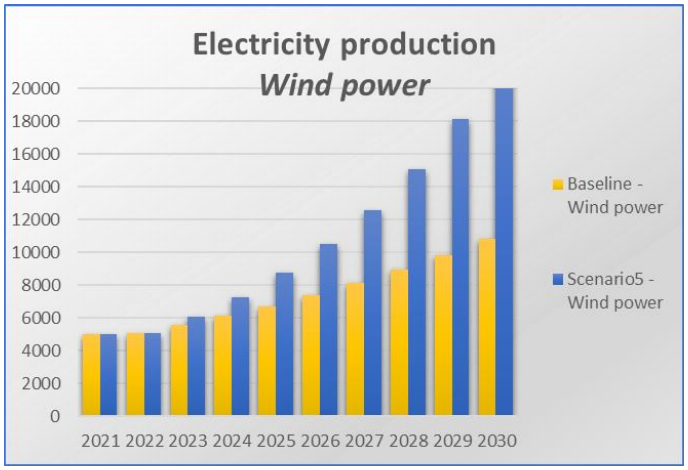


Electricity production

According to Figure 30, the total electricity production by power stations will increase by 47% from 2021 to 2030 and reach 57 430 MW of output (higher than baseline scenario by 24%). The main driver is wind power which will increase by 331% (significantly higher than baseline scenario by 216%) due to increased level of wind subsidies. The hydro power will increase slightly by 5%, which is a smaller rise in comparison with the baseline scenario (9%). This effect is explained by the change in energy mix mechanism where hydropower potentials are less valuable in comparison with wind power in the energy market.

Figure 30: Electricity production from hydro and wind power in the wind subsidies increase scenario relative to the base scenario

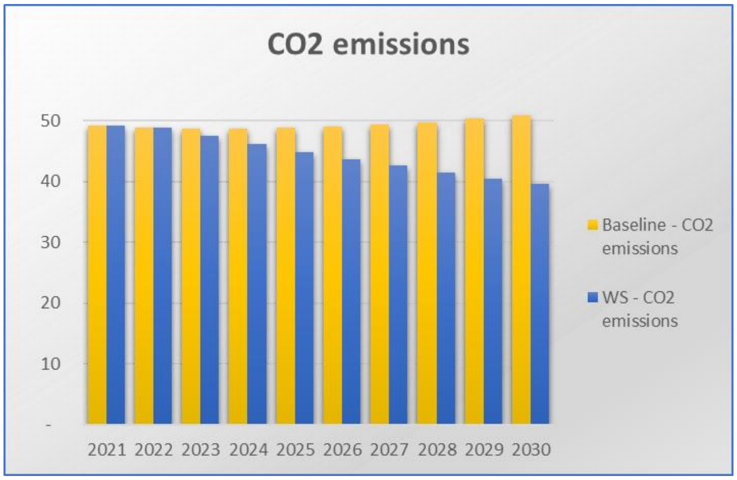




CO2 emissions

Figure 31 shows wind subsidies leading to reduction of CO2 emissions in the energy sectors by 19% from 2021 to 2030 and reaching 40 million tonnes CO2 equivalents. The CO2 emissions in the sectors of oil and gas extraction and manufacturing and mining fall by 44% and 15%, respectively. The effect can be explained by the higher share of renewable energy which comes from wind power that can be used in these sectors. In other minor sectors such as agriculture and road traffic, the CO2 emissions fall on average by 5%.

Figure 31: CO2 emissions in the wind subsidies increase scenario relative to the base scenario



8. Discussion

In this section of the paper, our objective is to analyze and interpret our findings through the application of various economic theories and concepts. This approach allows us to retrieve meaningful insights and understand the mechanisms and relationships between our findings and tangible realities of the world. For the underlying assumptions in the TIMES model you can refer back to section 4.4.

8.1.The effect of the increased carbon tax

The national carbon tax proves to be a somewhat effective policy as it leads to 24% CO2 reduction from 2022 to 2030, this occurs as all the industries have a financial incentive to switch to greener sources of energy.

In the TIMES model different energy carriers are substitutes if they can be used to meet the demand for energy services. While electricity may not be a perfect substitute for fossil fuels in certain sectors, the TIMES model is designed to compute the most cost-optimized energy mix if electricity can fulfill the required energy service demand. In other words, even if electricity is not an exact replacement for fossil fuels in all applications, the model can still determine the most cost-effective combination of energy sources to meet the overall energy service requirements. As can be seen in *Figure 20,* the consumption of electricity and biofuels is increasing, whereas the consumption of oil and natural gas is decreasing over time. This can be explained by *the substitution effect*, the carbon taxes incentivize the different sectors of the economy to switch from the high carbon emissions energy sources to low or zero-carbon alternatives. In the case of Norway, the significant percentage of electricity is generated by hydropower (90%), therefore the increased carbon tax would encourage the affected sectors to shift from the use of fossil fuels such as oil and gas, which has become more expensive, to electricity. This will increase demand for electricity in different sectors such as transport, agriculture, construction and others.

As can be observed in *Figure 20*, the electricity consumption increased by 55% compared to 30% increase in the baseline scenario. Since the cost of carbon-intensive energy sources would rise, electricity becomes relatively cheaper in terms of carbon emissions. This *price effect* is relevant in the case of Norway where hydropower has a low carbon footprint, and the relative price of electricity becomes relatively lower than the fossil fuel alternatives. Such decrease in electricity prices would incentivize households, businesses to increase their electricity consumption.

Since the substitution effect increases the demand for electricity, this would lead to an increased production of electricity. Referring to *Figure 21* one can observe that the production of hydropower and wind power increased by 18% and 148% respectively which is greater compared to the baseline scenario. As the carbon taxes increase the cost of emitting CO2 emissions, it becomes more economically attractive to invest into renewable energy such as hydropower and wind power. These technologies are significantly less carbon-intensive, and their production does not result in the high CO2 emissions. As the cost of emitting carbon increases, the TIMES model may prefer renewable energy sources like hydropower and wind power that can satisfy the demand for electricity while minimizing carbon emissions and the overall cost.

8.2. The effect of the increased EU-ETS prices

The increased EU-ETS prices have similar economic effects as the increased carbon taxes. However, in the case of the higher EU-ETS prices the effect is slightly stronger than in the case of the carbon taxes. We explain this by the fact that only the most carbon intensive sectors, EU-ETS sectors among which are oil and petroleum, have been subject to the carbon price increase.

As can be seen from *Figure 23*, overall energy consumption has increased by 90% which is slightly greater than in the second scenario. This can be due to the fact that the carbon price makes investing in the carbon intensive fuels for all sectors unfavorable, and incentivizes the electrification of all the sectors, hence 44% increase in electricity consumption.

On the other hand, investing in low carbon technologies becomes economically more attractive, so businesses switch to investing in renewable energy sources. As *Figure 24* demonstrates, higher carbon prices lead to even higher percentage growth in wind power and hydropower electricity generation than in the second scenario, 159% and 27% respectively. This can be due to the fact that there is a clear *price signal* to economic agents that the investment in the carbon intensive industries don't look lucrative, so there is even higher incentive to switch to cleaner energy sources than when there is merely higher carbon taxes for all the sectors.

Reduction in CO2 emissions is also greater than in scenario 2, leading to 27% reduction over the period from 2021 to 2030. Such a reduction can be explained by the fact that the oil demand decreases significantly as a result of higher carbon prices. However, in the real world this result seems counter-intuitive to us, because the petroleum sector in Norway is a very profitable industry, and this industry most probably has a higher incentive to merely buy EU ETS allowances rather than actually reducing CO 2 emissions, hence CO2 emissions shouldn't necessarily fall that much. However, since the TIMES model doesn't include such peculiarities of the industries and solely looks at cost optimization, it might give us such results.

8.3.The effect of the wind subsidies

Wind subsidies is a governmental economic support that is aimed to develop the wind energy market. The increased wind subsidies scenario shows the highest increase of wind power production in comparison with other scenarios, where it will be increased by 331% from 2021 to 2030, see Figure 30. These can be explained by *price elasticity of demand,* where lower electricity prices lead to increase in demand for wind-generated electricity. In addition, in the presence of *positive externalities*, the social marginal benefit of producing renewable energy exceeds the private marginal benefit, leading to higher wind power production.

The electricity production increase can be also explained by *economies of scale*. The wind subsidies allow wind farms to reduce costs and increase profitability. Hence, the wind farms gain from economies of scale by having lower average costs of operation. Junior, et al. (2019) showed that incentive programs and subsidies for the production of clean energy can make wind power more profitable and attractable.

The increased level of energy consumption by 102% from 2021 to 2030 can be explained by several economic theories. In general, wind subsidies have an impact on consumer behavior by lowering the cost of renewable energy production. Benhrmad & Percebois (2018), in their empirical findings show that increasing share of wind generation causes a sharp fall in electricity spot prices. It can be interpreted as the substitution effect. As a result, this leads to increased consumption of the goods that are subsidized. The main objective of the wind subsidies is to make wind energy more competitive with energy sources based on fossil fuels. As a result, the consumption patterns of the consumers will be shifted. According to many researches, including Hirth & Ueckerdt (2012), the moderate amounts of wind subsidies leave consumers and producers better off even if they bear the costs of subsidies.

The increase in energy consumption can also be indirectly explained by the *Income effect.* Wind subsidies increase employment and income level in the wind energy industry. By including the economic activity in the industry, both consumers and producers may increase energy consumption, more purchasing power can lead to higher energy use. Silva, Mccomb & Schiller (2014) found out that increase in wind farms capacity can lead to higher employment in the wind sector, agriculture and construction, and increase wages in all economic sectors.

Our findings of the reduction of CO_2 emissions by 19% from 2021 to 2030 in the context of wind subsidies can be supported by several economic theories. Firstly, wind subsidies that increase the wind production capacity have an objective to correct the *market failure* by reducing CO_2 emissions. There are many researches, including Xie et al. (2020), that imply that wind power has a priority to generate clean energy and significantly decrease CO_2 emissions. In addition, the increased wind energy production directly removes fossil fuel-based energy production. According to Valentino et al. (2012), as the wind power propagation increases, emissions that are related to pollution decrease due to replacement of fossil fuels.

8.4.The effect of the policy mix

The results show that the most effective policy is policy mix, which includes both carbon tax and EU-ETS price increase. Taking into consideration that carbon tax increase scenario results have similar economic effects as the EU-ETS price increase scenario, it is reasonable to state that the policy mix scenario has a double effect.
Both energy use and electricity production increase at the highest rate. All industries move from carbon based energy sources to renewable based energy sources due to the dual effect of financial burden. Higher pressure on carbon based energy sources will lead to cheaper prices for electricity. Hence, more consumers and producers will switch their preferences towards consumption of electricity. Price and substitution effects perfectly describe this case.

9. Limitations

There are several limitations related to both TIMES modeling framework and basis of analysis in our research.

Even though TIMES model is a widely used energy modeling framework, it has some limitations. Firstly, the TIMES model requires extensive data inputs. Therefore, we applied and used assumptions for unreliable or unavailable data. These assumptions could make an impact on some part of the model's outputs. Secondly, the TIMES model assumes that consumers and producers behave rationally over a specific range of time. However, in reality the behavior of the agents can be complicated. Thirdly, the model assumes perfect market conditions, which do not represent the reality of the energy market. In reality, there are interventions, market failures, etc. In addition, The TIMES model assumes perfect competition, meaning that all economic agents are price takers. However, in the energy market in the real world there are a few major producers and distributors that lead to a concentration of market power. Lastly, the TIMES model does not include the social and political constraints in the framework which can affect the whole energy system.

Our analysis and methodology limitations include the relatively simplification of the overall energy system, no uncertainty used in the model and not coverage of all energy policies. Energy system is essentially complex because of different interrelated features. Hence, there is a certain probability that our analysis does not cover recent changes in the interdependencies, infrastructure and supply chains etc. Another limitation might be the usage of deterministic modeling framework which does not allow to take uncertainties in the model. Finally, our research does not cover all energy policies that are active nowadays. We do not exclude that more coverage of them might impact the overall outcome.

10. Conclusion

In our research we made and elaborated analysis of the energy market in Norway and assessed the energy policies to answer our research questions. One of the objectives was to understand the impact of these policies on energy balance and environmental components such as energy use, electricity production and CO_2 emissions. Another objective was to make a scenario analysis to evaluate the reachability of CO_2 emissions targets in Norway set by Norwegian Ministry of Climate and Environment in the Norway's Climate Action Plan. We included the following scenarios: EU-ETS price increase, carbon tax increase, mix scenario and wind subsidies increase.

We used the TIMES model within VEDA interface as the main tool to perform analysis and make scenarios. TIMES model is a widely used optimization model that captures the whole energy sector and collaborates with the rest of the economy. It provided us with cost optimized outputs within different scenarios.

Our main findings show that the CO_2 emissions target of 50% reduction from 1990 is not achievable by 2030.The most effective policy is a mix scenario, the CO_2 emissions will reach 35 millions of tonnes in 2030, which is only 32% CO_2 emissions decrease from the level of 1990.

Other findings include the increase in energy use and electricity production in all scenarios. The percentage of increase varies between each of them.

Energy consumption will increase by 82%, 90%, 171%, and 102% in scenarios 2,3,4, and 5 respectively. The policy mix scenario has the most dramatic effect due to the double effect of policies where all sectors decide to move from carbon based energy to renewable based sources.

Electricity production will increase by 35%, 44%, 69%, and 47% in scenarios 2, 3,4, and 5 respectively. The highest increase has a policy mix scenario where more renewable energy will be developed because of the decrease of carbon-based energy.

However, there are some limitations in our research that should be considered and maybe helpful for future investigations. These limitations include the requirement of extensive data inputs, rationality of agents, perfect market conditions, complexity of energy systems and absence of uncertainties.

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APPENDIX

1. Mathematics of the TIMES equilibrium

1.1. TIMES objective function

The Total surplus maximization can be transformed into the Total cost minimization problem, by taking the negative of the Total surplus, and this value can be called *total system cost.*
The demand function for each commodity i is as the following (Loulou et al., 2016):

$$DM_i / DM_i^0 = (p_i / p_i^0)^{E_i} \qquad (4-1)$$

Or its inverse:

$$\boldsymbol{p_i} = \boldsymbol{p_i^0} \cdot (\boldsymbol{DM_i} / \boldsymbol{DM_i}^0)^{1/\boldsymbol{E_i}}$$

With inelastic demand TIMES model can be expressed like this linear cost minimization program (Loulou et al., 2016):

$$\begin{aligned} &Min \quad c \cdot X \\ &s.t. \quad \sum_k VAR\_ACT_{k,i}(t) \geq DM_i(t) \qquad i = 1,2,..,I;\; t = 1,..,T \\ &and \quad B \cdot X \geq b \end{aligned}$$

X is the vector of all variables included in TIMES. **I** is the amount of demand categories. **C** is the cost vector.

- The first equation is the objective function that has to be minimized.
- The second equation is the constraint, where VAR_ACT is the activity levels of the end-use technologies that must be more or equal to the demand levels on the RHS (DM).
- The third equation is all the other types of possible constraints.

In the case with elastic demands, the demand changes as the prices change. According to the Equivalence Theorem, when the total economic surplus is maximized the equilibrium will be reached.

$$Max \quad \sum_i \sum_t \left(p_i^0(t) \cdot \left[DM_i^0(t) \right]^{-1/E_i} \bullet \int_a^{DM_i(t)} q^{1/E_i} \cdot dq \right) - c \cdot X$$

$$s.t. \quad \sum_k VAR\_ACT_{k,i}(t) - DM_i(t) \geq 0 \qquad i = 1,..,I; \; t = 1,..,T$$

$$and \quad B \cdot X \geq b$$

- In the first equation, the objective function is the maximization of total net surplus.