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Consequences of green certificate and volatility in green certificate price

A case study of Norway

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Environmental Economics

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ABSTRACT

In last two decades national governments have increased their support to renewable energy sources (RES). The European Union (EU) has been considered as a pioneer in this area. The Norwegian governmental policies have also applied several support schemes to induce investment on environmental friendly technology. One of the main tools presented by the Norwegian government is the Norwegian-Swedish electricity certificate system.

The electricity certificate market is a market-based support scheme where the producers of renewable electricity receive one certificate per MWh of electricity they produce and the electricity consumers are obligated to support the system by purchasing certificates corresponding to a certain proportion (quota) of the electricity use.

The current study investigated the impacts of the electricity certificate quota on renewable production, wholesale electricity and certificate price and economic growth in Norway. Furthermore, the role of regulatory changes or economic uncertainty on the certificate price volatility was also investigated. The monthly data has been collected from the time period 2012 to 2016. Only Norwegian electricity certificate market has been considered.

The analysis criterion of the current study is that it should be understandable. The understandable means that the developed models should be clearly defined and easy to use. In order to meet this criterion, the models are limited to simple time series models such as regression and GARCH models. The regression model was used to analyze the relationship of different variables with the electricity certificate quota and the GARCH model was used to investigate the role of regulatory changes on price volatility in the Norwegian certificate market.

The findings agreed with previous research that as the electricity certificate quota increases, the supply of renewable electricity in the energy market increases, which tends to decreases the wholesale electricity price. Furthermore, increased certificate quota accelerates the investment in renewable electricity which contributes to the economic growth. On the other hand, the current findings did not verify the increased certificate price with raised certificate quota. Moreover, the regulatory changes or economic uncertainty have effects on the certificate market, resulting in period of higher volatility.

SAMMENDRAG

Flere stater har i løpet av de siste tyve årene økt støtten til fornybare energikilder. Den europeiske union (EU) har vært ansett som en pioner på dette området. Også norske myndigheter har søkt etter støtteordninger for å øke investering i miljøvennlig teknologi. Et av de viktigste verktøyene presentert av norske myndigheter har vært det norsk-svenske el-sertifikatsystemet.

El-sertifikatmarkedet fungerer ved at produsenter av fornybar elektrisitet får ett sertifikat per MWh elektrisitet de produserer. Strømforbrukere er forpliktet til å understøtte systemet ved å kjøpe sertifikater tilsvarende en andel av sitt elektrisitetsforbruk.

Denne oppgaven undersøker påvirkningen av el-sertifikatkvoter på produksjon og salg av fornybar energi, samt sertifikatprisen og økonomisk vekst i Norge. I tillegg undersøkes effekten av endrede politiske føringer og økonomisk usikkerhet på svingninger i sertifikatprisen. Den månedlige dataen er hentet fra tidsperioden 2012 til 2016. Kun det norske el-sertifikatmarkedet er undersøkt.

Analysekriteriet for oppgaven er at den bør være forståelig. Dette innebærer at de utviklede modellene er klart definert og enkle å bruke. For å møte dette kriteriet er modellene avgrenset til enkle tidsseriemodeller, som regresjon- og GARCH-modeller. Regresjonsmodellen ble brukt til å analysere forholdet mellom ulike variabler med el-sertifikatkvoten, og GARCH-modellen ble brukt til å undersøke effekten av endrede politiske føringer på prissvingninger i det norske el-sertifikatmarkedet. Resultatet indikerte at perioden mellom april og oktober 2015 var en periode med økte svingninger i el-sertifikatprisen.

Funnene samsvarer med tidligere forskning, som viser at når el-sertifikatkvoten øker, øker tilbudet av fornybar elektrisitet i energimarkedet. Dette resulterer ofte i redusert elektrisitetspriser. Økte sertifikatkvoter akselererer investeringer i fornybar elektrisitet, som igjen bidrar til økonomisk vekst. På den andre siden bekreftet ikke funnene den økte sertifikatprisen med hevet sertifikat kvote. I tillegg har endrede politiske føringer eller økonomisk usikkerhet påvirkning på sertifikatmarkedet, ved at det fører til perioder med større prissvingninger.

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LIST OF AB BREVIATIONS

ARCH	:	Autoregressive Conditional Heteroskedasticity
BG	:	Breusch Godfrey
CLRM	:	Classical Linear Regression Models
GARCH	:	Generalized Autoregressive Conditional Heteroskedasticity
LM	:	Langrangian Multiplier
MWh	:	Megawatt Hours
NVE	:	Norges Vassdrags og Energidirektorat
OED	:	Olje og EnergiDepartementet
OLS	:	Ordinary Least Square
RESET	:	Ramsey Regression Equation Specification Error Test
RES	:	Renewable Energy Sources
TWh	:	Terawatt Hours

CHAPTER I

INTRODUCTION

"***Some solutions are relatively simple and would provide economic benefits: implementing measures to conserve energy, putting a price on carbon through taxes and cap-and-trade and shifting from fossil fuels to clean and renewable energy sources***"

These are the words of David Suzuki, who is an environmental activist and the owner of David Suzuki foundation.

In last two decades national governments have increased their support to renewable energy sources (RES). The European Union (EU) has been considered as a pioneer in this area by capping emissions and implement ambitious targets for promoting electricity from new renewable energy sources. In 2009, the EU has introduced "Directive 2009/28/EC" also known as the RES-E Directive[1]. The Directive requires 20 percent of the total energy consumption within the EU must come from renewable sources by 2020 (European Commission, 2017). On 19th December 2011, the Norwegian directive "Fornybardirektivet" was incorporated as part of European Economic Association (EEA), stating the Norwegian government's commitment to increase the share of the domestic power consumption produced by renewable sources up to 67.5% by 2020 (Totland, et al, 2012). However, majority of Norwegian governmental policies have applied on several support schemes to induce investment on environmental friendly technology.

One of the main tools presented by the government for achieving this target is the Norwegian-Swedish green certificate system; this system has designed to motivate investment in renewable energy production and to achieve the required target by 2020.

The aim of green certificate market is to boost up further renewable energy investments. The main target of the joint green certificate scheme is to establish new renewable energy technologies that can generate about 28.4TWh of renewable energy in Norway and Sweden by 2020 (OED, 2015). The feature of electricity certificate has been taken into an imperative issue along with the quota obligation on the production of renewable electricity and to achieve RES-E targets.

[1]The EU Renewable Energy Directive sets binding national targets for the proportion of renewable Energy. Binding national targets have been set so as to ensure that by 2020 the EU will have a proportion of renewable energy corresponding to 20 per cent of total energy consumption.

The interaction of different green and black instruments is discussed several times in the literature. Nielsen and Jeppesen (1999) discuss the green certificates and its interaction with the mechanism of the Kyoto Protocol and argued that the two regulatory instruments could have a mutual impact. Morthorst (2001) discusses the impact of two separate international markets for green certificates and tradable emission permits. He analyses that the green certificate obligation can lead to a large expansion of renewable energy sources in each country and thereby impede the least-cost solution for carbon dioxide (CO_2) abatement. Amundsen and Mortensen (2001) analyze an electricity market with both green certificates and CO_2 emission permits. They model a green certificate market with price floors and ceilings and analyze their impact on prices and quantities. Bohringer and Rosendahl (2010) focus on the impact of an additional green quota on the emissions trading system. Bye (2003), presents a model for an energy market that include green certificate for suppliers of energy from renewables and a purchaser commitment to buy these certificates. He shows that the wholesale price of electricity declines as quota imposition increases but certificate and consumer prices and volume effects in the energy market are ambiguous under a wide range of alternative levels of the purchaser commitment.

As far as volatility in green certificate price concern, it is a critical issue. Several analyses illustrate that certificate prices could be highly uncertain and volatile. The certificate price volatility can be caused by the prolong construction of new power plants. The renewable energy projects are mostly capital intensive. Thus, in case of excess investment in the renewable sector, the certificate price would collapse causing massive capital losses to investors (Kildegaard, 2008). The certificate markets are characterized by a politically driven demand, causing investors to be heavily exposed to regulatory uncertainty (Holburn, 2012). The changes in the regulation can have an impact on certificate prices, price volatility and risk, ultimately affecting the cost of financing a project (Gross et al., 2010). Regularity Changes or any uncertainty (weather changes) could increases or decreases the electricity demand or supply, which directly influence the electricity certificate price as it is also acquired as a percentage of electricity consumption in Norway.

Increased electricity demand and decreased electricity supply could increase the certificate price vice versa. Figure 1.1 displays the volatility in certificate price from January 2012 to August 2016.

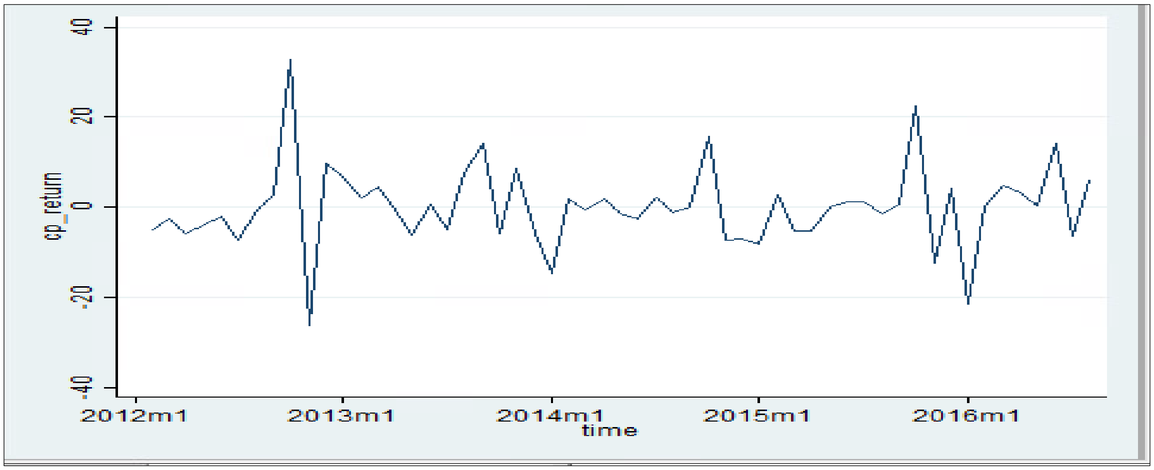

Figure 1.1: The return on the certificate spot price from January 2012 to August 2016 in Norway.

The current study complements these aforementioned papers by deriving all price and quantity effects analytically under a closed economy. Furthermore it will empirically investigate that whether the regularity changes or economics uncertainty has any impact on Norwegian electricity certificate price from 2012 January to 2016 August.

1.1 Study hypotheses

The joint Norwegian–Swedish electricity certificate scheme is intended to boost renewable electricity production in both countries. The market is technology-neutral that is all forms of renewable electricity are entitled to electricity certificate, including hydropower, wind power and bioenergy (Norwegian Ministry of petroleum and energy, 2015). The goal of the market is to increase13.2TWh of electricity production based on renewable energy in Norway by 2020 (The Norwegian-Swedish certificate Market, Annual report, 2015).

This study is focused to analyze the electricity certificate market in Norway based on the following hypotheses:

1) The wholesale price of electricity will decrease and the green electricity production and certificate price will rise followed by an increase in certificate quota.
2) The economic growth will be contributed by the introduction of green certificate market. The increased investment in electricity production will increase electricity production, high profit in electricity sector, create more jobs and increased electricity consumption. The price of equity index (STOXX Nordic 30) is used as an indicator of economic growth.
3) Economic uncertainty or the regularity changes will lead to increase certificate price volatility.

1.2 Study objectives

This study aims to investigate how electricity certificate market works in Norway and what are its impacts on renewable production, prices and economic growth. Furthermore, the current study will also investigate the possible role of regulatory changes or economic uncertainty on price volatility in the Norwegian certificate market.

The following study questions are asked in line with aforementioned hypotheses.

- **Does the electricity certificate quota effect the production of green electricity, wholesale electricity price and certificate prices?**
- **Does electricity certificate market contribute to the economic growth?**
- **Do the regulatory changes or economic uncertainty change the certificate price volatility?**

CHAPTER II
BACKGROUND

2.1 The Nordic electricity market

Norway started the liberalization of its electricity market in 1991 when the law of deregulating the market for trading power went into effect. The independent Norwegian power exchange was established in 1993, followed by the establishment of Norwegian-Swedish power exchange and the world's first international power exchange, Nord Pool, in 1996. Finland joined the market in 1998, and the Nordic market became fully integrated as Denmark followed in the year 2000 (Peljo, 2013). The process of liberalization was gradual and the changes and improvements are constantly implemented to further improve market integration and harmonization. The deregulation came as a response to the accumulated overcapacity and the goal was to increase the efficiency of capacity, improve cost efficiency of supply and introduce consumer choice (Sand, 2015).

The Nordic countries are very different in terms of their power generation structure. Table 2.0 is displaying the Nordic power generation capacity by countries in 2013. Denmark is the smallest power producer in the region. The total installed capacity was around 14, 841 MW in 2013. The country enjoys a slightly milder climate and uses thermal and wind as the main source of power generation with zero nuclear power capacity. Finland accounts for roughly a third of the power generation in the Nordic market with more than 35% power generation based on fossil fuels. The total installed capacity was 17,300 in 2013. On the contrary, In Norway about 95% of the installed capacity is hydro based. The installed Norwegian power production capacity was 32,879 MW in 2013. Sweden is the largest power generator in the region with the hydro and nuclear power together accounting for over 80% of the country's production.

The renewable sources of energy play an important role in all the Nordic countries' energy plans. Hydro, wind and biomass resources are plentiful and the availability of these resources played an important role in industrializing the Nordic countries. The total annual power generation in the Nordic power market was around 103,313, in 2013 and about half of which was produced by hydropower (Table 2.1).

The other renewable sources of electricity, such as wind power and solar power etc. represent in total ca.10% of the power generation and thus play a smaller role in the Nordic market. Nuclear power and other thermal power represent around 30% of the power generation.

Table 2.1: Nordic power generation capacity (MW) by countries in 2013 (Modified from: NordREG, 2014)

	Denmark	Finland	Norway	Sweden	Nordic region
Installed capacity (total)	14861	17300	32879	38273	103313
Nuclear power	-	2752	-	9531	12283
Other thermal power	6989	11135	1040	8079	27243
Condensing power	-	2465	-	1375	3840
CHP, district heating	1929	4375	-	3631	9935
CHP, industry	562	3180	-	1498	5240
Gas turbines etc.	-	1115	-	1575	2690
Hydro power	9	3125	30900	16150	50184
Wind power	4809	288	811	3745	9653
Sun power	563	0	N/A	43	606

2.2 The Norwegian energy market

In 1991, the power system and electricity market in Norway has been liberalized. Norway is a part of a joint Nordic market for electricity. The Norwegian energy system differs from the energy system of other European countries in some aspects. Norway has the biggest consumption of electricity per capita in the world. This is comparatively due to the fact that large measure of electricity use for household heating in Norway, whereas other countries depend on oil-based or district heating system (Goldstein, 2010). Relatively cheap access to electricity from hydropower has made Norway dependent on this source of energy for centuries.

Norway is among the countries that use the most electricity per person in housing. It also has the highest proportion of electricity in residential consumption. In 2015, the total electricity consumption in households in Norway was 213TWh per person (Statistic Norway, 2016).

This is 1.2 percent more than the previous year. Norway is the largest hydropower producer in the Europe and the sixth largest hydropower producer in the world.

The total electricity production has been estimated 141,968GWh, where 136,181GWh, 3570GWh and 2217GWh are from hydroelectric plant, thermal power and wind power during 2014 respectively (Statistics Norway, 2016) (Appendix J). In the same year the total net consumption was 117, 057GWh (Statistics Norway, 2016a).

2.2.1 Electricity generation in Norway

2.2.1a Hydropower

Electricity generated by hydropower considered as an important source of renewable energy. Hydropower is termed as a green energy because its production does not involve in harmful emissions. About 16% of world's total energy and 70% of renewable electricity is generated by hydropower in 2015 (Wikipedia, Hydroelectricity, 2017). The ten largest producers of hydropower in 2014 are presented below (Table 2.2). The table (2.2) shows the total hydropower production, capacity and share of electricity production.

Table 2.2: The ten largest producers of hydropower in 2014 (Modified from Wikipedia, 2017)

Country	Annual hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total production
China	1064	311	0.37	18.7%
Canada	383	76	0.59	58.3%
Brazil	373	89	0.56	63.2%
United States	282	102	0.42	6.5%
Russia	177	51	0.42	16.7%
India	132	40	0.43	10.2%
Norway	129	31	0.49	96.0%
Japan	87	50	0.37	8.4%
Venezuela	87	15	0.67	68.3%
France	69	25	0.46	12.2%

Above table represents that only 18.7 % of contribution of total hydro electricity in China. The smallest contribution of hydro is in USA where hydroelectricity only accounts for 6.5% of total electricity production, while it counts for 96 % of the electricity production of Norway.

Norway is blessed by the natural resources and a geography that enables Norway to build environment friendly hydropower plants. In Norway a typical hydropower plants based on reservoir located in a remote mountain area. Around 50 percent of the reservoir capacity in Europe is located in Norway (Patocka, 2014).

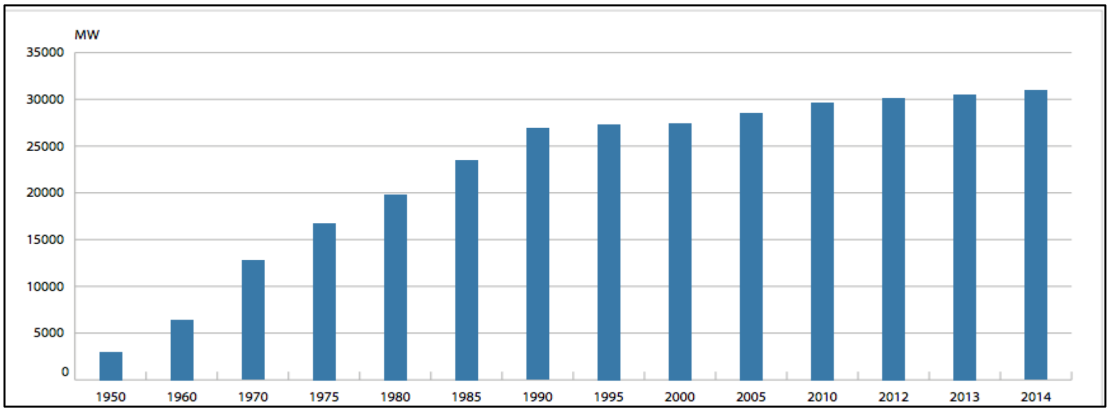

Figure 2.3: Installed capacity in hydropower plant in Norway from the period 1950-2014 (Source: NVE)

Figure 2.3 shows the installed capacity of hydropower plants. In 2014, the total installed capacity in Norwegian hydropower plants was 30,960 MW. In 2003, hydropower production amounted to 106 TWh, which was the lowest level since 1996.

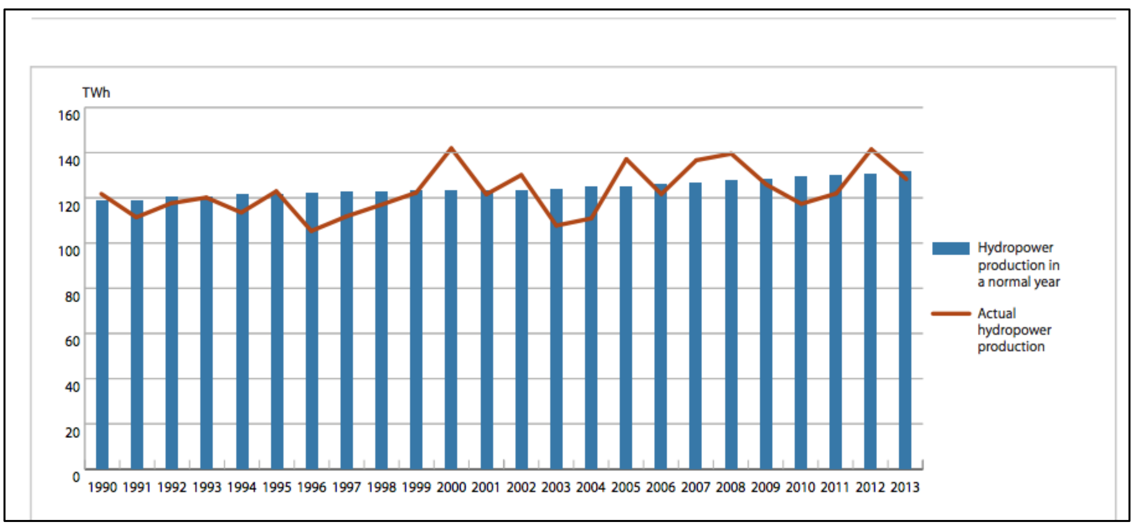

Figure 2.4: Hydropower production in a normal year and actual hydropower production from period 1990 to 2013 (Source: NVE)

Figure 2.4 shows hydropower production in a normal year and actual hydropower production in the period 1990–2013.

The classical hydropower plant in Norway is characterized by a high head hydropower, where energy is gained from flow of water being processed (Patocka, 2014). The head of reservoir is the difference in height between the water intake and the power plant outlet. The water is directed into the pressure shafts leading down the power station (Ferrier & Jenkins, 2010). The water reaches the turbine wheel at high pressure. The kinetic energy in the water is transferred through the turbine's drive shaft to a generator that converts it into electrical energy. The water is led from the turbine back into the river at the outlet. The volume of water that can be led into a hydropower plant depends on the useful inflow and the regulation reservoir's storage capacity. The water inflow is the volume of water from the drainage basin that can be utilized for electricity generation in the power plant. And thus the useful inflow varies from one part of the country to another, between seasons and between years. In Norway the water inflow is highest during the spring snowmelt, and normally declines towards the end of summer (Førsund, 2007). During the winter months, inflow is normally very low. Over the last 23 years, the annual useful inflow to Norwegian hydropower plants has varied by about 60 TWh. The lowest level was registered in 1996 and the highest in 2011 (Fig. 2.5).

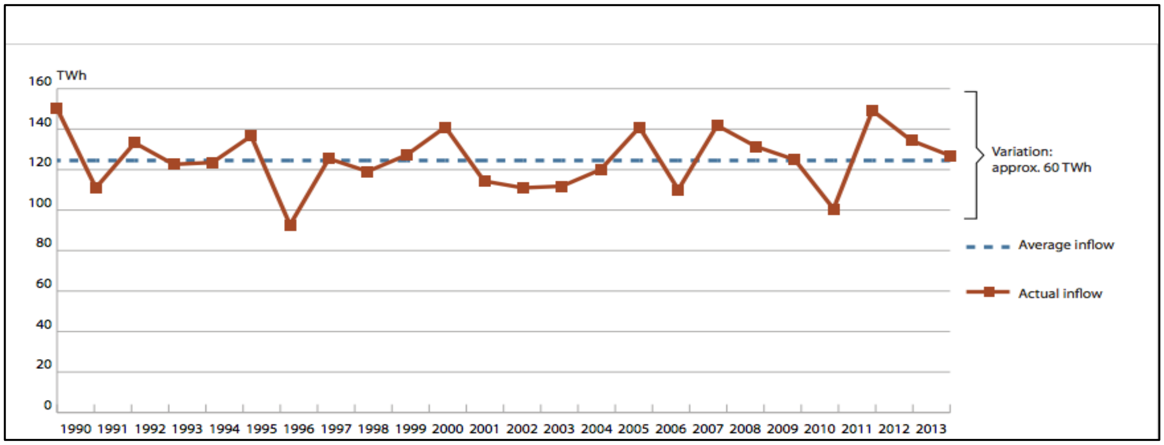

Figure 2.5: Annual inflow in to the Norwegian hydropower system from 1990 to 2013 (NVE/ Nordpool)

2.2.1b Economics of hydro power production

Figure 2.6 illustrates the economics of hydropower with reservoirs in the two period`s case. The floor of the bathtub represents the total available water for two periods and the demands curves anchored on each wall. The maximal storage assumed to be introduced, which is BC. The storage is measured from C toward the axis for period 1 because the decision of how much water to transfer to period 2 is made in period 1 (Førsund, 2007). The inflow and initial water is AC in period 1 and the inflow in period 2 is CD. The common price for the two periods can be determined by intersection of demand curves. The distribution of electricity production can be seen on the bathtub floor (point M). The case of optimal transfer exhibits when the reservoir limit is not reached but now it is assumed that there is scarcity in period 2, since all the available water is used in that period that is (MC+ CD). Therefore the amount AM is consumed in period 1 and MC is saved and transferred to period 2. Thus the total amount available for both the periods is used up and raises the price for both the periods. By considering that the water consumed in period 1 is at the expense of potential consumption in period 2 the water values become the same and equal to the price for both periods (Førsund, 2007).

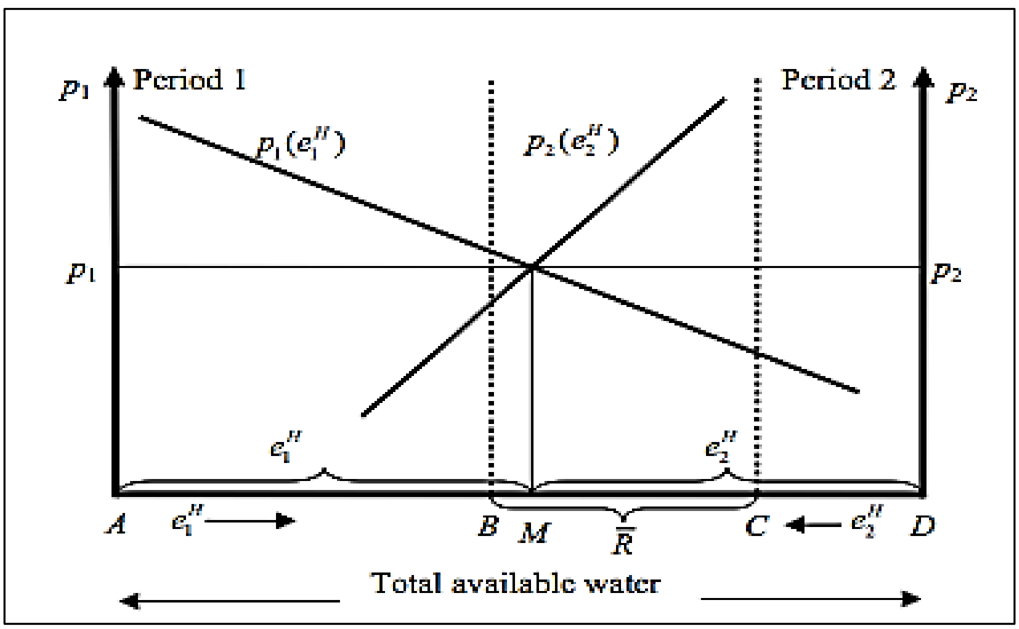

Figure 2.6: Two-period bathtub diagram with non-binding reservoir constraints (Førsund, 2007)

2.2.1c Wind power

The attractive locations for wind power generation are areas with a high average wind speed and even wind conditions throughout the year. The large part of Norway is considered to have some of the best wind resources in Europe. At the end of 2015, the electricity generation was 2.5TWh from wind power in Norway. The total installed capacity was 873MW distributed in 374 wind turbines (Norwegian Water Resources and Energy Directorate, 2015). The wind electricity accounted for 1.7% of Norway's total electricity production in 2015 (Appendix I).

The wind energy is also assumed to represent the main capacity when reaching towards the national goal of 13.2TWh increased renewable production by 2020, as well as complying with RES-E Directive. The expected wind energy production has been set about 6-8TWh by government by 2020 (Table 2.4).

Table 2.4: Wind energy production for 2014 (Vindportalen, 2015)

Installed capacity	856 MW
Production in 2014	2.2TWh
Capacity factor 2014	31%
Built in 2014	45 MW
Expected (government) installed power in 2020	3000-3500 MW
Expected (government) production power in 2020	6-8TWh

The table 2.5 displays the overview of winds parks in Norway that are currently the recipients of electricity certificate. Midtfjellet and Raggovidda Wind Park are considered the only commercially sized wind parks in Norway that have been built on the basis of the common electricity certificate system (Sand & Stubsjøen, 2015). In addition, two smaller wind power plants Valsneset and ÅsenII are also recipients of electricity certificates.

Table 2.5: An overview of Norwegian wind power generators under the green certificate (Sand & Stubsjøen, 2015).

Wind Power projects	Installed Capacity	Owner	Ownership category
Midtfjellet	57.5MW	Midtfjellet Vindkraft AS	Utility types (municipal energy companies)
Raggovidda	45MW	Varanger KraftVind AS	Utility types (municipal energy companies)
Valsneset	3MW	Blaaster Valsneset AS	Independent power producer (test facility)
ÅSEN II	1.6MW	Solvind Åsen AS	Independent power producer

2.2.1d Investing in wind power

There are the several factors that have to be considered when investing in wind power. In general, it is important to find a good wind conditions site. Another main factor is the cost of wind power plant. A lower operational cost and the large resource potential are making it more attractive for the investors in Norway. The cost of wind power plant can be divided in to investment cost and operational and maintenance cost. The investment and the operational cost depend on location, size of the wind park, number of turbines and type of technology.

Similarly, with Johannessen (2015), the average investment cost of five wind parks, which started operation in Norway between 2011 and 2013, are estimated (Fig. 2.8). The five projects had an average investment cost of approximately 12000 NOK/kW (NVE, 2015). According to Norwegian water resource and energy directorate, the estimated investment cost for the five projects is 20 percent lower in 2014 than the average investment cost between 2011 and 2013. This cost reduction is mainly because of lower turbine prices as well as lower construction and project management costs (NVE, 2015).

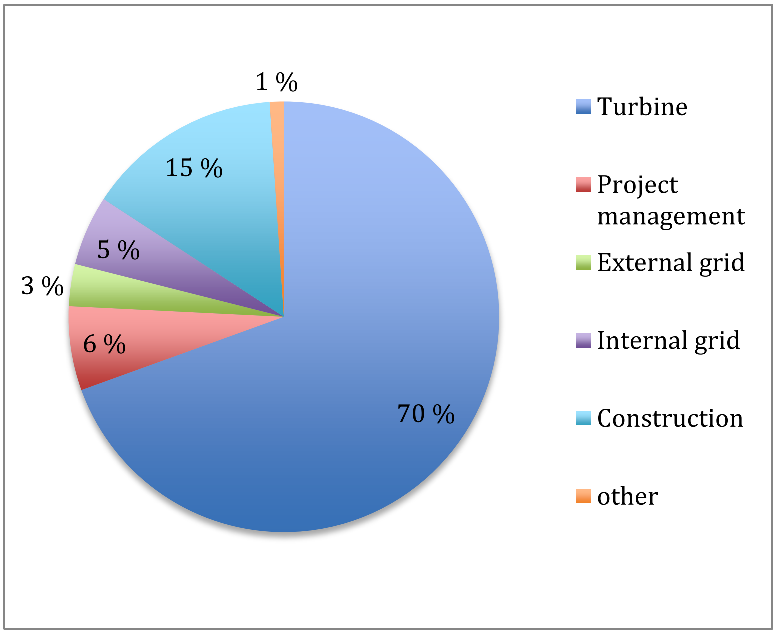

Figure 2.8: Average distribution of investment cost for five wind power projects in Norway, NVE (2015).

As far as the operational and maintenance cost of wind power concern, it is considered relatively lower compared to other power generating cost (The European Wind Energy Association, 2009). This is because that the wind is a natural resource that is given by nature and under normal circumstances frequent maintenance of the equipment is not required. The operational and maintenance cost may include a number of components for example Insurance, regular maintenance of roads and grids, repair, services and spare parts and administration or operation personnel etc. These costs are often project specific and data about the cost is difficult to collect. NVE estimates that 15 øre/kWh is a reasonable operational and maintenance cost for the wind power plant (NVE, 2015).

Beside the cost of wind power plant the best turbine technology for the given site and wind conditions is also considered. The rapid development has been found in wind power technology over the last decades. The height of turbine and the size of the rotor blades play an important role in improved efficiency and reduced cost of the wind power park (Johannessen, 2015). Which turbine class is favorable for a site depends on the wind speed at the site, the degree of turbulence and the maximum wind speed that might occur in a 50-year period (Renewablesfirst, 2015).

In Norway, it is estimated that the average full load hours for winds can be expected to increase by 1.5 percent each year till 2020 due to the improved rotor design and the advanced control system that can adjust for the unstable wind conditions (NVE, 2015).

2.3 What is green certificate?

The electricity, which comes from coal, nuclear, natural gas and from some renewable sources such as wind, hydro power plant or solar etc., is mixed together in the transmission and distribution lines that deliver electricity to the consumers. Once electricity comes in a grid, it becomes impossible to distinguish renewable electricity from non-renewable electricity. Green certificate acts like a tracking system that certain electricity is generated using renewable energy source. Typically, one certificate represents generation of 1MWh of renewable electricity. Electricity consumers are obligated to support the renewable electricity generation by purchasing certificates corresponding to a certain proportion of the electricity use. Producers of renewable energy, which are approved by Swedish Energy Agency and NVE, receive electricity certificates in relation to their electricity generation. The producers sell the certificate and receive revenue in addition to the revenue they receive from selling the electricity. Commercial electricity suppliers are obligated to buy electricity certificates in relation to how much electricity they sell.

2.3.1 How does green certificate market work?

A green certificate is a mechanism aiming to support the electricity generation from RES. The mechanism works with regulatory imposition of a quota for a certain amount of the electricity consumed has to be produced by renewable resources sources, issuing certificates to producers offering renewable electricity (Swedish Energy Agency & NVE, 2015). Parties having a quota obligation, usually retailers or distributors, regularly surrender certificates to the regulator corresponding to their quota. Hence, obliged parties can decide to either buy certificates from existing generators or to build power plants and produce certificates on their own. This way, the regulator creates a market mechanism in which the price paid for renewable electricity is determined by the interaction between certificate demand and supply.

2.3.2 A joint Norwegian- Swedish green certificate market

Norway and Sweden have operated a joint electricity certificate market since 1st January 2012, which means that certificates can be traded across the country border. The producers of renewable electricity can receive electricity certificates regardless of whether the electricity is produced in Norway or in Sweden; they can invest in production wherever the conditions are most favorable (Swedish Energy Agency & NVE, 2015). The aim of green certificate market is to boost up further renewable energy investments. The main target of the joint green certificate scheme is to establish new renewable energy technologies that can generate about 28.4TWh of renewable energy in Norway and Sweden by 2020 (OED, 2015). An increased development of new energy will lead to improve future energy supply, stable energy prices and help reaching climate policy targets. Another objective of green certificate is to stimulate the wind power.

2.3.3 How does Norwegian green certificate market work?

The function green certificate market is illustrated in the following steps:

1. Firstly, the producers of renewable electricity receive one green certificate for each (MWh) of renewable electricity produced through green certificate system.
2. Secondly, the electricity producers can sell their certificates, where supply[2] and demand[3] determine the prices. In this way producer receive income plus the income they receive from selling the electricity.
3. Demand for electricity certificates arises as electricity suppliers and consumers are obligated by law to buy green certificate corresponding to a certain quota of their electricity sales or consumption.
4. The electricity consumers pay for the development of renewable electricity production because the cost of green electricity certificates is included in the electric bill.

[2]Supply of new renewable energy sources that have the right to be assigned certificate.

[3] Demand for electricity is created by the requirement for electricity suppliers and end-users to purchase certificates corresponding to a certain quota of their sale or consumption of electricity.

2.3.4 Quota obligation

The quota curve is designed to stimulate the development of renewable power production in accordance with countries' settled target. A complete table of the annual quotas and the corresponding forecasted new renewable production in Norway for the year 2012-2035 illustrates that quotas are gradually increases until 2020, which increases the demand for green electricity certificates (Appendix K). The quotas are specific to each country. Norway's quotas run from 2012-2035 (Swedish Energy Agency & NVE, 2015). Quotas are calculated for each country respectively from the estimates of future electricity consumption subjected to certificate obligations. If actual electricity consumption deviates from expected consumption, this may mean that quota curve must be adjusted and these adjustments will be performed at so called control stations, the first of which will be held in 2015 (Swedish Energy Agency & NVE, 2013). For 2015, Norwegian market participants with quota obligations had to purchase electricity certificates corresponding to 8.8 per cent of their electricity consumption. In Sweden, the quota was 14.3 per cent (Appendix K). The difference in quotas is due to the calculation-relevant electricity consumption being higher in Sweden than in Norway (Swedish Energy Agency & NVE, 2015).

CHAPTER III

MODEL OF THE STUDY

3.1 The general model for Green certificate market (without trade)

The model is formed in order to analyze the green certificate market. This model is a deterministic model[4], where one country is assumed corresponding to a closed economy, i.e. no international trade. The only commodity assumed is electricity. The market contains “n” firms, which generate electricity with different technologies “black “, non-renewable energy sources and “green”, renewable energy sources. For simplicity one consumer and two producers. I assume the market for electricity to be characterized by perfect competition. The following variables and functions will be used in the model:

Y_b	:	Black electricity produced with non-renewable sources
Y_g	:	Green electricity produced with renewable sources
$Y = Y_b+Y_g$	:	Total production of electricity
P_w	:	Whole sale price of electricity
P_c	:	Consumer price of electricity
P_s	:	Price of green certificates
α	:	Quota obligation for green certificates
C (Y)	:	Cost function for black/green electricity production with increasing marginal cost $\partial C_i/\partial Y_i > 0$ and $\partial C_i^2/\partial Y_i^2 \geq 0$, for i=b, g
Y_{bs}	:	Supply of black electricity with $\partial Y_{bs} / \partial Pw > 0$
Y_{gs}	:	Supply of green energy with $\partial Y_{gs} / \partial Pw > 0$
$Y^s = Y_{bs}+Y_{gs}$	:	Supply of electricity
Y^D	:	Demand of electricity
$Y_t = \alpha Y^D$	:	Demand of green certificates, since all the electricity consumer are obliged to purchase a number of green certificate equals to α times of their electricity demand.
U (Y^D)	:	Utility of electricity demand

[4]Deterministic model is the model where the output of the model is fully determined by the parameter values and the initial conditions.

Producers

Electricity producers use either renewable energy "green" or non-renewable energy "black", in order to produce electricity. The generation of black electricity causes CO_2 emission, resulting from the use of carbon-based non-renewable resources. It is assumed that the emissions are directly proportional to the amount of electricity produced.

Profit of black electricity producers is:

$\pi^b_i = P_w Y_{ib} – C_i Y_{ib}$

Maximization problem for the black electricity producer:

$\max \; P_w Y_{ib} – C_i(Y_{ib})$

First order condition

$P_w - \partial C_i/\partial Y_{ib} = 0$

$P_w = \partial C_i/\partial Y_{ib}$ ……………………………………………………………………………[1]

The generation of green electricity is not associated with the production of emissions. It is assumed that all the renewable technologies have the same cost function and a single firm produces all the green electricity. It is also assumed that it is more expensive to generate electricity from the green technology than to generate from the black technology and thus green electricity is not able to compete in the market without any kind of government subsidies.

Profit of green electricity producers is:

$\pi^g = P_w Y_g – C_g Y_g$

Maximization problem for the green electricity producer:

$\text{Max } P_w Y_g - C Y_g$

First order condition

$P_w = \partial C/\partial Y_g$………………………………………………………………………………...[2]

Retailers buy the electricity from the producer at wholesale price P_w and sell it to the end-users for the consumer price P_c. As the market is described as perfect competition, it makes zero profit.

$\pi^d = P_c Y – P_w Y_{ib} - P_w Y_g = 0$,   where $Y = Y_b + Y_g$

Consumer is assumed to have a strictly concave utility function U, which depends on the amount of electricity consumed Y at price P_c. The consumer maximize utility U (Y^D) of electricity demand net of purchaser cost PY^D (Bye, 2003)

$$\mathbf{max\ U\ (Y^D) - P_w.Y^D}$$

Market equilibrium

In market equilibrium total economic surplus, together consumer and producer surplus is maximized. As producers maximizes their profits indicating the wholesale price equals the marginal costs of production (see equation 1and 2). In equilibrium on the electricity market demands equals the supply

$$\mathbf{U\ (Y^D) = Y_{bs} + Y_{gs}}$$

Green certificate market

By regulating the green certificate, the government requires that a certain annual proportion of electricity must come from new renewable sources. The demand after imposed share of green consumption is equal to Y_t, which indicates that the amount of renewable electricity should be equal to a percentage (α) of the total domestic electricity consumption. Electric suppliers on behalf of their consumers are obliged to ensure that renewable electricity consumption reaches this specific level. Producers of renewable electricity issue green certificates and have to buy by retailers at price P_s in proportion to electricity consumption. Thus green producers receive the certificate revenue in addition to the wholesale electricity price. The green certificate in essence works as a combination of a renewable subsidy and an electricity consumption tax and thereby increases the profitability of renewable energy sources (Bye and Bruvoll, 2008).

After introducing green certificate, the black electricity producer's profit function will be the same while the subsidy revenue "$P_s.Y_g$" increases green producer's profit.

$$\boldsymbol{\pi^b_i} = P_w Y_{ib} - C_i(Y_{ib})$$

$$\boldsymbol{\pi^g} = P_w Y_g - C_g\,(Y_g) + P_s.Y_g$$

The retailers profit function with the green quota obligation is

$$\boldsymbol{\pi^d} = P_c Y - P_w Y_{ib} - (P_w + P_s).Y_g = 0$$

At the power market, retailers buy electricity certificate from the producers at price P_w or $P_s + P_w$ and sell it to the end users at price $P_c = P_w + P_s\alpha$. Moreover, they buy green certificates from the certificate market at price P_s to meet the quota obligation $Y_g = \alpha Y$. After implementing green certificate, the demand function became the function of price, green certificate price and the share of green electricity.

$\mathbf{U\ (Y^D)\ = f\ (}P_w + \alpha P_s)$

Market equilibrium

Electricity market

In market equilibrium producers plus consumers surplus is maximized under the constraint of renewable electricity quota. In equilibrium a share α of demand equals the supply of green electricity and a share (1-α) equals the supply of black electricity.

$$\mathbf{Y_{gs}\ (}P_w + P_s) \ = \alpha\ \mathbf{.f\ (}P_w + \alpha P_s) \ldots\ldots\ldots\ldots\ldots\ldots..[4.1]$$

$$\mathbf{Y_{bs}\ (}P_w\mathbf{)\ = (}1- \alpha)\ \mathbf{f\ (}P_w + \alpha P_s) \ldots\ldots\ldots\ldots\ldots\ldots[4.2]$$

The consumer price in equilibrium is equal to the wholesale price plus α times the price for the subsidy.

$$P_c = P_w + P_s\,\alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots[4.3]$$

The profit maximization first order conditions of the black and green electricity producer is respectively,

$$P_w = \partial C_i/\partial Y_{ib} \qquad \text{and} \qquad P_w + P_s = \partial C/\partial Y_g$$

Green certificate market

The supply of green certificates is given by the capacity of green electricity, while the renewable energy quota determines demandαY^D. Green Certificates will be sold at price P_S. The price of green certificate depends on the level of the quota and the marginal costs of green and black electricity generation (Will, n.d).

The certificate price is the difference between the marginal costs of green electricity generation and the wholesale price of electricity. Following from equation (4.3) the equilibrium price for a green certificate is-

$$P_s \ = (P_c - P_w)/\alpha.\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[4.3a]$$

Comparative statics

Now it will be examined that what is the effect of introducing the green certificate market on the different factors in the market? How are prices and the quantities of electricity influenced by the introduction of the green certificate system? And how do these change when the quota is altered?

Fischer (2009) focused on the effect on the consumer price and showed that the effect depends on the supply curves of black and green technologies. Bye (2003) showed that the producer price decreases when the share α is increased, while the effect on the consumer price and the green certificate price is whether increasing or ambiguous. I extend his approach to assess the quantity effects also.

Prices

The prices of electricity and certificate change with the imposition of green certificate. By taking the derivative of equation 4.1 and 4.2 with respect to α leads to the following equation (for derivation see Appendix L).

$$(\alpha.\ f' - Y_{gs}')\partial P_w / \partial\alpha + (\alpha^2 .f' - Y_{gs}')\ \partial P_s / \partial\alpha = -f - \alpha f'.\ P_s \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4.4]$$

$$((1-\alpha).\ f' - Y_{bs}')\partial P_w / \partial\alpha + ((1-\alpha).f'.\alpha)\ \partial P_s / \partial\alpha = f - (1-\alpha).\ f'.\ P_s \ldots\ldots\ldots\ldots [4.5]$$

From equations 4.4 and 4.5, the solution for $\partial P_w / \partial\alpha$ becomes

$$\partial P_w / \partial\alpha = \frac{-f.\ f'.\alpha + f.\ Y_{gs}' - (1-\alpha).\ f'.\ P_s.\ Y_{gs}'}{(1-\alpha)^2.\ Y_{gs}'.\ f' + \alpha^2\ .\ f'.\ Y_{bs}' - Y_{gs}'.\ Y_{bs}'} < 0 \ \ldots\ldots\ldots\ldots\ldots\ldots [4.6]$$

The equation 4.6 indicates that when the quota share **α** is increases, the wholesale price for electricity $\mathbf{P_w}$ decreases.

The influence of quota share α on electricity certificate price P_s can be derived as

$$\partial P_s / \partial\alpha = \frac{f.\ f' - f.\ (Y_{gs}' + Y_{bs}') + f'.\ P_s\ .\ ((1-\alpha).\ Y_{gs}'.\ \alpha\ Y_{bs}')}{(1-\alpha)^2.\ Y_{gs}'.\ f' + \alpha^2\ .\ f'.\ Y_{bs}' - Y_{gs}'.\ Y_{bs}'} \ \ldots\ldots\ldots\ldots\ldots [4.7]$$

Being the negative denominator, the sign of numerator will explain the effect of quota share on certificate price. The certificate price is positive if the expression in the bracket $((1-\alpha). Y_{gs}'. P_s. \alpha\, Y_{bs}')$ is positive, which is satisfied when

$$(1-\alpha). Y_{gs}' > \alpha. Y_{bs}' \Leftrightarrow Y_{gs}' / Y_{bs}' > \alpha / 1-\alpha$$

The above condition indicating that the quota effect on certificate price depends on the slopes of the supply curves and on the size of quota (α). The $\partial P_s / \partial\alpha$ is positive, if the black energy supply curve is flatter than that of green energy supply curve. Recalling the equation 4.3a, indicating that the certificate price (P_s) is the difference between marginal productions costs of green and black electricity producers in market equilibrium. When the supply of black energy (Y_{bs}) is reduced with an increasing quota obligation (α), the marginal black energy production costs decreases. The certificate price increases as difference between the marginal productions costs for green and black energy increases.

The consumer price of electricity could both increase and decrease as the quota share (α) increases, i.e. $0 \geq \partial P_c / \partial\alpha \geq 0$ (Bye, 2003). The derivative of equation 4.3 with respect to α is stated below:

$$\partial P_c/\partial\alpha = \partial P_W / \partial\alpha + \partial P_s / \partial\alpha. \alpha + P_s \qquad [4.8]$$

By inserting equation 4.6 and 4.7, the above equation 4.8 becomes

$$\partial P_c / \partial\alpha = P_s + \frac{f. ((1-\alpha). Y_{gs}' - \alpha. Y_{bs}') - Y_{gs}'. Y_{bs}'. P_s}{(1-\alpha)^2. Y_{gs}'. f' + \alpha^2 . f'. Y_{bs}' - Y_{gs}'. Y_{bs}'} \qquad [4.9]$$

With the denominator being negative, the sign of numerator determines the effect of quota on consumer price. For the consumer price to increase along with quota, the supply derivatives and the equilibrium price of certificate have to be positive. If the relation between the supply derivative for green and black electricity, $Y_{gs}' / Y_{bs}' > \alpha / 1-\alpha$, then $f.((1-\alpha).Y_{gs}' - \alpha.Y_{bs}') < 0$ and $\partial P_c/\partial\alpha > 0$. The higher the quota, the more likely the consumer price is to increase.

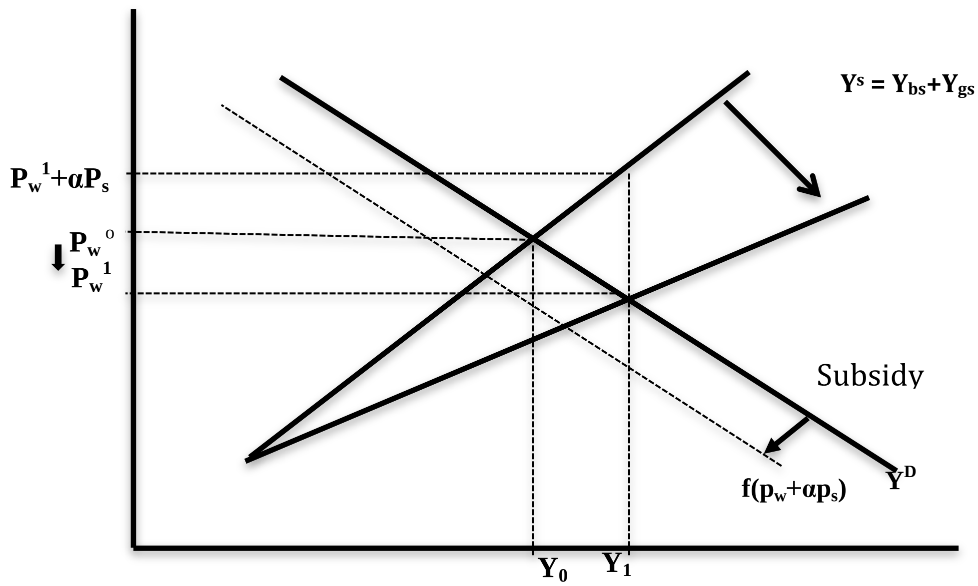

Figure 3.1: Effect of green certificate on wholesale electricity price, consumer price and the certificate price

Figure (3.1) describes that the market equilibrium before the introduction of the green certificate market is ($P_w^{\,o}$, Y_0). After introduction of the green certificate scheme the demand curve shifts inwards as purchaser prices increases and the supply curve rotate to the right as rise in the quantity supply of renewable electricity increases the aggregate supply of electricity. The new equilibrium price and volume is ($P_w^{\,1}$, Y_1), where the purchaser price is ($P_w^1 + \alpha\, P_s$). The certificate price will depend on the slope of supply curve.

Quantities

The consumed and produced quantities of electricity are influenced by the introduction of a green certificate system. The total amount of demanded electricity $Y_D\,(P_c) = Y^S(P_c)$ depends on the change in P_C. If the consumer price rises, demand decreases, and vice versa.

$$\partial Y^D / \partial\alpha = \underbrace{\partial Y_s / \partial\alpha}_{<0} . \underbrace{\partial P_c / \partial\alpha}_{?}$$

When the share of quota obligation (α) is increased, the amount of black electricity consumed decreases in equation 5

$$\partial Y_b / \partial\alpha = \partial Y_{bs} / \partial P_w + \partial P_w / \partial\alpha < 0 \text{ ……………………………………[5]}$$

When a green certificate quota share is increased, the rise of green electricity is ambiguous. As the quota only regulates the ratio of green and black electricity, an increased quota can either be achieved by an increase in green electricity or by a decrease in black electricity. Depending on the change of certificate price P_s, the amount of green electricity Y_g either increases or remains unchanged.

$$\partial Y_g / \partial\alpha = \partial Y_{gs} / \partial (P_w + P_s). (\partial P_w / \partial\alpha + \partial P_s / \partial\alpha) \text{……………………………[5.1]}$$

By inserting equation 4.6 and 4.7 above equation (5.1) leads to:

$$\partial Y_g / \partial\alpha = \partial Y_{gs} / \partial (P_w + P_s). \frac{((1-\alpha) f. f' -(f +\alpha. f'. P_s). Y_{gs}')}{(1-\alpha)^2. Y_{gs}'. f' + \alpha^2 . f'. Y_{bs}' - Y_{gs}'. Y_{bs}')} \text{ ………..[5.2]}$$

With the denominator being negative, the numerator determines the sign. The numerator will be negative, when ($f +\alpha. f'.P_s$) is positive. It is more likely to be fulfilled for lower values of α. For a high quota α the effect of a high consumer price P_c dominates, which leads to a reduction in demand. This demand reduction can be so strong that not only black supply is cut back but also green supply. On the other hand, the reduction of renewable electricity supply has an impact on the certificate price P_s. A reduced renewable electricity supply lowers the certificate price P_s.

CHAPTER IV

MATERIALS AND METHODS

This chapter will explain the methodological steps that were performed in this study and how the relevant data was collected and analyzed.

The statistical methods used to determine the results are the regression analysis and the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) analysis. There are certain assumptions required to meet in order for the regression and GARCH to be validated. These assumptions were examined with relevant statistical tests.

4.1 Data handling and processing steps

The method can be described as following steps:

1. Data collection and processing with Stata software
2. Description of data
3. Regression analysis to check the relationship among different variables with the green certificate quota
4. The assumptions for the regression analysis
5. Test for structural break in certificate price series
6. GARCH model for investigating the volatility in certificate price return
7. The GARCH model with different dummy variables to take into account for structural breaks.

4.2 Data collection and processing with Stata software

The collected data chosen for analysis was a set of secondary data. The monthly data was collected from January 1st, 2012 to August 1st, 2016, which consists of 56 observations for each variable, as Norway joint the tradable green certificate market from January 2012. The data was gathered from data published online by Statnett, Nordpool, STOXX30 Nordic limited and eklima.

The raw data was run into Stata software to check the stationary or non-stationary of the time series. Moreover, the all given time series were also checked that whether they are co-integrated or not.

These are the assumptions of time series analysis that data has to be stationary and the time series has to be co-integrated between each other. The all five time series are co-integrated (Appendix H).

4.3 Description of data

4.3.1 Certificate price

For the certificate price (cp), the average monthly price data published by Statnett.no was used. The price is presented in Norwegian Kroner (NOK).

The descriptive statistics of the certificate price are presented in table 4.1. The table indicates the both positive excess kurtosis and skewness. The Augmented Dickey-Fuller test has indicated that cp series is stationary table 4.1.

4.3.2 Wholesale electricity price

The primary source of revenues for renewable energy generation derives from participating in the electricity market. For the analysis the monthly wholesale electricity price data in NOK published by Nordpool was analyzed.

The descriptive statistics of the electricity price (Avg_p) are presented in table 4.1. The table indicates the positive excess kurtosis with negative skewness. The Augmented Dickey-Fuller test has indicated that Avg_p series is stationary table 4.1.

4.3.3 Equity price

Economic growth has a vital role in determining the demand of energy commodities and electricity (Chen et al., 2007). Similarly to Bredin and Muckley (2011) and Creti et al (2012), the equity index was used as a measure of economic condition. In addition to the fact that this variable reflects financial and economic conditions expectations with the required monthly frequency. It allows considering the certificate as a financial asset.

The variable used for the analysis is the STOXX Nordic 30 index, which includes 30 stocks of the bigger companies of Norway, Sweden, Denmark and Finland. Monthly data from STOXX limited was gathered. The price is presented in NOK.

The descriptive statistics of the index price (equity_p) is presented in table 4.1. The table indicates the positive excess kurtosis with negative skewness. The Augmented Dickey-Fuller test has indicated that the return of equity_p series is stationary table 4.1.

4.3.4 Electricity production

To analyze the effect of electricity production on certificate price, monthly electricity production data from 1st January 2012 to 1st August 2016 was collected from **Nordpool.** The quantity of electricity generated was available in unit Megawatt hour (MWh).
The descriptive statistics of the electricity production (pro) series is presented in table 4.1. The table indicates the positive excess kurtosis with positive skewness. The Augmented Dickey-Fuller test has indicated that the production of electricity (pro) series is stationary table 4.1.

4.3.5 Average monthly temperature

The changes in temperature influence the electricity demand and supply especially for the countries and regions where hydropower and wind power contributes important role in the electricity generation. Increasing temperature influences the energy demand because of less need for heating or high demand for cooling vice versa. Since 50 per cent of the electricity use in the Nordic countries is used for heating purposes this may have a major impact on the electricity demand. To analyze the effect of temperature on certificate price, monthly temperature data in degree Celsius (°C) from period from January 2012 to August 2016 was collected from the web link: eklima.met.no as Xcel file.
The descriptive statistics of the temperature are presented in table 4.1. The table indicates the positive excess kurtosis with positive skewness. The Augmented Dickey-Fuller test has indicated that the average monthly temperature (AVG_temp) series is non-stationary table 4.1.

Table 4.1: Descriptive statistics of the variables for the period from January 2012 to August 2016

Variables	Number of observations	Mean	Skewness	Kurtosis	Variance	Dickey-Fuller test (p-value)
Wholesale electricity price (Avg_p)	56	330.4	-0.428	3.330	6816.793	0.0372**
Certificate price (cp)	56	161.1	0.139	2.409	388.145	0.0144**
Electricity production (pro)	56	1.2e^07	0.593	2.422	3.18e^12	0.0264**
Euity price (equity_P)	56	9270.9	-0.217	1.646	3645772	0.000***
Average monthly temperature (AVG_tem)	56	6.794	0.029	1.853	34.981	0.1539

Significance at 5% is represented with * corresponding p-value. The level of significance is characterized with ** (p-value ≤ 0.01), and *** (p-value ≤ 0.001)

4.4 Regression analysis

A regression analysis describes and evaluates the relationships among variables. During the regression analysis, important assumptions for a valid regression were tested in order to ensure the validation of the models.

- The following equation was investigated-

Quota = c+ b2* electricity production (pro) + b3*Certificate Price (cp) + b4* Equity Index price (equity_p) -b5* wholesale electricity price (Avg_p)………………….[1]

With the help of above equation the relationship of Quota with the other variables was estimated.

The following statements were investigated by using the aforementioned equation.

1. The wholesale energy price will go down as the certificate quota share increases (Bye, 2003).
2. The production of renewable energy increases as the certificate quota share.
3. The increases in certificate quota will contribute to the economic growth as the investment in renewable electricity increases, which will increase electricity production, high profit in electricity sector, create more jobs and increased electricity consumption.
4. The certificate price will increases as the share of quota increases (Bye, 2003).

4.5 Model checking

The following tests were conducted to the assumptions of the linear regression.

4.5.1 White's test for homoscedasticity

A one of the critical assumptions of the classical linear regression model is that there is homoscedasticity or equal variance in the error term.

Mathematically it can be expressed as

Var $(e_i|x_i) = \sigma^2$, where e_i is the error term and x_i is the measure of covariate (Gujrati, 2003).

White's test for heteroskedasticity was used. This test was estimated via the command estat imtest. The test developed under the null hypothesis,

$$\boldsymbol{H_o: \rho = 0, \text{homoscedasticity}}$$

Against the alternative hypothesis,

$$\boldsymbol{H_\alpha: \rho \neq 0, \text{unrestricted heteroskedasticity}}$$

Under the null hypothesis, the test statistic is asymptotically distributed as chi-squared.

4.5.2 Breusch-Godfrey test for serial correlation

The Breusch-Godfrey test is the likelihood- based two-sided LM type test, which is the most appropriate test for detecting autocorrelation in dynamic models (Rois, 2012). The test developed under the null hypothesis,

$$H_o\text{: } \rho = 0\text{, no serial correlation}$$

Against the alternative hypothesis,

$$H_\alpha\text{: } \rho \neq 0\text{, presence of serial correlation}$$

Under the null hypothesis, the test statistic *(n-p)**R2 is asymptotically distributed as chi-squared with one degree of freedom (Gujrati, 2003). R^2 is obtained from the regression.

4.5.3 Model validation

In order create a predictive regression model it is important to examine how well the model represents the data it is derived from and to what extent it is possible to use the model for predictive purpose. This type of analysis is referred to as model validation and may be done with different types of statistical tests.

4.5.4 Evaluating R^2

R^2 is a measure of goodness of fit. It measures how well the estimators in the model explain the variance in the dependent variable. R^2 is equal to the square of the sample correlation coefficient between y and xβˆ (Lang, 2013).

$$R^2 = Var(x\hat{\beta}) / Var(y)$$

The sample variance of y can be decomposed into two terms:

$$Var(y) = Var(x\hat{\beta}) + Var(\hat{e})$$

Thus, R^2 can also be expressed as

$$R^2 = 1 - V ar(\hat{e}) V ar(y)$$

The model should have as high R^2 as possible since this minimizes the error term ˆe and therefore implies an improved estimation of the dependent variable y.

4.5.5 Residual analysis

The one of assumptions of the linear regression model states that the expected value of the error term is zero. It is thus important to study the residual in order to examine in what extent assumption may be violated. This will make it possible to recognize patterns in the residual that could increase the understanding of the regression and eventually improve it. This is referred to as residual analysis.

The general regression equation:

$Y_i = \beta_0 + x_1\beta_1 + \ldots.. + x_{ik}\beta_k + e_{i,}$ where $i = 1, 2, \ldots, n$

When the regression is done and estimates of β_k are determined, the residuals $e^{\wedge}$ can be achieved by the following equation (Lang, 2013):

$$\hat{e}_i = Y_i - (\beta^{\wedge}_0 + x_1\beta^{\wedge}_1 + \ldots..+ x_{ik}\,\beta_{\wedge k}), \text{ where } i = 1,2,\ldots.., n$$

4.5.6 Histogram

The residuals were illustrated in the histogram. If the residuals are normally distributed around zero (well bell shaped curve), the assumption regarded the error term is zero becomes valid.

4.5.7 Normal probability plot

A normal probability plot is another way of displaying the residuals in order to see if they are normally distributed. If the probability plot follows a straight line the residuals are normally distributed and thus the second assumption is valid.

4.6 Test for structural breaks

The structural breaks occur when a time series abruptly changes at a point in time. This change could involve a change in mean. Structural break tests help to determine when or whether there is a significant change in our data. The structural breaks were then compared with the regulatory changes or uncertainty in certificate market in order to investigate if there was any relation between them.

Estat sbknown performs a Wald test of whether the coefficients in a time-series regression vary over the periods defined by known break dates. **Estat sbsingle** performs a test to find out whether the coefficient in a time series regression varies over the periods defined by an unknown breaks date.

4.7 Generalized Autoregressive Conditional Heteroskedasticity (GARCH) analysis

Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model is often uses to investigate the volatility of time series (Engle, 1982). Initially, the return of certificate price was modeled (Table 5.6) by using the GARCH equation presented below

$r_t = \rho r_{t-1} + \rho\varepsilon_t$

$\varepsilon_t \sim s_t e_t$

$s_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta s_{t-1}^2$ ……………………………………...................................[3]

Where, r_t is the return on the certificate price, e_t follows the standard normal distribution, s_t^2 is the conditional variance, ε_t^2 is the squared error term at time t, ω is the constant. β, α & ω must not be non-negative in order to ensure that the conditional variance remains positive (Nelson, 1991).

4.7.1 Diagnostics tests for GARCH model validation

Before executing the GARCH model, the ARCH LM test and BG serial correlation tests were performed in order to satisfy the validation of the models. ARCH test is a Lagrange multiplier test that performs to assess the significance of ARCH effects and to test the existence of ARCH behavior based on the regression (Wang et al., 2005). This test describes the presence of ARCH effects in Ordinary Least Square (OLS) model, which indicates whether the model has cluster volatility.

4.8 GARCH with dummy variables

After comparing the results of the break test with the regulatory changes or uncertainties of the certificate market in order to investigate correspondence between them, GARCH model with introducing dummy variables in the variance equation was estimated. With the addition of dummy variables equation 3 turned to as follows:

$r_t = \rho r_{t-1} + \rho \varepsilon_t$

$\varepsilon_{t\sim} \sim s_t e_t$

$s_t^2 = \omega + \sum \phi D_t + \alpha \varepsilon_{t\sim-1}^2 + \beta s_{t-1}^2$ ……………………………………………………[4]

Where D_t is numbers of dummy variable

CHAPTER V

RESULTS

Firstly, the relationship among different variables with the green certificate quota has been analyzed using "ordinary least squares regression" analysis. This analysis is required to test all possible contradictions to the Classical Linear Regression Model (CLRM) assumptions. The regression analysis was performed in StataSE 14 software (http://www.stata.com/).

5.1 Variables relationship between green certificate quota

The result of the regression analysis is displayed in the Table 5.1. The **table (5.1)** is illustrating that all the variables are statistically significant except for the average monthly temperature (**AVG_temp**). The coefficient of electricity production (**pro**) and Equity price (**equity_p**) are positively co-related to electricity certificate quota whereas the electricity certificate quota share has the inverse impact on the electricity price (**AVg_p**), certificate price (**cp)** and Average monthly temperature (**AVG_temp**) Table 5.1 and Fig. 5.1

Table 5.1: Regression output with White's robust estimates. The level of significance is symbolized with asterisk (*) on the vertical column. The level of significance is characterized with * (p-value ≤ 0.05) and *** (p-value ≤ 0.001)

Variable	**quota**	**p-value**	**t-value**
Pro (Electricity production)	$4.05e^{-09}$***	0.000	3.79
Cp (Certificate price)	-.001117***	0.000	-4.37
equity_p (Coefficient of Equity price)	0.000012***	0.000	11.12
AVg_p (Electricity price)	-0.000115*	0.032	-2.20
AVG_temp (Average monthly temperature)	-0.0003408	0.64	0.47
R^2	0.82		

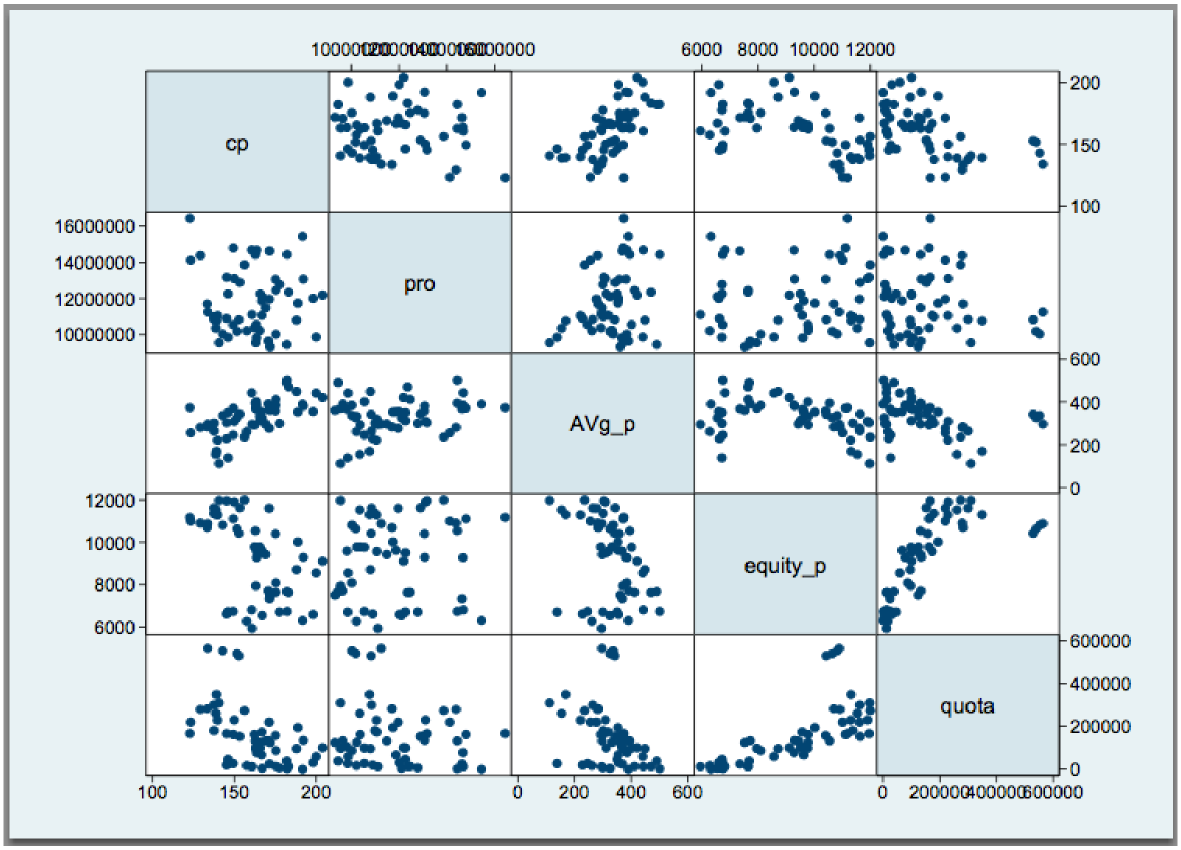

Figure 5.1: Scatter plot matrix showing the relationship between the variables

5.1a Regression equation

The regression analysis results presented in the table 5.1 can be illustrated in accordance with regression equation as follows:

Quota = 0.0134296+4.05e-09*pro-0.001117*cp+0.000012*equity_p-0.000115*Avg_p-0.0003408*AVG_temp

The above equation shows the same parameters signs of different variables as they are suggested in the hypothesis except certificate price (cp). The parameters of electricity production and price of Index (Stoxx Nordic 30) have positive signs indicating that increase in the Quota has positive influence on them. Conversely, increased Quota share declines the electricity price and certificate price. The effect of temperature is statistically insignificant on certificate quota but the coefficient of variable is negative.

5.2 Classical Linear Regression Model (CLRM) assumptions

5.2.1 Functional form

The Ramsey Regression Equation Specific Error (RESET) test was performed in order to detect if there are any neglected nonlinearities in the model. The Ramsey RESET test is showed that there is no evidence against linearity (Appendix A).

5.2.2 Heteroskedasticity test

The White's homoscedasticity test has been used to compute the equal variance among the estimators. The result for heteroskedasticity test has rejected the null-hypothesis of homoscedasticity because $p = 0.0044 \leq 0.05$. Thus heteroskedasticity exits (Appendix B).

5.2.3 Serial correlation test

The Breusch-Grey (BG) test has been used to test the presence of serial correlation in the residuals. The BG test has found no presence of serial correlation in the residuals of model since the test has failed to reject the null hypothesis ($p = 0.0045$) (Appendix C).

5.3 Model validation

Model validation is first done using residual analysis. Secondly the R^2 is evaluated and finally the *p*-values for the covariates are evaluated.

5.3.1 Residuals analysis

The residuals analysis was done to recognize the patterns in the residual that could increase the understanding of the regression and eventually improve it. A regression analysis was performed with and without incorporating for White's robust estimators and a residual analysis on this result is done with the histogram over the residuals.

The histograms indicate that there is no major difference between the regressions with (Fig 5.2a: A) and without (Fig 5.2a: B) White's robust estimates. Here the residuals seem to follow a normal distribution (Fig. 5.2a).

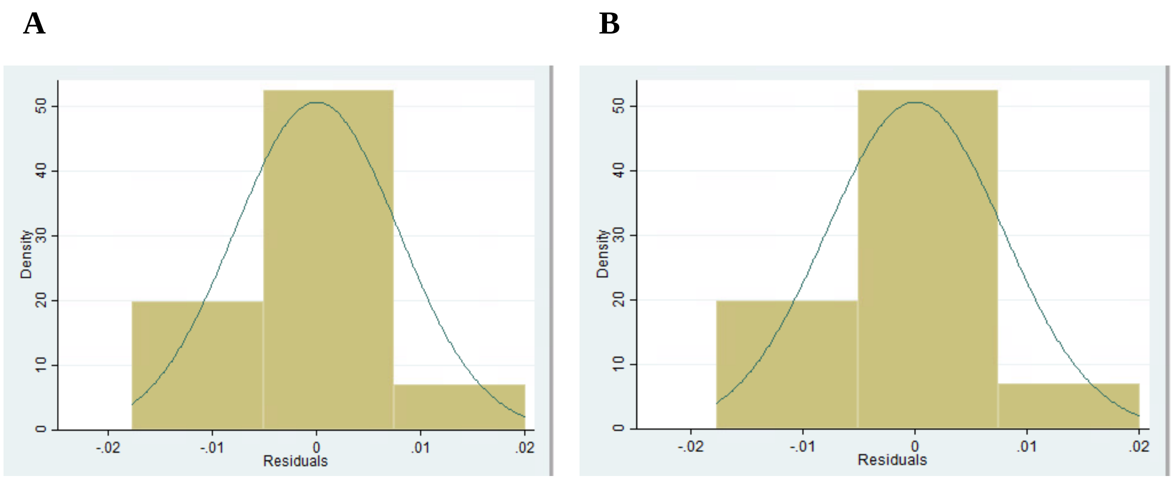

Figure 5.2a: Histogram over the regression with (A) and without (B), Whites' robust estimators

5.3.1a Normal probability plot

A normal probability plot over the White's robust residuals explains the dispersion of residuals along the regression trend line. The plot shows that there is deviation from normal distribution at the upper and lower tail (Fig. 5.2b).

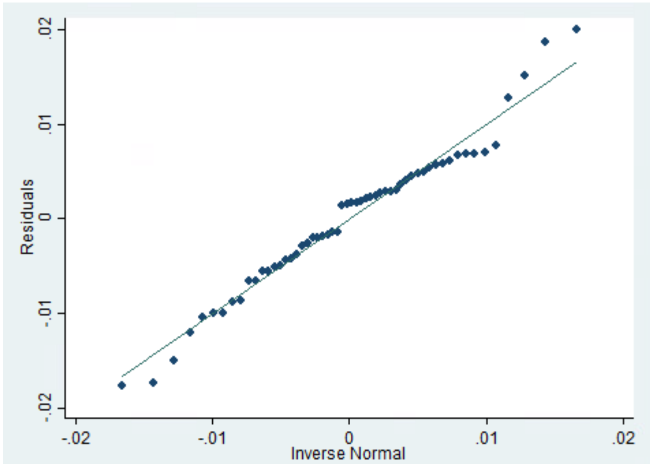

Figure 5.2b: Normal probabilities plot over the Whites's robust residuals

5.3.2 Evaluating the R^2 and *p*-value

The R^2 is 0.82 for the regression (Table 5.1), which shows that the analysis explains 82% of variation in the data. Furthermore, the *p*-values are lower (< 0.05) for all the variables except the variable average monthly temperature (AVG_temp). The *p*-values ≤0.05 support the alternative hypothesis that each covariate is statistically significant.

5.4 Structural breaks in time series (certificate price)

Estat sbsingle and **estat sbknown** test were performed for a structural break after estimating the certificate price series with regression analysis. The Estat sbsingle test rejects the null hypothesis (P = 0.000) of no structural break and detects a break in the first month of 2015 (Appendix D). The break is associated to the increased wind electricity production up to 856MW (+11.5%) (The wind power, 2016).

Additional structural break test was also performed with ex-ante information about when the break might be happened by using **estat sbknown** command. It has suspected that there might be the structural breaks on **April 2015** and **October 2015.** The **estat sbknown** test rejects the null hypothesis of no structural break at the 5% level for the specified months (Appendix E). The break on **April 2015** can be associated with the joint agreement, which took place on March 2015 between the Norway and Sweden in order to increase their target for renewable electricity production by 2020. The break on **October 2015** can be connected with incidence of wind farm investment plunged with power prices in Nordic Region in the mid of 2015.

Finally, the model using different dummy variables corresponding to the regulatory changes has been estimated. The GARCH model by adding three dummy variables d1, d2 and d3 in the variance equation has estimated to take into account for these breaks as presented in **equation 4**.

5.5 GARCH analysis

Now the mean equation (3) in Chapter IV, by using OLS method and the coefficient of the GARCH model has been estimated. Table 5.2 indicates the return of certificate price is statistically significant for both OLS and GARCH.

Table 5.2: OLS and GARCH model estimates without dummy variables. The level of significance is symbolized with asterisk (*) on the vertical column. The level of significance is characterized with *** (p-value ≤ 0.001)

	Certificate price return (cp return)	**P-value**	**t-value**	**z-value**
GARCH	165.3302***	0.00	-	66.76
OLS	-161.119***	0.00	61.20	-
No. Of observation	55			

Before executing the GARCH model, following diagnostic tests were performed.

5.5.1 The ARCH Langrange Multiplier test

The ARCH LM test shows the presence of ARCH effects, which indicates that the model has cluster volatility and the model is more appropriate. The LM test shows a *p-value* of 0.0315, which is below 0.05; hence the null hypothesis gets rejected with no ARCH effects (Appendix F).

5.5.2 Breusch-Godfrey test for serial correlation

The Breusch-Godfrey **(**BG) test found there is no presence of serial correlation in the residuals. The test has failed to reject the null hypothesis of no serial correlation (P = 0.0195) (Appendix G).

5.6 The description of dummy variables

The model has estimated with the different dummy variables in order to investigate the role of regulatory difference and uncertainty on certificate price volatility. Description of different dummy variables is explained below:

d1-The increased wind electricity production up to 856MW (+11.5%) in Norway in the end of 2014.

d2-The joint agreement which took place on March 2015 between the Norway and Sweden in order to increase the targets for renewable electricity production by 2020.

d3-Wind power investment collapsed in Sweden, Denmark, Finland and Norway. The Investors were pulled back from wind farms in Nordic regions as the lowest electricity prices in 12 years cut the profitability of new projects in the mid of 2015.

The estimated results are presented in table 5.3 comprising the coefficients of the dummy variables d2 and d3 are statistically significant which indicates that volatility increased after the structural break of April 2015 (d2 = 1.093472) and it decreased after the structural break of October 2015 (d3 = -2.096158). The dummy variable d1 is not statistically significant (Table 5.3).

Table 5.3: GARCH (1, 1) estimates with different dummy variables. The level of significance is symbolized with asterisk (*) on the vertical column. The level of significance at 5% is represented with ** corresponding with the t- value and p-value. The level of significance is characterized with *** (p-value ≤ 0.001)

Dummy variables	lcp	P-value	t-value
d1	-0.1450866	1.00	-2.10
d2	1.093472***	0.00	-11.37
d3	-2.096158***	0.00	347.26
No. Of observation	56		

CHAPTER VI

DISCUSSION

This chapter is elaborated on the results from the analysis and compares them to the established hypotheses. The other findings that were found in the general model were also been discussed.

6.1 Discussion of the general model for the green certificate market

Table 6.1 summarizes the result of the general model for the green certificate market without trade. It can be seen that the introduction of renewable energy quota via green certificate for domestic market leads to a decrease of black electricity generation and to a lower wholesale price of electricity. Theoretically, the effects on the consumer price, certificate price and quantity demanded and supplied from renewable resources are ambiguous. The signs of these effects depend on the elasticity of the supply and demand functions.

Table 6.1: Comparative statics result on prices and consumption, when introducing a green certificate system with the green quota (α)

	Wholesale price for electricity **(P_w)**	Green certificate price **(P_s)**	Consumer price for electricity **(P_c)**	Total production of electricity **(Y)**	Quantity of black electricity produced **(Y_b)**	Quantity of green electricity produced **(Y_g)**
quota **(α)**	**-**	**?**	**?**	**?**	**-**	**?**

The results of the general model are partially in line with the previous studies. The distinctive impact of the quota obligation on green electricity production, total electricity production, consumer and certificate price were not able to determine (Bye, 2003; Amundsen & Nese, 2009) which suggests the strengths of the current studies. In addition, the certificate quota has negative impact on black electricity production**,** but the impact on green electricity production is ambiguous (Fischer, 2009).

6.2 Discussion of the results

6.2.1 Regression analysis

The results of the regression analysis for the model are displayed in (Table 5.1). The robustness of the model was verified through diagnostic statistics. The Breusch-Godfrey test was conducted to detect serial correlation and the White's homoscedasticity test was conducted to find the existence of heteroskedasticity in the models. The tests detected no indication of serial correlation and heteroskedasticity in the model. The residuals for the model follow the normal distribution path. The model explains 82% of variation in the data. The regression analysis found to show both positive and negative relationship among variables.

A further discussion will follow how different variables are related to electricity certificate quota.

6.2.2 Variables relationship with the green certificate quota

6.2.2.1 Wholesale electricity price

The expansion of energy production in Norway by the regulation of green certificate market would decrease the wholesale electricity prices (Ola Borten, 2011). The previous Prime Minister of Norway Jens Stoltenberg speculated the same thoughts "as a result of green certificate market, the Nordic countries will experience a power surplus that shall lead to decrease wholesale electricity price (Hope, 2011). The regression outcomes support the Moe and Stoltenberg`s arguments (Table 5.1 in the result chapter). The regression findings also confirmed the hypothesis that the wholesale electricity prices decreases as the supply of renewable electricity in the energy market increased by imposition of certificate quota.

Bye (2003) also supports Stoltenberg and Moe's arguments and states that increasing supply and decreasing the demand of electricity may lead to lower the wholesale prices of electricity.

6.2.2.2 Electricity production

The variable Electricity production (pro) is statistically significant and positively correlated with the certificate quota obligation (Tables 5.1 in results chapter).

This result seems to be precise as compared with the conclusion generated from the general model and previous studies. Amundsen and Nese (2009) summarized that the effect of quota imposition on the generation of green electricity is indeterminate. Thus, an increase of the quota will not necessarily lead to an increase of green electricity generation. However, the share of ‘green electricity’ as compared to the total consumption will increase. Notably, the electricity generation in Norway is totally based on renewable energy.

The increment of renewable electricity in Norway with the introduction of green certificate market is due to along with the Norwegian power supply system (based on Hydropower), the other renewable energy sources such as wind and solar are continuously being subsidized. This subsidy is helping to achieve the target to increase the renewable energy by a total of 28.4TWh (Swedish Energy Agency & NVE, 2013).

In the 2015, the electricity generation is 2.5TWh from wind power in Norway. The total installed capacity was 873MW distributed in 374 wind turbines (Norwegian Water Resources and Energy Directorate, 2015). The wind electricity accounted for 1.7% of Norway’s total electricity production in 2015. Table 2.5 provides an overview of Norwegian wind power generators under the green certificate (Sand & Stubsjøen, 2015).

6.2.2.3 Equity price

The purpose of including the price of equity (STOXX Nordic 30) variable was to measure the effect of certificate market on economic growth. The variable equity price (equity_p) is statistically significant and positively correlated with certificate quota (Table 5.1 in result chapter).

The results are satisfying the established hypothesis that the economic growth should also be influenced by certificate demand since it is also acquired as a percentage of electricity consumption.

Increased electricity certificate quota tends to increase the investment in renewable electricity sector, which further increases the electricity demand and the electricity certificate price. Thus the revenue generated by the accelerated investment contributes to country's economic growth.

The current findings are in line with the previous studies. The numbers of previous studies have highlighted the emission allowance as an indicator of economic growth. A rise in emission allowance price (in my case certificate price) leading to higher economic growth (Christiansen, 2005).

According to the Wisconsin Bureau "The investment in locally available renewable energy generates more jobs, greater earnings, and higher output" (US Department of Energy, 1997). The Bureau estimates that the overall renewables create three times as many jobs as the same level of spending on fossil fuels.

6.2.2.4 Certificate price

The variable Certificate price (cp) is statistically significant and negatively correlated with certificate quota. The result indicates that 0.001% increased in quota brings 1% decrease in certificate price (Table 5.1). It occurred might be with increased consumer price due to high quota, which further decreases the demand of electricity and hence certificate price.

The regression result is unfortunately not satisfying the outcomes as discussed in the general model of the green certificate that the certificate price depends on the slopes of the supply curves and on the size of quota (α). The Certificate price increases when the supply of green energy is increased with an increasing quota obligation (α). The outcome does not agree with Bye (2003) that the certificate price increase as the mandatory green share increases. Notably, the electricity generation in Norway is totally based on green energy.

6.2.2.5 Temperature

The variable Average monthly price (Avg_p) was used to measure the effect of temperature on certificate market. The variable is not statistically significant but negative. As it has discussed before that 50 percent of the electricity use in the Norway is used for heating purpose due to cold weather, which will partially influence the certificate demand since it is obtained as a percentage of electricity consumption.

6.3 Structural breaks in time series (certificate price)

The Wald test for structural breaks has indicated the three structural breaks corresponding to January 2015, April 2015 and October 2015. All the breaks are statistically significant at 5% level. The first break (January 2015) was associated to the increased wind electricity production up to 856MW in the end of 2014 (The Wind Power, 2016). The second break (April 2015) was connected with the regularity change. On March 2015 a joint agreement took place between the Norway and Sweden in order to increase the targets by 8% under subsidy scheme for renewable electricity by 2020 (Adomaitis, 2015). The third break (October, 2015) was associated to wind power collapsed in Sweden, Denmark, Finland and Norway. The prices of electricity certificate with wholesale electricity price were also being dropping due to oversupply (Climatism, 2015).

6.3.1 Dummy variables analysis with GARCH

Above-mentioned dummy variables have been introduced in the variance equation of the GARCH model corresponding to the three breaks. The findings from GARCH estimated that dummy variable d2 and d3 are statistically significant and the volatility increased around April 2015, which remained high until the third break October 2015 and then decreased afterwards (Table 5.3 in the result chapter). Conversely, the dummy variable d1 is not statistically significant indicating that the increased wind electricity production up to 856MW at the end of 2014 brought no volatility spillover on certificate price. The results provide evidence for negative impact of regulatory and economic changes in certificate market, indicating that uncertainties lead to increased volatility, exacerbating price risk, and restraining investment.

Thus the results can be inline with previous studies. The regulatory changes strongly affect the certificate markets (Fagiani, 2013). A certificate market designed to support wind generators using a system dynamic approach, reaching to the conclusion that such a market will experience investment cycles and high price volatility (Ford et al., 2007). The electricity certificate price could become highly volatile due the fluctuations of RES and the inelasticity of certificate demand (Morthorst, 2000). Price volatility could be further worsening by the variations of natural resources from year to year. To compensate the higher risk, the investors will require higher expected returns on renewable energy projects, leading to under-investment and higher certificate prices (Klessman et al., 2008).

6.4 Limitations of the study

The current study is focused to analyze the impacts of electricity certificate market on wholesale electricity price and certificate price, renewable electricity production and economic growth. Moreover, it analyzed the role of regulatory changes or economic uncertainty in volatility of certificate price. The following limitations might be taken into consideration.

Firstly, the focus was only on the Norwegian energy and certificate market, though certificate market is a joint Norwegian-Swedish green certificate market.

Secondly, the electricity certificate market's influence on energy market was the only impact from environmental programs, which would be investigated. The study did not compare the certificate market with other tools that could promote the renewable energy and thus reaching the RES-E targets.

Thirdly, the empirical analysis was based on the data set from the period of January 2012 (when Norway joint the Swedish electricity certificate market) to August 2016. In order to provide more accurate analysis of the green certificate market the more parameters from both of the markets Norwegian and Swedish are required.

CONCLUSION

The econometric findings in this study suggested that after the regulation of electricity certificate market in Norway, the development of new renewable energy sources has increased and the wholesale electricity price has decreased. However the green certificate price has decreased as certificate quota increased since 2012.

The increased investments in renewable electricity sector (wind energy) by the subsidy under green certificate market have positive impact on economic growth.

The findings further suggested that the volatility in electricity certificate price could be increased with regulatory and economic uncertainty. Therefore, policy makers should be very careful in altering the regulatory structure of certificate market, deeply investigating the impact of their decisions on future certificate prices before to act.

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APPENDICES

Appendix A

Ramsey RESET test

```
. ovtest

Ramsey RESET test using powers of the fitted values of Quota
       Ho:  model has no omitted variables
                 F(3, 46) =      0.37
                 Prob > F =      0.7767
```

Appendix B

White's homoscedasticity test , [p = 0.0044≤0.05]

. estat imtest

Cameron & Trivedi's decomposition of IM-test

Source	chi2	df	p
Heteroskedasticity	40.45	20	0.0044
Skewness	10.87	5	0.0540
Kurtosis	0.45	1	0.5007
Total	51.78	26	0.0019

Appendix C

White Langrangian Multiplier (LM) test for autocorrelation, [p = 0.0045≤0.05]

. estat bgodfrey

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob > chi2
1	8.057	1	0.0045

H0: no serial correlation

Appendix D

Test for a structural break: unknown break date, [p = 0.0000≤0.05]

```
. estat sbsingle
-----+---- 1 ----+---- 2 ----+---- 3 ----+---- 4 ----+---- 5
.....................................

Test for a structural break: Unknown break date

                                        Number of obs =         56

Full sample:                             2012m1  -  2016m8
Trimmed sample:                         2012m10  -  2015m12
Estimated break date:                    2015m1
Ho: No structural break

     Test               Statistic              p-value
-----------------------------------------------------------
     swald               55.8699               0.0000
-----------------------------------------------------------
Coefficients included in test: _cons
```

Appendix E

Wald test for a structural break: Known break data, [p = 0.0000≤0.05]

```
. estat sbknown, break(tm(2015m4))

Wald test for a structural break: Known break date

                                        Number of obs  =         56
Sample:          2012m1  -  2016m8
Break date:      2015m4
Ho: No structural break

                  chi2(1)        =    44.6845
                  Prob > chi2    =     0.0000

Coefficients included in test: _cons
```

Wald test for a structural break: known break date, [p = 0.0001≤0.05]

```
. estat sbknown, break(tm(2015m10))

Wald test for a structural break: Known break date

                                        Number of obs  =         56
Sample:          2012m1  -  2016m8
Break date:     2015m10
Ho: No structural break

                  chi2(1)        =    15.4580
                  Prob > chi2    =     0.0001

Coefficients included in test: _cons
```

Appendix F

Langrange Multiplier (LM) test for ARCH, [p = 0.0315≤0.05]

```
. estat archlm
LM test for autoregressive conditional heteroskedasticity (ARCH)
```

lags(p)	chi2	df	Prob > chi2
1	4.628	1	0.0315

```
        H0: no ARCH effects      vs.  H1: ARCH(p) disturbance

.
```

Appendix G

Breusch-Godfrey LM tests for auto-correlation, [p = 0.0195≤0.05]

```
. estat bgodfrey

Breusch-Godfrey LM test for autocorrelation
```

lags(p)	chi2	df	Prob > chi2
1	5.455	1	0.0195

```
                        H0: no serial correlation

.
```

Appendix H

Test for time series co-integration, series are co-integrated

```
. vecrank Quota AVG_temp AVg_p pro cp equity_p, trend(constant) lags(1)

                          Johansen tests for cointegration
Trend: constant                                         Number of obs =      55
Sample:  2012m2 - 2016m8                                         Lags =       1
```

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	6	-1684.9767	.	132.2781	94.15
1	17	-1662.7918	0.55368	87.9082	68.52
2	26	-1641.1829	0.54423	44.6905*	47.21
3	33	-1629.4933	0.34628	21.3113	29.68
4	38	-1622.9667	0.21127	8.2581	15.41
5	41	-1619.3027	0.12474	0.9301	3.76
6	42	-1618.8377	0.01677		

Appendix I

Wind energy production in 2015, (Vindportalen, 2016)

Vindkraftverk	Eier	I drift år	Antall turbiner	Installert Ytelse [MW]	2015 produksjon [GWh]
Andøya	Andøya Energi AS	1991	1	0,4	0,6
Hovden	Vesterålskraft Produksjon AS	1991	1	0,4	0,2
Fjeldskår	Norsk Miljø Energi AS	1998	5	3,8	8,6
Harøy, Sandøy	Sandøy Energi AS	1999	5	3,8	9,7
Smøla I&II	Smøla Vind AS (Statkraft)	2002	68	150,4	400,6
Havøygavlen	Arctic Wind AS	2002	16	40,5	90,9
Utsira I&II	Solvind Prosjekt AS	2004	2	1,2	3,7
Hitra	Hitra Vind AS (Statkraft)	2004	24	55,2	159,1
Nygårdsfjellet I&II	Nordkraft Vind AS	2005	14	32,2	86,9
Kjøllefjord	Kjøllefjord Vind AS (Statkraft)	2006	17	39,1	121,9
Valsneset	TrønderEnergi Kraft AS	2006	5	11,5	29,6
Bessakerfjellet	TrønderEnergi Kraft AS	2008	25	57,5	183,6
Mehuken II	Kvalheim Kraft AS	2010	8	18,4	58,2
Høg-Jæren I&II	Jæren Energi AS	2011	32	73,6	256,7
Åsen II	Solvind Åsen AS	2012	2	1,6	4,0
Fakken	Troms Kraft AS	2012	18	54,0	140,0
Ytre Vikna	Sarepta Energi AS	2012	17	39,1	126,7
Lista	Lista Vindkraftverk AS	2012	31	71,3	250,1
Raggovidda	Varanger Kraft AS	2014	15	45,0	196,9
Annen vindkraft*			68	174,3	383,3
sum			374	873	2511

Appendix J

Generation of electricity (GWh) in Norway (1998-2014), (Source: Statistic Norway)

	Production, total	Hydro power production	Thermal power production	Wind power production	Imports	Exports
1998	116 787	116 280	496	11	8 046	4 412
1999	122 445	121 882	538	25	6 857	8 776
2000	142 816	142 289	496	31	1 474	20 529
2001	121 608	121 026	555	27	10 760	7 162
2002	130 473	129 837	561	75	5 329	15 002
2003	107 245	106 084	943	218	13 472	5 587
2004	110 472	109 291	929	252	15 334	3 842
2005	137 811	136 452	860	499	3 653	15 695
2006	121 400	119 729	1 035	636	9 802	8 947
2007	137 164	134 736	1 536	892	5 284	15 320
2008	142 108	139 981	1 214	913	3 414	17 291
2009	131 773	126 077	4 719	977	5 650	14 633
2010	123 630	117 152	5 599	879	14 673	7 123
2011	127 631	121 553	4 795	1 283	11 255	14 329
2012	147 716	142 810	3 358	1 548	4 190	22 006
2013	133 975	128 699	3 395	1 881	10 135	15 140
2014	141 968	136 181	3 570	2 217	6 347	21 932

Appendix K

Norwegian-Swedish annual quotas from 2012-20135 (Swedish Energy Agency & NVE, 2015).

Year	Quota Sweden	Quota Norway
2012	0.179	0.03
2013	0.135	0.049
2014	0.142	0.069
2015	0.143	0.088
2016	0.231	0.119
2017	0.247	0.137
2018	0.27	0.154
2019	0.291	0.172
2020	0.288	0.197
2021	0.272	0.196
2022	0.257	0.196
2023	0.244	0.195
2024	0.227	0.193
2025	0.206	0.186
2026	0.183	0.174
2027	0.162	0.156
2028	0.146	0.131
2029	0.13	0.109
2030	0.114	0.09
2031	0.094	0.072
2032	0.076	0.054
2033	0.052	0.036
2034	0.028	0.018
2035	0.013	0.009

Appendix L

Wholesale electricity price P_w, Consumer Price P_c and electricity certificate Price P_s

By differentiating the equation (4.1) and (4.2) with respect to α gives-

$(\alpha.\ f' - Y_{gs}')\partial P_w / \partial\alpha + (\alpha^2.f' - Y_{gs}')\ \partial P_s / \partial\alpha = -f - \alpha f'.\ P_s$ …………………… …….... [7.1]

$((1-\alpha).\ f' - Y_{bs}')\partial P_w / \partial\alpha + ((1-\alpha).f'.\alpha)\ \partial P_s / \partial\alpha = f - (1-\alpha).\ f'.\ P_s$……………………………………[7.2]

Here f stands for f $(P_w + \alpha P_s)$ and f′ stands for $\partial f (P_w + \alpha P_s)$

Reduced Equation 7.1and 7.2, we have

$\alpha_{11}\ \partial P_w/\partial\alpha + \alpha_{12}\partial P_s/\partial\alpha = b_1$

$\alpha_{21}\ \partial P_w/\partial\alpha + \alpha_{22}\ \partial P_s/\partial\alpha = b_2$

By applying Cramer's rule, in order to solve for $\partial P_w / \partial\alpha$ and $\partial P_s / \partial\alpha$:

$|A| = \alpha_{11}\, \alpha_{22} - \alpha_{12}\alpha_{21}$

$= (\alpha.\, f' - Y_{gs}').\, ((1-\alpha).f'.\, \alpha) - (\alpha^2.f'-Y_{gs}').\, ((1-\alpha).\, f' - Y_{bs}')$

$= \alpha^2.\, f'\, .f' - \alpha^3.\, f'\, .f' - \alpha.\, f'\, .g' + \alpha^2.\, f'\, .g' - (\alpha^2.\, f'\, .f' - f'\, .g' - \alpha.\, g'\, .f' - \alpha^2.\, b'\, .f' + g'\, .b')$

$= -\alpha.\, g'\, .f' + \alpha^2.\, g'\, .f' + f'\, .g' - \alpha.\, f'\, .g' + \alpha^2.\, b'\, .f' - b'\, .g'$

$= -2g'f'\alpha + \alpha^2 g'f' + f'g' + \alpha^2 b'f' - b'g'$

$= f'g'(-2\alpha + \alpha^2 + 1) + \alpha^2 f'b' - b'g'$

$= f'g'(1-\alpha) + \alpha^2 f'\, b' - g'b'$ ………………………………………………………[7.3]

$|A| < 0$

For wholesale electricity price

$$|A_1| = \begin{vmatrix} b_1 & \alpha_{12} \\ b_2 & \alpha_{22} \end{vmatrix}$$

$= (f - \alpha f' P_s)\, ((1-\alpha).\, f'\alpha) - (\alpha^2 f' - g')\, (f - (1-\alpha) f' P_s)$

$= -ff'\alpha + g'f' - (1-\alpha) f'g' P_s$ ………………………………………………………[7.4]

$|A_1| > 0$

Hence,

$\partial P_w / \partial\alpha = |A_1| / |A| < 0$

For electricity certificate price

$$|A_2| = \begin{vmatrix} \alpha_{11} & b_1 \\ \alpha_{21} & b_2 \end{vmatrix}$$

$= (\alpha f' - g')\, (f - (1-\alpha).\, f'.\, P_s) - ((1-\alpha) f' - b')\, (-f - \alpha f' P_s)$

$= ff' - f.\, (g' + b') + f' P_s\, .(\, (1-\alpha) g' - \alpha b')$ ………………………………………[7.5]

If term $((1-\alpha)\, g' - \alpha b')$ is positive, then the derivative $\partial P_s / \partial\alpha$ will be positive since $|A_2|$ is negative.

For Consumer Price

$P_c = P_w + \alpha P_s$

$\partial P_c / \partial \alpha \;=\; |A_1| / |A| + \alpha . |A_2| / |A| + P_s$

$\partial P_c / \partial \alpha \;=\; \partial P_w / \partial \alpha + \alpha . \partial P_s / \partial \alpha + P_s$

By substituting

$\partial P_c / \partial \alpha \;=\; f.((1-\alpha)g' - \alpha\, b') - g'\, b'P_s) / f'g'(1-\alpha) + \alpha^2 f'\, b' - g$

Appendix M (Raw data)

M	Eq_p	Os_p	Kr_p	Br_p	Tr_p	Tro_p	Cp	T_Os	T_Br	T_Tro	T_Kr	T_Tr	Pro
1/1/12	6,317.4	279.96	268.44	269.75	282.76	282.76	191.72	-2.40	2.70	-2.50	0.20	-1.90	15444260
2/1/12	6,740.4	357.87	337.03	344.92	366.46	366.46	182.28	-2.20	2.70	-2.20	-0.20	-0.60	14433820
3/1/12	6,712.9	216.16	215.70	215.70	212.45	213.02	177.61	5.60	4.00	0.40	6.40	3.60	12777981
4/1/12	6,552.4	229.91	228.81	229.90	237.55	231.49	167.02	4.90	5.70	0.40	5.10	2.80	12105222
6/1/12	6,278.5	176.63	176.95	172.99	197.44	194.26	157.58	13.60	12.90	9.10	12.40	11.00	10215391
7/1/12	6,709.6	97.71	102.67	93.24	99.81	99.81	146.20	16.40	14.80	10.90	15.40	13.30	9854916
8/1/12	6,621.4	146.08	151.04	143.90	175.24	175.24	145.23	16.10	15.20	9.90	15.40	13.30	10898506
9/1/12	6,739.5	138.01	138.52	117.35	212.52	205.55	149.26	11.10	10.60	7.60	11.60	8.70	10547874
10/1/12	6,598.3	254.35	254.35	254.14	256.44	250.06	198.22	5.20	7.00	3.20	6.60	4.00	12005935
11/1/12	6,714.8	249.48	249.42	249.64	250.88	251.05	146.16	3.20	6.00	1.60	4.70	3.00	12258223
12/1/12	6,813.8	313.43	299.64	312.28	322.48	322.47	160.65	-5.10	-0.10	-3.10	-3.30	-5.40	14684717
1/1/13	7,345.3	311.67	299.12	311.35	306.72	305.84	171.47	-4.90	0.30	-1.50	-3.00	-3.80	14631052
2/1/13	7,645.8	295.87	295.25	295.87	293.08	293.04	175.33	-3.20	1.50	-2.40	-2.50	-2.60	12456271
3/1/13	7,637.1	338.77	338.24	341.33	333.05	332.95	183.19	-2.10	0.90	-3.90	-1.90	-2.70	12352054
4/1/13	7,680.4	359.85	359.37	364.33	349.04	334.87	182.08	4.30	5.00	1.30	3.00	3.60	9456133
5/1/13	7,715.0	279.62	279.59	279.26	279.60	278.32	170.79	12.80	11.30	8.70	9.00	11.90	9648392
6/1/13	7,517.2	250.11	250.17	250.10	263.98	263.19	171.76	15.00	13.30	10.00	14.00	12.50	9330040
7/1/13	7,948.9	260.23	260.25	259.02	268.27	267.66	163.12	18.40	15.60	11.90	17.50	14.20	9556858
8/1/13	8,091.3	259.33	259.35	258.91	287.44	285.39	175.35	16.30	15.20	11.90	15.80	13.80	10025563
9/1/13	8,561.8	283.81	282.68	283.81	345.14	333.38	200.03	12.00	12.50	6.00	12.30	11.00	9869160
10/1/13	8,715.3	299.38	297.40	299.24	337.19	336.90	188.03	7.50	4.00	3.50	8.70	5.90	10802762
11/1/13	9,112.8	295.55	293.76	295.55	305.51	304.33	203.94	2.40	5.50	0.30	2.00	2.50	12185161
12/1/13	9,295.4	273.22	271.45	271.50	272.78	272.78	192.18	2.00	5.70	0.00	4.50	2.50	13071804
1/1/14	9,278.8	278.57	278.11	266.97	275.67	275.67	163.65	-2.60	3.40	-4.80	0.70	-2.30	14671760
2/1/14	9,625.0	252.51	250.34	251.27	254.13	254.23	166.70	1.80	5.50	0.60	3.20	3.70	11868973
3/1/14	9,509.5	219.38	218.34	218.12	225.87	225.87	165.84	4.30	6.00	0.20	5.30	3.40	12262420
4/1/14	9,432.8	194.16	189.95	191.76	228.44	227.15	169.07	7.70	8.90	1.50	8.20	5.70	11487090
5/1/14	9,570.9	157.48	157.30	157.48	281.25	281.29	166.87	12.00	11.40	5.10	11.30	9.50	11070779
6/1/14	9,783.4	155.85	155.89	155.82	252.65	246.44	162.34	15.70	14.50	9.10	15.40	12.00	10376400
7/1/14	9,781.3	224.64	224.64	223.92	248.77	245.98	165.62	20.80	19.00	15.20	19.20	19.10	10228065

M-months, Eq_p-Equity price (NOK), Os_p-Electricity spot prices in Oslo (NOK), Kr_p- Electricity spot prices in Kristiansand (NOK), Br_p- Electricity spot prices in Bergen (NOK), Tr_p- Electricity spot prices in Trondheim (NOK), Tro_p- Electricity spot prices in Tromsø (NOK), cp-Green certificate price (NOK), T_Os- Air temperature mean (Oslo) in Celsius, T_Br- Air temperature mean (Bergen) in Celsius, T_Tro- Air temperature mean (Tromsø) in Celsius, T_Kr- Air temperature mean (Kristiansand) in Celsius, T_Tr- Air temperature mean (Trondheim) in Celsius, Pro- Monthly Electricity production in Norway (MWh).

Appendix M (Raw data)

M	Eq_p	Os_p	Kr_p	Br_p	Tr_p	Tro_p	Cp	T_Os	T_Br	T_Tro	T_Kr	T_Tr	Pro
8/1/14	9,592.2	245.92	246.00	245.06	274.02	273.77	163.57	15.80	15.50	11.80	17.00	15.00	9825466
9/1/14	9,769.4	271.43	271.42	271.42	298.06	297.71	163.43	13.10	13.60	7.90	13.40	11.50	10552850
10/1/14	10,017.5	228.24	228.24	228.24	269.77	270.85	188.87	8.90	10.60	4.00	10.50	7.40	11741681
11/1/14	10,403.5	238.19	237.14	238.04	269.56	269.56	175.11	4.10	7.30	1.00	5.90	3.40	13062531
12/1/14	10,545.1	280.45	279.29	279.69	283.54	283.54	162.82	-2.20	3.20	-1.20	1.20	-0.20	14430572
1/1/15	11,113.1	257.30	255.49	255.80	272.29	272.29	149.38	-0.30	3.40	-3.00	2.10	0.10	14794161
2/1/15	11,628.5	246.16	246.16	246.15	244.76	244.78	153.32	0.30	3.40	-1.10	2.10	1.70	12893355
3/1/15	11,954.6	214.27	214.27	213.31	218.78	218.69	145.36	3.50	5.20	1.70	4.00	3.50	13175532
4/1/15	11,366.7	211.89	211.30	211.31	219.11	216.41	137.58	7.10	6.20	2.60	7.00	4.30	10992884
5/1/15	11,618.4	181.35	181.35	181.35	199.23	190.96	137.58	10.00	10.00	6.40	8.90	8.00	10850073
6/1/15	11,307.6	118.69	118.69	118.69	128.33	116.48	139.09	14.20	11.40	8.10	13.40	9.60	10767245
7/1/15	11,972.5	79.94	80.05	79.94	80.99	78.44	140.63	16.20	14.40	11.70	15.50	12.80	9554242
8/1/15	11,534.0	101.31	105.54	98.40	126.34	107.81	138.76	16.50	16.50	13.20	16.00	16.40	10358506
9/1/15	11,295.3	120.47	120.47	120.47	189.07	183.43	139.71	12.50	13.50	9.50	12.60	11.50	11056360
10/1/15	11,609.6	198.85	198.85	198.85	206.47	188.66	171.26	7.20	9.60	4.90	8.30	7.30	11961258
11/1/15	11,898.1	230.46	227.23	227.23	221.17	209.57	149.92	3.20	6.80	1.60	5.70	3.70	13105895
12/1/15	11,991.3	168.02	165.90	166.36	176.35	163.58	156.28	2.10	5.80	-0.40	4.60	2.30	13865770
1/1/16	11,179.3	291.37	248.30	248.72	271.81	267.83	122.88	-5.50	0.00	-4.80	-3.30	-4.10	16433821
2/1/16	11,004.4	183.34	183.32	182.96	185.80	180.55	123.34	-0.70	2.10	-2.20	1.20	-0.50	14120587
3/1/16	10,911.3	201.95	201.95	201.85	203.83	197.47	129.22	3.10	4.90	-0.10	3.50	2.30	14383087
4/1/16	10,694.5	204.30	204.29	204.36	208.90	194.54	133.45	5.90	6.20	2.90	5.80	3.80	11700034
5/1/16	10,886.3	210.20	210.20	210.10	218.95	208.16	133.74	12.30	12.20	7.70	12.10	9.80	11254757
6/1/16	10,424.0	224.85	224.85	223.09	287.02	231.36	152.81	16.70	15.30	8.50	15.60	12.20	10829795
7/1/16	10,819.3	219.39	219.39	208.14	275.96	242.14	142.86	17.20	14.70	12.30	15.00	14.80	10036568
8/1/16	10,640.7	201.22	201.22	194.13	276.16	240.92	151.63	15.50	14.20	10.40	7.60	13.00	10185494

M-months, Eq_p-Equity price (NOK), Os_p-Electricity spot prices in Oslo (NOK), Kr_p- Electricity spot prices in Kristiansand (NOK), Br_p- Electricity spot prices in Bergen (NOK), Tr_p- Electricity spot prices in Trondheim (NOK), Tro_p- Electricity spot prices in Tromsø (NOK), cp-Green certificate price (NOK), T_Os- Air temperature mean (Oslo) in Celsius, T_Br- Air temperature mean (Bergen) in Celsius, T_Tro- Air temperature mean (Tromsø) in Celsius, T_Kr- Air temperature mean (Kristiansand) in Celsius, T_Tr- Air temperature mean (Trondheim) in Celsius, Pro- Monthly Electricity production in Norway (MWh).

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