NTNU – Trondheim
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# Analysis of the Norwegian-Swedish Market for Green Certificates Using the EMPS Model

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# Problem description

The Norwegian-Swedish market for green certificates started in 2012 and will provide 26,4 TWh of new renewable power production, divided between Norway and Sweden, by 2020. This will be a crucial contribution for Norway to abide by EUs' Renewables Directive. The certificate market sales value and significance indicates that there should be established models for forecasting prices and certificate holdings, and overall analysis of the system. This is important so that the new market will work as intended.

The new certificate market is closely connected to the power market. The certificates must be bought by the power suppliers, they are issued to producers of renewable power and are ultimately financed by the end users on their utility bill. As a consequence of this close correlation between the markets, a tool for forecasting and analysis of the certificate scheme that is based on a good model of the Nordic electricity market will be a great advantage. At the same time, it will be an advantage that the system's impact on the electricity market will be included in these power market models.

The objective of this thesis is to analyze the market for green certificates using the EMPS model, which includes descriptions of both the power market and the certificate market. The thesis is based on a realistic dataset for the Nordic power market, which must be adapted and updated for the use of realistic analysis of the green certificate market. In the analysis, the candidate will focus particularly on factors affecting the level and fluctuations in certificate prices.

# Preface

This master thesis is written on behalf of the course "TET4900 Electric Power Engineering and Smart Grids, Master's Thesis" to fulfill the requirements for a Master of Science degree in Electrical Power Systems at the Norwegian University of Science and Technology (NTNU), Department of Electric Power Engineering. The work has been done in cooperation with the largest independent research organization in Scandinavia, SINTEF Energy Research, and is inspired by ongoing research and changes in the Nordic power market.

I would like to thank my supervisors Magnus Korpås and Ove Wolfgang, at SINTEF Energy Research and NTNU, for their helpful guidance and advice. I would also like to thank SINTEF Energy Research for providing me with the necessary tools and data for this thesis.

Finally I would like to thank my family and friends for their support and motivation during my 5 years at NTNU.

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# Summary

Over the last few years it has been important for the European countries to support green energy as a countermeasure against climate changes. Norway and Sweden have chosen to implement a common green certificate market, which is a support scheme for renewable energy technology. The scheme will be a crucial contribution for Norway to abide by EUs' Renewables Directive. So far the market is doing really well and is on track to complete the goal of 26,4 TWh new electricity production from renewables before the end of 2020.

The joint certificate market is very closely connected to the power market. Therefore, the EMPS model, which is a good model of the Nordic power market, was chosen as the model to use for testing and forecasting in this thesis.

The main objective has been to analyze the Norwegian-Swedish certificate market in the EMPS model with particular focus on factors that affect the green certificate price levels and price fluctuations. This has been done by adjusting and updating a realistic dataset for the Nordic power market. The historic values from the real certificate market were used as inputs and as a basis for the simulations.

10 different cases have been presented and simulated, where the main differences between them were the expansion rate of new production and the expansion of different energy sources. The results obtained from the simulations corresponded to theoretical findings about the green certificate market. Currently the certificate storage holds 13 million certificates, but it appears like it might increase towards a value of 15 million during 2015, before it will start to decrease considerably from 2016.

In order to achieve different price scenarios in the simulations, the initial certificate storage needed to be lowered a great deal from the real value, so that the EMPS model could see a possibility of deficit in the future. The most ideal cases with the most even price levels were achieved when the amount of production and consumption of green certificates were as close together as possible.

It was demonstrated by the simulations that the expansion rate of new production greatly influences the certificate prices. If the expansion rate is fast, a smaller probability of deficit

exists, and as a result the certificate prices will be lower. The opposite is true for a slow expansion rate.

The different types of production sources (hydropower, wind power and biofuels) also affected the certificate price levels in different ways, even though the storage developments were the same. When there was more hydropower expansion the average price was the lowest, but the price curve was the most extreme. Expansion in wind power lead to a higher average price, while expansion in biofuels had the most even price curve.

A reason for these different price scenarios could be that both hydropower and biofuels can be adjusted in response to power prices. However, different calibrations for the EMPS model had to be performed for the different cases. It is therefore likely that this also influenced the price levels for the different types of production.

All things considered, it looks as if 2015 is going to be a very important year regarding the future of the common certificate market. A lot of decisions needs to be made regarding both changes in regulation and potential new investments, which will affect whether the common goal will be met or not. The future is uncertain, but with more work and testing  the EMPS model could hopefully predict some of it.

# Sammendrag

I løpet av de siste årene har det vært viktig for de europeiske landene å støtte fornybar energi som et mottiltak mot klimaendringer. Norge og Sverige har valgt  inngå et felles elsertifikatmarked, som er en støtteordning for fornybar energiteknologi. Ordningen vil være et avgjørende bidrag for at Norge skal overholde EUs Fornybardirektiv. Så langt gjør markedet det veldig bra og er på vei til å fullføre målet om 26,4 TWh ny kraftproduksjon fra fornybar energi innen utgangen av 2020.

Det felles sertifikatmarkedet er tett integrert med kraftmarkedet. Derfor ble Samkjøringsmodellen, som er en god modell av det nordiske kraftmarkedet, valgt som modellen som skal brukes til testing og prognoser i denne masteroppgaven.

Hovedmålet har vært å analysere det norsk-svenske sertifikatmarkedet i Samkjøringsmodellen, med spesielt fokus på faktorer som påvirker nivå og –svingninger i sertifikatprisene. Dette er gjort ved  justere og oppdatere et realistisk datasett for det nordiske kraftmarkedet. De historiske verdiene fra det virkelige elsertifikatmarkedet ble brukt som input og som grunnlag for simuleringene.

Ti forskjellige tilfeller har blitt presentert og simulert, hvor de viktigste forskjellene mellom der var hastigheten på ekspansjon av ny produksjon og utbygging av ulike energikilder. Resultatene fra simuleringene samsvarer med teoretiske funn fra elsertifikatmarkedet. For tiden holder sertifikatlageret 13 millioner sertifikater, men det ser ut som om det kan øke til en verdi av 15 millioner i løpet av 2015, før det vil begynne å avta betydelig fra 2016.

For å oppnå forskjellige prisscenarioer i simuleringene måtte det opprinnelige sertifikatlageret senkes en god del fra den virkelige verdien, slik at Samkjøringsmodellen kunne se en mulighet for underskudd i fremtiden. De mest ideelle tilfellene med de mest jevne prisnivåene ble oppnådd når mengden av produksjon og forbruk av elsertifikater var så like som mulig.

Av simuleringen ble det demonstrert at ekspansjonsraten av ny produksjon har stor innvirkning på sertifikatprisene. Dersom ekspansjonshastigheten er rask vil det være mindre sannsynlighet for underskudd, og som et resultat vil sertifikatprisene være lavere. Det motsatte gjelder for en langsom ekspansjonsrate.

De ulike produksjonskildene (vannkraft, vindkraft og biobrensel) påvirket også sertifikatprisene på ulike måter, selv om utviklingen av sertifikatlagrene var lik. Når det var mest utbygging av vannkraft var gjennomsnittsprisen lavest, men priskurven var den mest ekstreme. Ekspansjon av vindkraft førte til en høyere gjennomsnittspris, mens utvidelsen av biobrensel førte til en jevnere priskurve.

En årsak til disse ulike prissenarioene kan være at både vannkraft og biobrensel kan justeres som følge av kraftprisene. Likevel så måtte forskjellige kalibreringer for Samkjøringsmodellen utføres for de ulike tilfellene. Det er derfor sannsynlig at dette også påvirket prisnivået til de ulike produksjonstypene.

Alt tatt i betraktning ser det ut som om 2015 kommer til å bli et svært viktig år når det gjelder framtiden til det felles sertifikatmarkedet. Mange beslutninger skal tas, både angående forskriftsendringer og eventuelle nye investeringer, noe som vil påvirke om det felles målet blir oppfylt eller ikke. Fremtiden er usikker, men med mer arbeid og testing av Samkjøringsmodellen kan den forhåpentligvis forutse noe av den.

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# 1 Introduction

From January 1st 2012 a joint certificate market was implemented in Norway and Sweden. This is a support scheme for renewable energy technology, where the overall goal is to increase the renewable power production in Norway and Sweden with 26,4TWh by 2020.

The market makes it more profitable to invest in renewable energy, such as solar power, hydropower, wind power, wave power, geothermal energy and biofuels. In turn, an increased production of renewable energy will make it possible to scale down the use of fossil energy and thereby reducing emissions of greenhouse gases.

The green certificates market value and importance indicates that there should be established models for forecasting prices and certificate storages and overall analyzes of the system. This is important for the market to work as intended. The green certificate market is also closely integrated with the power market, so it is important that the forecasting is based on a good model of the Nordic power market, such as the EMPS model.

This master thesis is based on, and is the continued work of a specialization project report [1]. The main scope is to analyze the green certificate market using the EMPS model. The analyses are based on a realistic dataset for the Nordic power market, which will be adjusted and updated to represent the green certificate market in Norway and Sweden.

First some theory describing green certificates, and how the joint certificate market is doing so far, will be presented. Then the EMPS model will be introduced and the dataset that is being used will be described. Finally 10 cases with different input changes will be presented, simulated and analyzed. The focus will be particularly on factors that affect the green certificate price levels and price fluctuations.

# 2 Theory

## 2.1 How the Green Certificate Scheme Works

[2]

For every 1 MWh of renewable power produced, the producer may receive a green certificate, over a maximum of 15 years. When selling the certificates in the market they will receive an additional income to the power sales. This is a market based system, meaning that supply and demand will determine the certificate price.

To create a demand for the certificates the Norwegian and Swedish government implemented a law that obligates electricity suppliers, and some end users, to buy a certain amount of green certificates based on their total sale or consumption. This quota must be fulfilled every year. The price of the green certificates is then included in the final bill for the end users, making it them who pays for the expanded renewable electricity production. The market mechanisms are illustrated in Figure 2-1.

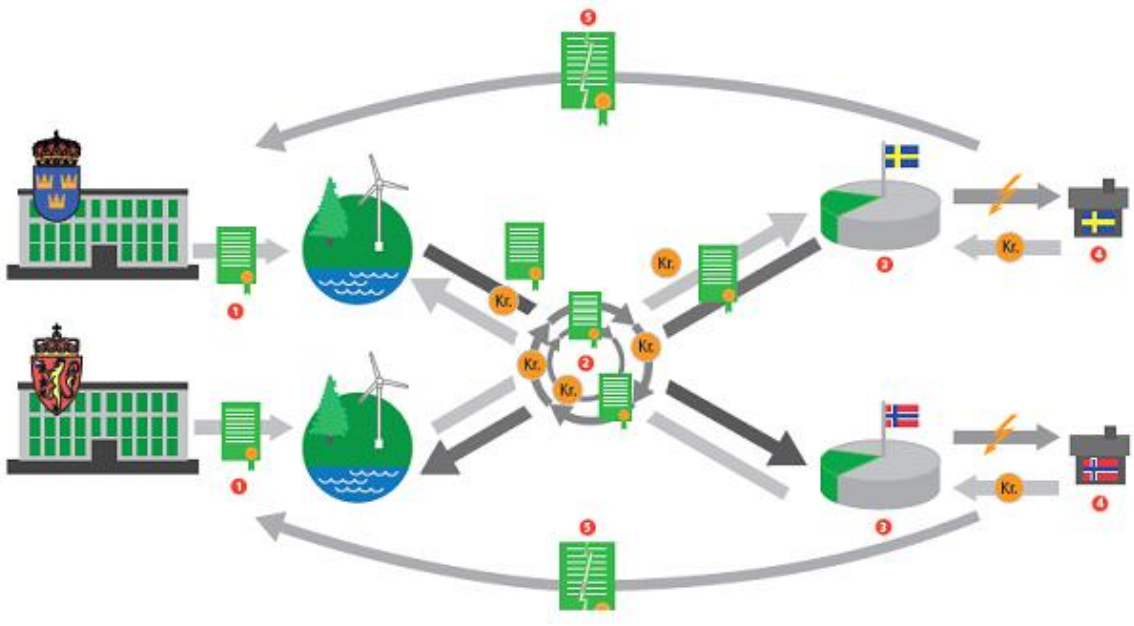



Figure 2-1: How the green certificates work
Source: Energimyndigheten; NVE [2]

## 2.2 A Joint Certificate Scheme

Several countries operate nationally with green certificate schemes, for example Denmark, Germany, the UK, Italy, Belgium and some states in the US. However, in 2012 Norway joined Sweden in the first ever joint certificate market. An important advantage of the joint market is that the renewable resources are being used more efficiently because, between the two countries, the investments take place where the profitability and conditions are the best. A number of factors such as licensing policy, development costs, transmission capacity, grid connections and expected future prices, will determine where the production actually takes place.

Sweden has been operating with a green certificate market since 2003. Before Norway joined them in 2012, Sweden managed to increase their renewable power production with 13,3 TWh [2]. Figure 2-2 shows the production of green electricity in Sweden as well as the distribution of the renewable energy sources. Their original goal was to finance 28 TWh new renewable power production by 2020, which is an increase of 23 TWh compared to 2002. However, the Swedish government now want to increase it even further, to 30 TWh by 2020 [3].

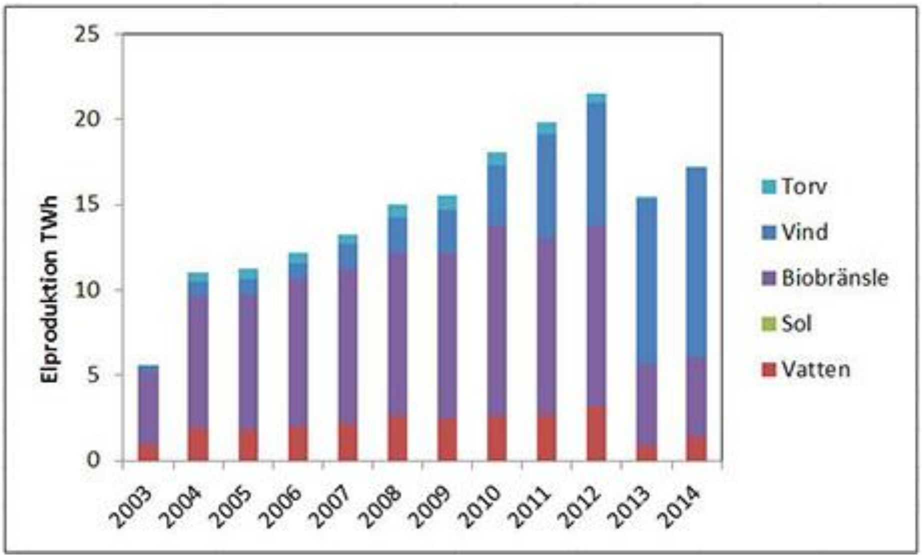



**Figure 2-2: Renewable electricity production in Sweden since the start of the green certificate scheme**
**Source: Energimyndigheten [4]**

Norway and Sweden have the highest renewable national targets of all the EU-countries with 68% and 40% by 2020. As mentioned, the common goal is to increase the electricity from renewables to 26,4 TWh by 2020, which is more than half of the power consumption of all Norwegian households. The countries are responsible for financing 13,2 TWh each. Because there is access to a larger production base, this can be done in a more lucrative way than by having separate markets. As a result, having a common market makes it more attractive for investors to invest in renewable energy [2].

A bigger market and more participants will also lead to increased competition and liquidity, and the prices might become more stable. However, the market power of Swedish producers will decrease in a bigger market, which may lead to an increase in certificate price volatility [2]. Price volatility and uncertainty are discussed further in section 2.4.

### 2.2.1 Authorities and Issuing of Certificates

[2]

The Norwegian Water Resources and Energy Directorate (NVE) and the Swedish Energy Agency decides who is eligible to receive green certificates. The producers have to apply and get their plant approved before certificates can be issued. To get approved the energy has to be produced from one of the renewable energy sources; solar power, hydropower, wind power, wave power, geothermal energy or biofuels. In Sweden producers of peat are also eligible for receiving certificates.

In Sweden, plants that started operating after the implementation of certificates in 2003, are allowed certificates for 15 years. In Norway the same principle applies from 2012, but one subtracts the time the plant has been operational before that time. An increase in production in Norway or Sweden gives them allocation rights for 15 years for the new renewable energy produced. If there is made a huge reconstruction or expansion on an existing plant in Sweden they will get 15 new years of allocation. However the years cannot exceed 2035 when the scheme comes to an end.

Plants that were put into operation before 2012 are not a part of the common 26,4 TWh goal, and this is generally referred to as the transition scheme. If they are built after 1.1.2004 only plants smaller than 1 MW are eligible for receiving certificates, but after 7.9.2009 all plants are eligible.

## 2.2.2 Quota Obligations

[2]

The demand for green certificates is created by quota obligations. Suppliers and some end-users have an obligation to buy a certain percentage of their sales or consumption of electricity from renewable energy and green certificates. If the industry is electricity-intensive, they only have to buy green certificates for the proportion of electricity that is not used in the manufacturing process.

There is a law that sets the quotas for each year, and the quotas are individual for Norway and Sweden. Norway's is set from 2012-2035 and Sweden's is set from 2003-2035. The quotas for the green certificates are developed with the aim of getting an even expansion rate of new renewable energy up until 2020. The storage of certificates is therefore dependent on when the producers start up new power plants. Figure 2-3 show how the quotas change from year to year for both countries.

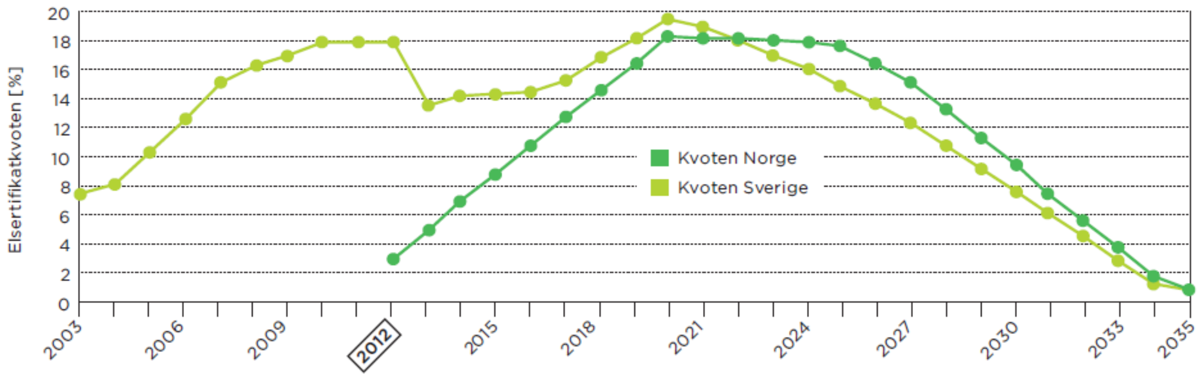



**Figure 2-3: Green certificate quotas for Norway and Sweden**

**Source: Energimyndigheten; NVE [2]**

The quotas are calculated in a way as to encourage expansion of renewable energy that matches the countries' goal. However, if the consumption of electricity deviates a lot from the expected values the quotas might need to be readjusted. This is done by the governments in Norway and Sweden, and the first adjustments are planned to happen in 2015. This will be discussed further in section 2.7.

The main advantages of a quota-based certificate scheme are [5] :

- It is a cost effective way to fulfill renewable electricity target (competition drives production costs down)
- It is compatible with EU state aid rules (Non-discriminatory, i.e. not technology specific)
- It is a market-based instrument (full exposure to market signals)
- It is financed off state budget

### 2.2.3 Penalty Fee for Missing Certificates

[6]

If a market participant does not fulfill their quota obligation they have to pay a penalty fee. The fee will be 150 % of the average green certificate price for that year. The point of this is to motivate the participants to fulfill their obligations instead of paying a last minute fee. The reason for making the penalty a percentage is to keep the fee from being viewed as a maximum price.

However, there may be a few challenges with this dynamic penalty fee. Climate variations (wind, water, temperatures) affects the production of wind- and hydropower, as well as the electricity consumption, while the production of biofuels is dependent on price. If one year there is a deficit of green certificates, there will not be enough certificates in the market and some suppliers have to pay a fee for not fulfilling their quota.

Let us say that the spot price for certificates this year is 50 øre/kWh, which gives a penalty fee of 50 øre/kWh × 150% = 75 øre/kWh. If the fee is 75 øre/kWh the consumers would want to buy more certificates for 50 øre/kWh. However the production is already running at maximum capacity which pushes the certificate price to 75 øre/kWh. This would mean a penalty fee of 75 øre/kWh × 150% = 112,5 øre/kWh, and the consumer would want to buy more certificates at 75 øre/kWh etc. This leads to an upwards spiral for green certificate prices and penalty fees.

Fortunately this phenomena has not occurred in the joint certificate market so far. A reason for this is that Sweden already had a built up storage of certificates in 2012 when Norway joined them. Figure 2-4 shows how the storage of green certificates, in addition to the certificates issued and cancelled (more on cancellation in section 2.9), have developed over the years since the startup in 2003.

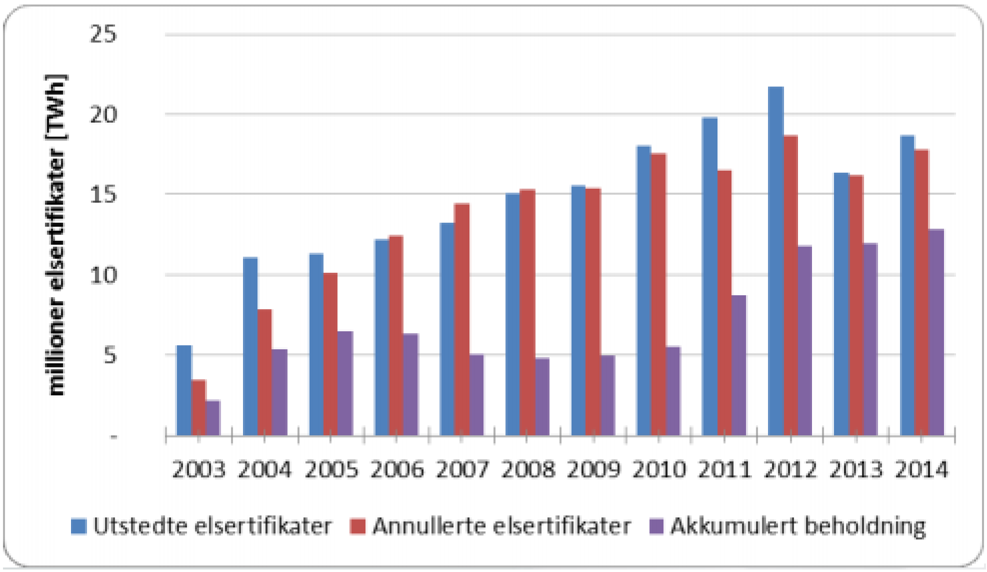



**Figure 2-4: The storage development of the green certificate market**
**Source: Eliston, A [7]**

## 2.3 The Nordic Power Market

[8], [9]

In 1991 Norway was the first Nordic country that deregulated their power market. This meant that the state no longer ran the market, competition ran freely, and it opened up for more electricity producers and distributors. After the remaining Nordic countries also deregulated their markets, all the individual markets were brought together to a common market. In the late 2000's the Baltic countries also deregulated their markets.

The customers in Norway and Sweden can choose for themselves which power supplier they want. Norway operates with 5 different price areas for electricity, while Sweden has 4. There are no taxes for transferring power across the border, so the only limitation will be transmission capacity.

The common electricity market is run by Nord Pool Spot, and it is the largest market in the world measured in volume (TWh) and market share. More than 70 % of the power exchange in the Nordic countries goes through Nord Pool Spot. It offers both an auction based day ahead market  (Elspot) and a trading system intraday market (Elbas). The participants are producers, distributors, large industrial businesses, energy suppliers, TSOs and large consumers. The buyers' and sellers' orders are registered and makes up a demand and supply curve that determines the price.

### 2.3.1 The Green Certificate Market and Trading

[2]

The market for green certificates is, like any other market, made up of buyers and suppliers. The sellers are the producers of renewable energy and they sell their energy on the electricity spot market. They will then receive both the spot price for electricity and the price for the green certificate, but the certificates can be sold separately from the electricity produced. They can choose to sell their green certificates immediately, at a later time or not at all.

The buyers are the consumers and retailing companies that are required by law to purchase a certain amount of green certificates. This amount corresponds to a certain percentage of their total electricity consumption, which means that there is a direct link between the electricity- and the green certificate market. The demand for green certificates is therefore obtained directly from the electricity demand.

The green certificate price is determined by demand and supply. When the supply is low, the price will be high and vice versa. This will make it more desirable for investors to invest in, and producers to produce more renewable electricity. Who is able to sell their certificates depends on who is able to provide the cheapest renewable electricity.

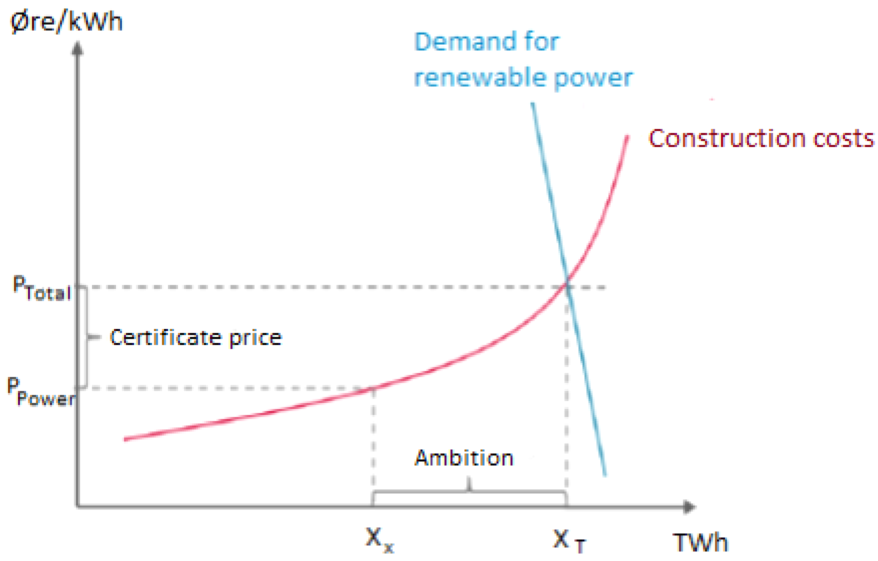



**Figure 2-5: How the certificate price level is determined**
**Source: Hansson; Øydgard [10]**

Figure 2-5 shows how the green certificate price is determined by demand and supply. There is initially one price for electrical power, $P_{Power}$, and bids of renewable energy sorted in ascending order of construction costs, given by the construction costs' curve. The government sets a goal of how much new renewable power that is to be built during the period of the green certificate market, as well as a mandatory demand (quota obligations) for renewable power, shown by the demand curve. The certificate price is given by the distance between $P_{Total}$ and $P_{Power}$, and it needs to rise to the level where supply meets demand for the goal to be achieved [10].

The green certificates are mainly handled by means of spot contracts or forward contracts. With the spot contracts the transfer and payment of the certificate will happen within 5-10 days. With the forward contracts it will take place at a set time in the future. However, with both types of contracts the price is set when the agreement is made.

The market participants with quota obligations have to report each year how many green certificates they need. They will all have a certificate account, and when there is a trade the certificate will be transferred from the seller's to the buyer's account. On April 1st every year the certificates are cancelled and cannot be reused. This way the participants again have to fill up their accounts for the next year and a demand for certificates is created. Based on the quotas it is predicted that the total demand for the entire period will be 396 TWh in Norway and Sweden combined [11].

## 2.4 Price Volatility and Uncertainty

[2]

The green certificate market is heavily regulated by authorities, so the investors are exposed to a lot of regulatory uncertainty. For example, if the quota obligations or the certificate allocation to producers is changed, it can lower the economic profitability of renewable energy projects. Green certificate prices, price volatility and risk can be affected by regulatory changes, which ultimately affects the cost of financing a project.

A study performed by Riccardo Fagiani and Rudi Hakvoort [12] on regulatory uncertainty in the Swedish-Norwegian certificate market, proves the negative impact of regulatory changes in the market. It shows that regulatory uncertainty leads to increased volatility, exacerbating price risk and restraining investors. Policy makers should therefore think carefully about any planned changes in the certificate market, and investigate how it will affect future prices before acting.

As mentioned, the green certificates can be saved from one year to the next, which is called banking. The saved certificates makes up the storage. This possibility has a major influence on prices, and price fluctuations caused by the yearly stochastic variation of renewables. In years with more than enough supply the certificates can be saved for years with limited supply, and therefore it might help stabilize the prices. Without any storage, producers might retain their certificates in case the prices becomes higher at a later point, which would create a high volatility level and uncertainty in the market.

Still, even with the storage producers can decide to hold on to their certificates in case the prices should increase later. This could make it difficult to obtain enough certificates even in years with a surplus. It all depends on who owns the certificates in the storage, and how long they can afford to hold on to them before they have to sell.

## 2.5 Financing the Certificates

The green certificate market is financed by the electricity end users, because the costs from buying green certificates are added to the utility bill. The end users will not buy the certificates themselves since the power suppliers are required to buy them. However, the suppliers are required to inform their costumers about the extra costs from their green certificate quota obligation [2].

This means that the electricity end users are helping to pay for the expansion of renewable energy in Norway and Sweden. In 2014 4 TWh of new renewable power was built in the two countries, and in Norway the average green certificate price was 2,1 øre/kWh. This means that a Norwegian family with a consumption of 20 000 kWh contributed with 420 NOK for the expansion of renewable power. This is a total of 1,6 billion NOK [13].

Even though the green certificate price is the same in both countries, different quotas makes the cost per kilowatt hours differ, and in Sweden it was 2,6 øre/kWh. Since the start of the joint certificate scheme in 2012 the electricity customers in Norway and Sweden have helped financing 10,3 TWh new renewable power production [13].

## 2.6 Common Market but Different Laws

[2]

The green certificate market is common for Norway and Sweden, but each country has its own legislation regulating the certificate system. There are a few important differences between the two countries:

- If a plant starts up after 2020 in Sweden they may receive green certificates, which is not the case in Norway
- After extensive reconstruction in Sweden, certificates can be received for the entire production. In Norway they will only get certificates for the production added
- In Sweden producers of peat are entitled to green certificates
- In Norway the amount of biofuels in mixed waste are permitted green certificates

The Swedish Energy Agency in Sweden and NVE in Norway have the same responsibilities in each country. They are responsible for developing and managing the green certificate scheme. Among other things they receive and approve applications for green certificates and keep records of the market participants with quota obligations. They also supervise the laws in each country concerning green certificates, and inform continuously of the development in the market in both countries and the common market.

Svenska Kraftnät (SvK) used to be  responsible for the registration of green certificates in Sweden and for the Swedish accounting system, but the task has been forwarded to the Swedish Energy Agency instead. Statnett has the same responsibilities in Norway. They issue green certificates on the 15th of each month, and cancel all certificates on April 1st. If the Swedish Energy Agency and NVE decides to cancel green certificates, the job is carried out by the Swedish Energy Agency and Statnett. They also update continuously information about certificates sold, issued and cancelled, as well as the average prices of certificates [14].

## 2.7 Progress and Changes

[15]

In the agreement of the joint green certificate market between Norway and Sweden, it is stated that there will be progress reviews with regular intervals. The reason for this is to see if there needs to be any changes to the rules in order to achieve the common goals. If any of the parties wants to change the goal and the commitment, it needs to happen after an agreement between both parties and preferably in connection with a progress review.

On February 11th 2014 both NVE and the Swedish Energy Agency handed in their reports for the first progress review. The reports showed that Norway and Sweden were well on their way to complete the goal of 26,4 TWh new electricity production from renewables before the end of 2020. At that time the green certificate scheme had contributed to 6,2 TWh of new production since 2012. Research have also shown that there are a lot of opportunities for more projects in both countries in the future.

Part of the progress reviews is to evaluate the quota obligations and potential changes. In Norway the electricity consumption was higher than expected, and the generation from power plants built before 2012 was lower than expected in the transition period. Therefore NVE recommended to slightly reduce the quota obligations. However, in Sweden the electricity consumption was lower, and the construction of new power plants faster than expected. As a result the Swedish Energy Agency recommended to increase the quota obligations. The next progress review will take place in 2017.

### 2.7.1 The Change Agreement

[16]

A new agreement of changes to the common market was negotiated in the winter of 2014/2015, and is now being processed in the Norwegian and Swedish parliaments. The first point of the agreement is that the common goal of new electricity from renewables is to be increased from 26,4 TWh to 28,4 TWh. However, this change only affects the Swedish quotas and has no impact on the Norwegian quota obligation whatsoever.

The second point in the agreement determines that the Swedish government will make a proposition for the Swedish Parliament by 2015. The proposition is to remove the exemption for energy tax on electricity made in renewable power plants by a producer that does not occupationally supply electrical power. The proposition applies to all plants that are put into operation after July 1st 2016, and where the installed production capacity leads to a yearly electrical production  that exceeds the effect limit that are exempted from energy taxes in Norway (100 kVA).

The third point is to allocate certificates to hydro power plants in Norway that were built after January 1st 2004 with a production of less than 10 MW. Originally only plants with a production of less than 1 MW were eligible to receive certificates. This change will include about 240 more power plants in the certificate scheme, and it will add an electricity production of about 2 TWh/year. The transitional scheme will then be increased from the original 9,25 TWh to 30,9 TWh [17]. Because of this increase a higher number of certificates will be issued, and therefore new quotas for Norway that overrules the suggested changes from the progress review report have been calculated.

The suggested quota changes will lead to an increase in the demand for green certificates with about 9 TWh between 2016-2019. The Norwegian quotas will be increased with about 1 TWh, and the Swedish quotas will be increased with 8 TWh in 2016. Figure 2-6 and Figure 2-7 demonstrates the original quotas and the new suggested quotas in Norway and Sweden. Tables with the exact values can be seen in Appendix A.

Finally, it is suggested in the change agreement to expand the final date in Norway for when a plant needs to be in operation to be eligible to receive certificates by one year, from December 31st 2020 to 2021. This will reduce the risk for projects that are planned to start operating in 2020.

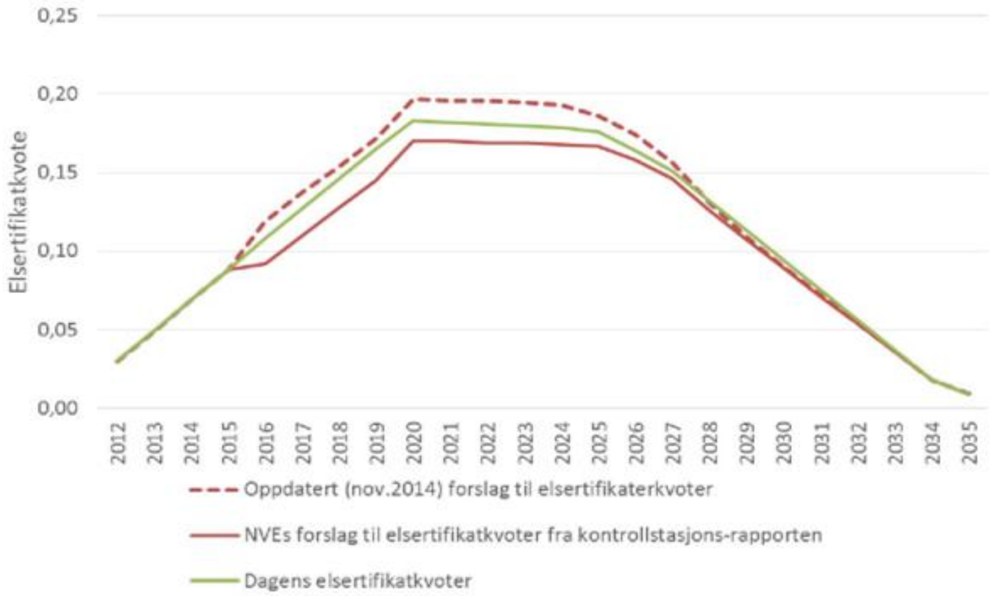



**Figure 2-6: Today's quotas, proposed quotas from the progress review report and the proposed new quotas due to an expanded transitional scheme in Norway**
**Source: Regjeringen [17]**

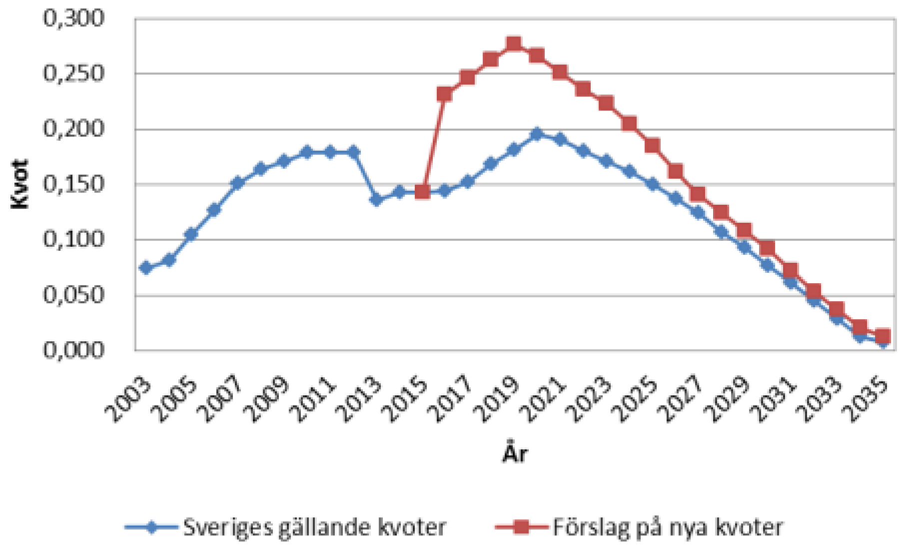



**Figure 2-7: Today's quotas and the proposed new quotas in Sweden**
**Source: Energimyndigheten [18]**

## 2.8 Reaching the Goal

[2]

There are several reasons why the predicted demand of 396 TWh might not be met. One reason is that there are too many or too few investments in the market, based on the average yearly production from certified plants. Another reason is that the production from the certified plants will deviate from the average yearly production, and will probably not equal 396 TWh aggregated over the whole period. However, if there are not enough investments before 2020, so that it is expected to be too few certificates to cover the demand for the remaining years, it is possible to make new investments in Sweden to increase the supply even after 2020 [11].

To reach the goal of 26,4 TWh new renewable energy by the end of 2020 there needs to be commissioned 2,93 TWh on average every year (3,11 TWh on average for the goal of 28,4 TWh). There is no set goal each year. Since 2012, the Norwegian-Swedish green certificate scheme has contributed with 10,3 TWh new renewables production capacity, where about two thirds is wind power. In 2014 alone 3,3 TWh was built in Sweden and 0,8 TWh in Norway [4].

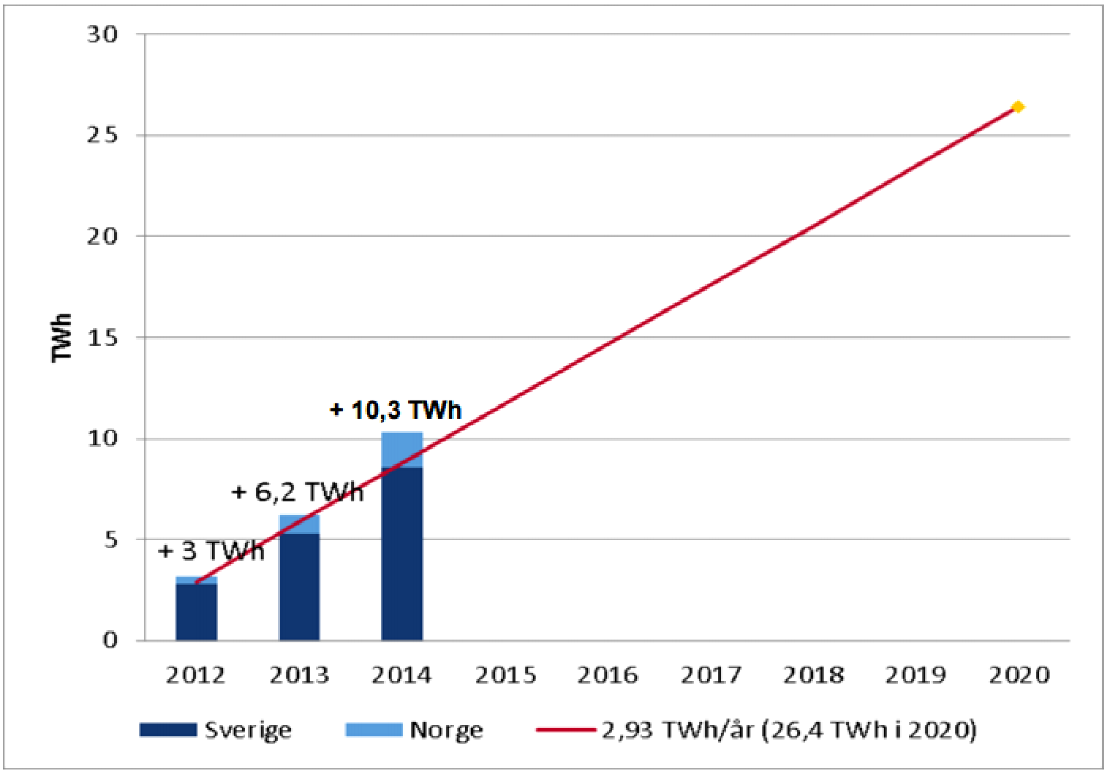



**Figure 2-8: New expected mean annual production within the 26.4 TWh goal**

**Source: Energimyndigheten [19]**

Figure 2-8 shows the new expected mean annual production within the common goal, and it shows that Norway and Sweden are well on their way to reach it. It is being built a lot of wind power in Sweden which dominates the construction for the common goal, which was demonstrated earlier in Figure 2-2. In Norway the main contributor is new hydro production.

In 2014, 18,7 million green certificates were issued, and the distribution is shown below in Figure 2-9. Certificates equal to 1,7 TWh were issued in Norway, 80 % was for hydropower, and 8,7 TWh were issued in Sweden, where 77 % was for wind power. There are few approved production facilities in Norway, and most approved facilities are small, which is why the distribution of certificates between the two countries is so uneven [20].

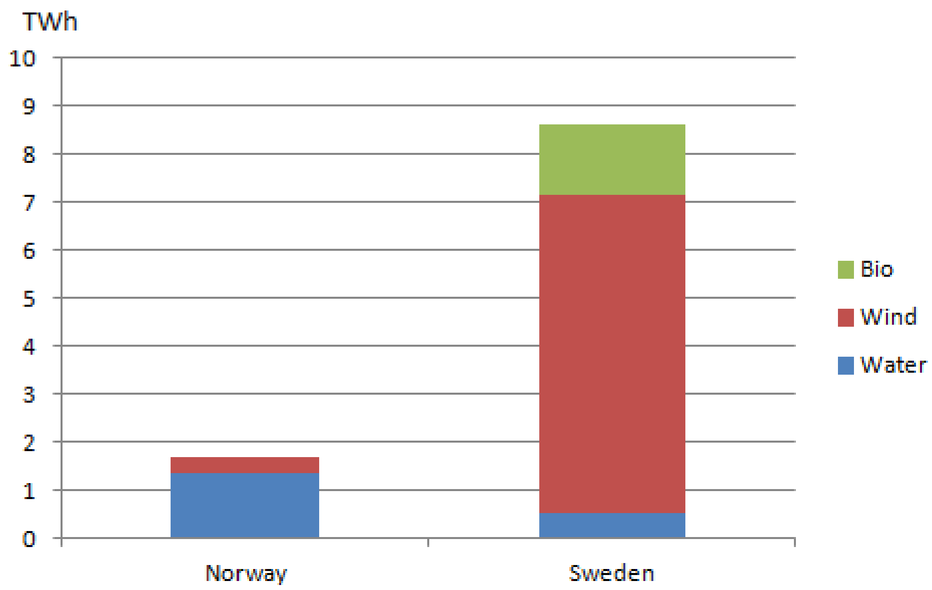



**Figure 2-9: Certificates issued in Norway and Sweden in 2014**

There are a lot of planned new projects for the upcoming years in both Norway and Sweden. 331 projects were reported in Sweden, where 27 are under construction and where 40 became operational during 2014 or the first quarter of 2015. In Norway the construction of wind power has had a slow start, but there are a lot of investable projects, and a high volume of wind power can be implemented towards 2020. However, an important condition is that the grid capacity is being built as expected [19].

## 2.9 Cancellation of Green Certificates

[2], [20], [21]

As mentioned, 18,7 million green certificates were issued in 2014. 17,8 million green certificates were cancelled, where 12,5 million were cancelled in Sweden and 5,3 million in Norway. This means that the overall storage of certificates increased by 0,9 millions to a total of 13 million certificates.

If a participant does not cancel enough certificates to fulfill their quota obligation, they will be charged a fee of 257,4 NOK (1,5 x 171,6 NOK ) for each certificate missing. This fee is calculated as 150 % of the registered average certificate price between April 1st 2014 to March 31st 2015.

The quotas set for each year are based on a relationship between how much electricity from renewable resources needs to be financed, and the assumed amount of electricity consumption in each country. The quotas are fixed, but the electricity usage will vary with climate changes and the financial position. This means that in a year with higher electricity consumption than assumed, too many certificates will be cancelled and vice versa. The quotas are different for Norway and Sweden, and to make sure that they both finance the same amount of renewable production the quotas will be adjusted continuously. Figure 2-10 shows the amount of certificates in 2014 that was expected to be cancelled, versus the actual amount of cancelled certificates.

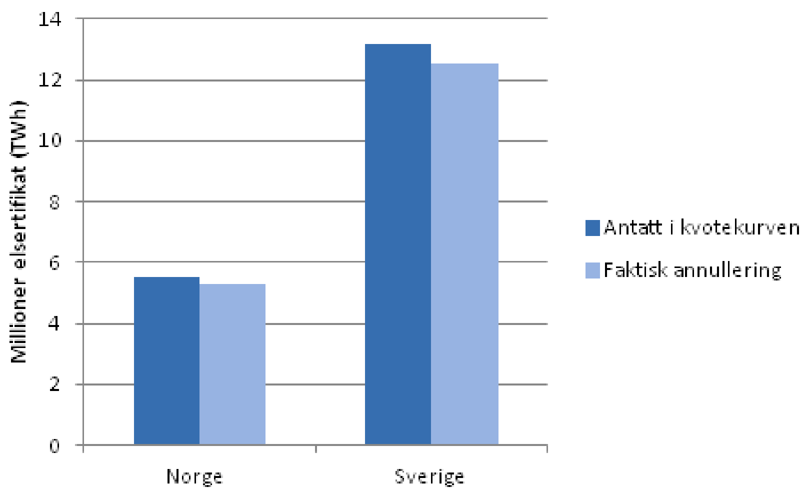



**Figure 2-10: How many certificates that was expected to be cancelled versus the actual amount of cancelled certificates in 2014**

**Source: Energimyndigheten [22]**

# 3 The EMPS Model

## 3.1 Name and Usage

[8], [23], [24]

The EMPS model (EFI's Multi-area Power-market Simulator) is a model for the optimization and simulation of hydro-thermal power systems. The first version was developed in 1975 and included 4 regions in Norway. Because of its many application areas the model is being used by all the big hydro producers in Scandinavia, as well as system operators, regulators, consultants and researchers.

The EMPS model is being used for a number of analyses like:

- price forecasts in the power market
- power balance analysis, for a future state or based on the basis of actual reservoir and market situations, for example analysis of the risk of power shortage
- analyses of transmission capacities between areas and/or countries
- expansion planning of hydro or thermal generation projects
- analyses of changes in legal framework or regulations
- decision support for the use of a producer's own hydropower

The EMPS model uses a standard module to describe each hydro module. The standard module exists of a reservoir with storable and non-storable inflow and a power station, as illustrated below in Figure 3-1. The fundamental time step in the model is a week, with duration curves for different load levels within the week. Although the time step in the model is one week, it is possible to divide the week in several load periods to simulate the variations within the week and day.

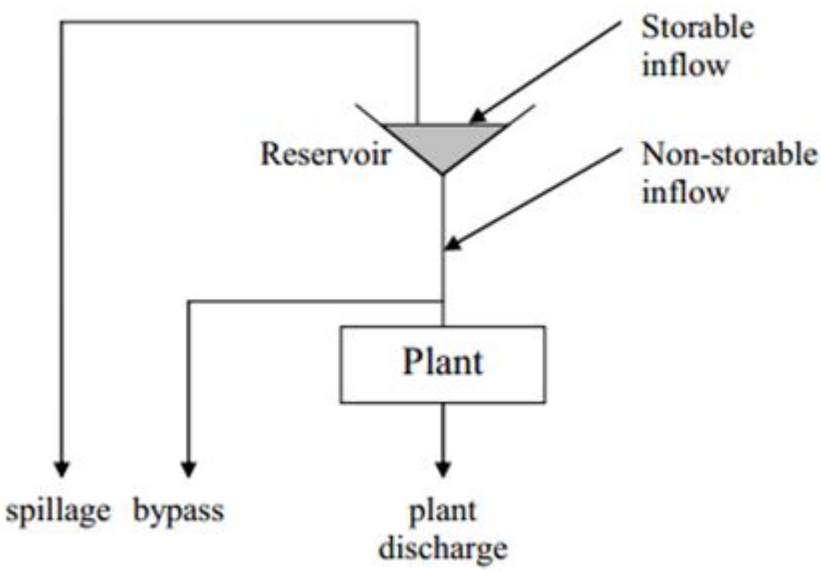



**Figure 3-1: Standard hydropower module**

**Source: Doorman, G. L. [8]**

The planning horizon is up to 10 years and the calculations are based on historical inflow and temperature data, for example for 75 years. For Norway, NVE makes the hydrological series that are inputs to the model. Stochastic series specifies wind-power variability for each area, climatic year and time-step. Different users have different datasets for the model, but the biggest users such as SINTEF Energy Research, have a detailed representation of the whole Nordic system.

## 3.2 Optimization and Calibration

[8]

The EMPS model consists of a strategy part and a simulation part. In the strategy part a residual demand is specified for the hydropower in each area, and this is the demand that needs to be matched by hydropower generation. Then stochastic dynamic programming is used to calculate the expected water values based on the water value method. This method greatly simplifies the representation of the hydropower so that we end up with acceptable computation times. Within each area all plants are aggregated into one aggregate plant and all reservoirs into one aggregate reservoir.

A very important part of the optimization is the valuation of the water in the reservoirs. Figure 3-2 shows an example of computed water values as a function of total reservoir in GWh and the time of the year as so called iso price curves.

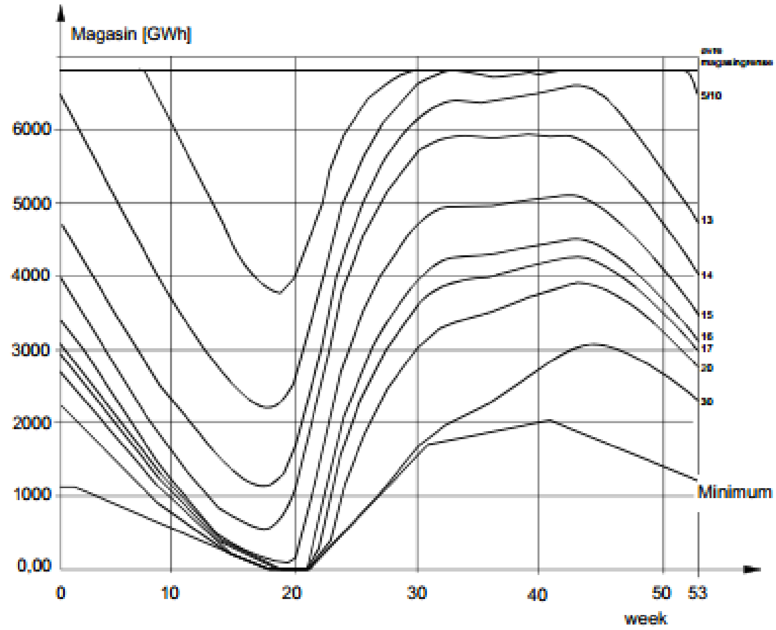


**Figure 3-2: Example of iso price curves for selected water values**

**Source: Doorman, G. L. [8]**

The exchange of power with other areas in the system needs to be taken into consideration. If not, an area with a lot of production (i.e. western Norway) would have more or less a constant water value of zero. A demand area however, would have a water value equal to the rationing cost. Therefore, the demand and supply of other areas needs to be taken into account. In the EMPS model these parameters are estimated as default values, but the user can change them based on the results of the simulations. This is the calibration process that will be discussed further in section 3.4.

The system simulation part is based on the already calculated water values, which are now simulated in detail. The user finds out how the system is operated for the different inflow alternatives. The water values will not give one optimal solution for a specific inflow scenario because it is impossible to know the inflow ahead of time. However, they are used in such a way where the extreme outcomes and their economic impact are taken into account, and thus a decision criterion will result in the optimal utilization of the system in the long run.

The results from the simulation part includes:

- allocation of the production system
- deliveries of various categories of power
- exchange between subareas, both domestic and international
- economic results
- price development in the spot market
- emission of greenhouse gases
- various marginal utility values

## 3.3 Green Certificates and the EMPS Model

[25], [26]

Because of the close correlation between the Nordic power market and the green certificate market, the EMPS model, which is a good model of the Nordic market, has an advantage when it comes to forecasting the certificate market. Also, the actors involved already know about and use the model. The implementation of the green certificate market in the EMPS model is however a working project within SINTEF Energy Research, and only small datasets have been tested.

Important qualities with the EMPS model are:

- It is already integrated with the power market
- It makes decisions based on stochastic dynamic programming for a model that includes both water reservoirs and certificate storages
- It handles uncertainty and variation with inflow, temperatures and wind
- It has got good time resolution and dynamic within the year
- It has got optimal reserve management

To utilize the existing qualities of the EMPS model, the green certificate market has been implemented as one extra area in the model. The new reservoir storage represents the net balance for the certificate market. The model then uses stochastic dynamic programming to calculate the optimal strategy for the certificate inventory. The green certificate market is simulated as a parallel simulation, where the reservoir level and net certificate level is known at the start of the current week.

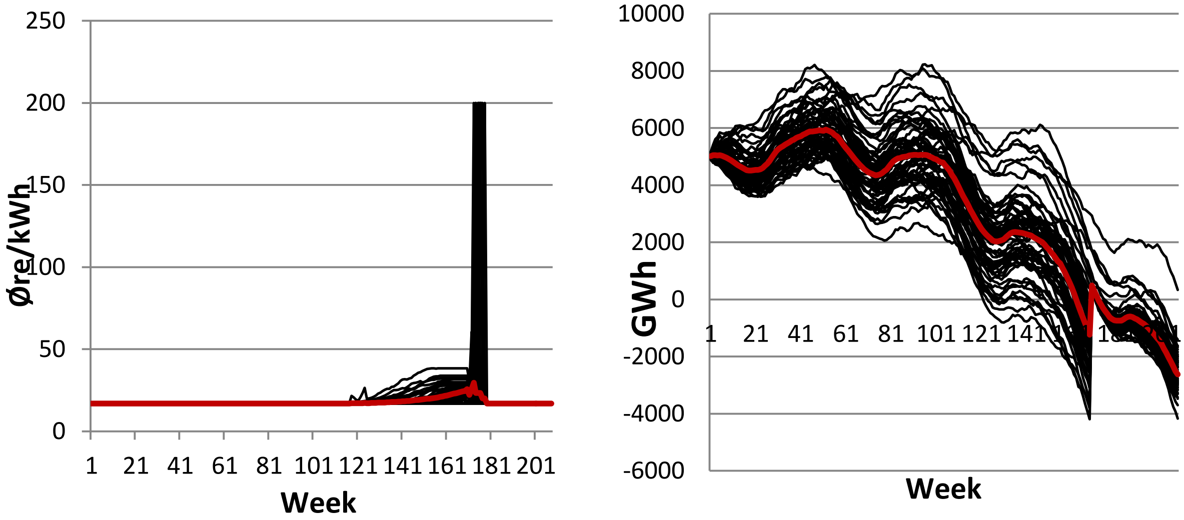
## 3.4 Calibration of the Certificate Area

[8], [26]

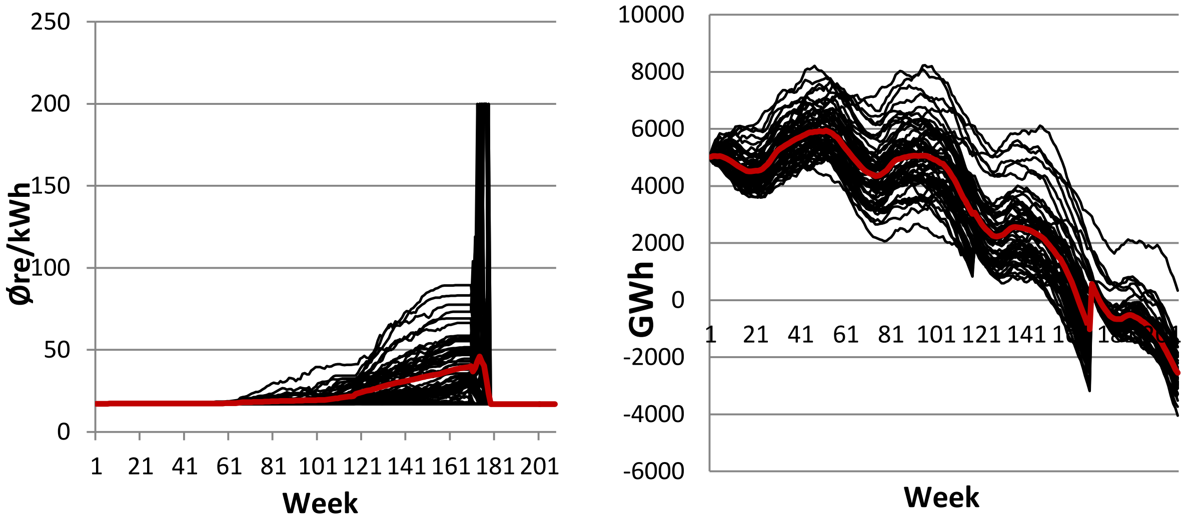
In the EMPS model the water values are calculated independently of the other reservoirs. However, in reality they depend on the situations in the other areas in the same power market. The residual demand curve and inflow to the certificate storage represents all the production and consumption that affects either demand or supply in the market. To supply each area with information about the opportunities for exchange with other areas during the water value calculation, a calibration of the model needs to be performed. The objective is to obtain the optimal strategy for the utilization of the total system. As a result, the calibration will compensate for other simplifications that are made in the model, and imperfect elements, to be able to solve the full problem at acceptable computational times.

There are three different calibration factors in the EMPS model; the feed-back factor, form factor and elasticity factor. The feed-back factor represents the total firm demand as seen by the model in the strategy calculation. The form factor describes how firm demand is distributed over the year in the area as compared to the interconnected system's annual distribution. The elasticity factor represents the prices flexible demand.

The feed-back is the most important factor as it controls how much firm demand is taken into account during the water value calculation. Therefore, only the feed-back factor has been changed in this thesis. The calibration process for one of the cases studied and presented in a later section is explained below in Figure 3-3. The black lines in the figures are scenarios that represent different realizations for climate variables, while the red line is the average value of all scenarios. The model simulates each stochastic scenario before the average price is calculated.


250
200
150
100
50
0
Øre/kWh
1 21 41 61 81 101 121 141 161 181 201
Week
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
GWh
Week

(a) 1,000


250
200
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100
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Øre/kWh
1 21 41 61 81 101 121 141 161 181 201
Week
10000
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2000
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-2000
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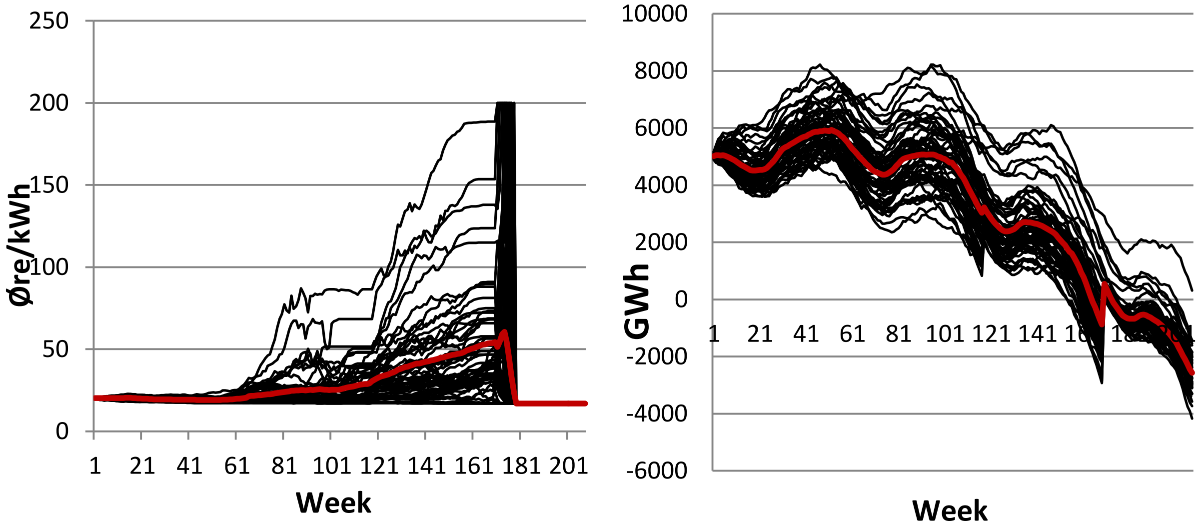
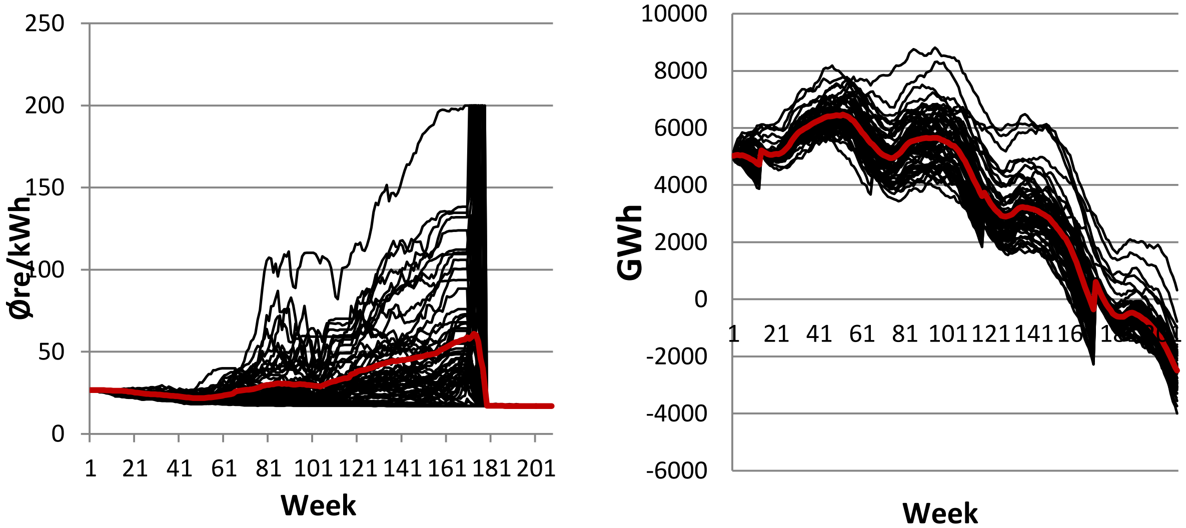
-6000
GWh
Week

(b) 1,040




(c) 1,050




(d) 1,060

**Figure 3-3: Green certificate prices to the left and green certificate storage to the right**

In case (a) the feed-back factor is set to 1,000, which seems to be too low. The prices in all of the scenarios in this case are constant until the settlement in year three (week 118). The reason for this is that the demand seen in the strategy-calculation is too low. Before the final settlement however, there is a large probability for deficit which leads to increasing prices. In a real market this rise would have happened a lot sooner. The feed-back factor is therefore increased, which makes the demand for certificates increase during the strategy-calculation.

In case (b) the feed-back factor is set to 1,040. In this case the prices start to spread out after the second settlement (week 66), which is earlier than in case (a). However, the prices are still constant during the first year of the simulation. The feed-back factor is therefore increased again to see if the results can be improved further.

In case (c) the feed-back factor is set to 1,050. Here the prices start to spread out after the first settlement (week 14), and the average price remains fairly even until the second year. The model then predicts that there might be a deficit in the future, and the average price rises continuously until the final settlement in week 170. After that it drops to the set end-value for the certificates.

In case (d) the feed-back factor is set to 1,060. The average price drops a bit more after the first settlement than in case (c). The certificate storage figure indicates that a penalty is chosen here in many of the scenarios, and as a result the certificate storage increases. This sudden increase shows that the amount of penalties taken is too high, and this is a sign that the demand specified in the strategy calculation is higher than it should be. The feed-back factor should therefore be reduced.

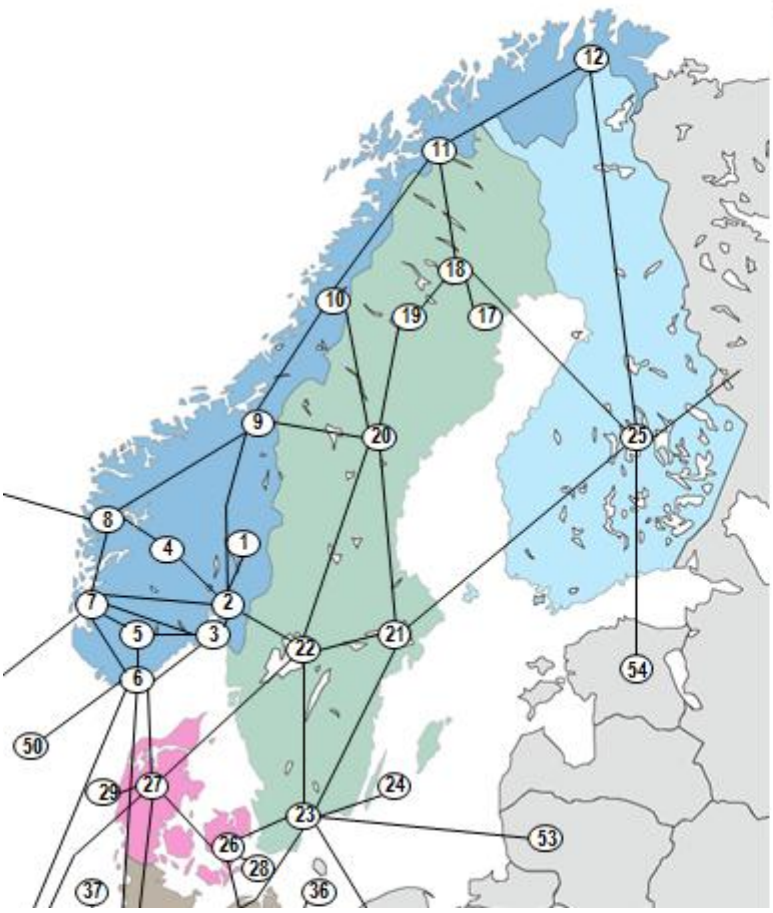
The best calibration factor for this case was 1,050, but this value will vary for different cases. However, it is important to remember that it can only provide the correct result for the specified problem. If there is a major unbalance or deficit, the results will be unbalanced and it cannot be solved by calibration of the model.

# 4 Simulations

## 4.1 Basis

A number of cases for the green certificate market in Norway and Sweden have been tested in this thesis. The set of data used is based on a project by SINTEF Energy Research from 2012; "Evaluating North Sea grid alternatives under EU's RES-E targets for 2020 - EMPS energy system simulations for Northern Europe" [24]. In the project the power market in northern Europe is simulated for year 2020 by using the EMPS model. Renewable power generation is set in accordance with national action plans, while the rest of the system is updated in accordance with forecasts for 2020.

In this thesis the dataset have been reduced by giving all areas outside the Nordic a set price of 3 Eurocent/kWh, and no wind power is defined here. This way only Norway and Sweden are included in the green certificate market. Norway is divided into 16 areas, and Sweden is divided into 8 areas as shown below in Figure 4-1.



| No | Area |
|---|---|
| 1 | NOR-GLOMMA |
| 2 | NOR-OSTLAND |
| 3 | NOR-SOROST |
| 4 | NOR-HALLING |
| 5 | NOR-TELEMARK |
| 6 | NOR-SORLAND |
| 7 | NOR-VESTSYD |
| 8 | NOR-VESTMIDT |
| 9 | NOR-MIDT |
| 10 | NOR-HELGE |
| 11 | NOR-TROMS |
| 12 | NOR-FINNMARK |
| 13 | NOR-S-OWP (not shown) |
| 14 | NOR-VS-OWP (not shown) |
| 15 | NOR-V-OWP (not shown) |
| 16 | NOR-M-OWP (not shown) |
| 17 | SVER-ON1 |
| 18 | SVER-ON2 |
| 19 | SVER-NN1 |
| 20 | SVER-NN2 |
| 21 | SVER-MOST |
| 22 | SVER-MVEST |
| 23 | SVER-SYD |
| 24 | SVER-S-OWP |

**Figure 4-1: Simulated system and area division**
**Source: Wolfgang; Skjelbred; Korpås [24]**

The energy system is simulated by utilizing information of climate variables (inflow, temperatures and wind-speeds) for the period 1948-2004 in a 52-week series simulation. Each year is simulated week by week. In week 14 of every year the settlement for certificates takes place, and the penalty for missing certificates is 150 % of the average price of certificates in the previous year.

### 4.1.1 Basecase

As a basecase it was attempted to recreate the real Norwegian-Swedish certificate market for 2014. The reason for this is that the actual values for issued and annulled certificates, the storage value and consumption are obtainable and easy to implement into this model. By only simulating for 2014 it is possible to see if the model works as intended by comparing the results from the simulations to the real outcomes. The values aimed for in this case are shown below in Table 4-1. Solar power and peat are not included in the simulations in this thesis, which is why the total production is 18,6 TWh and not 18,7 TWh as mentioned in section 2.9.

**Table 4-1: Certificates issued and certificates annulled (consumption) in 2014**

| | Norway | Sweden | Total |
|---|---|---|---|
| Biofuels (TWh) | 0 | 4,706 | 4,706 |
| Wind power (TWh) | 0,217 | 11,023 | 11,240 |
| Hydropower (TWh) | 1,306 | 1,376 | 2,682 |
| Total production (TWh) | 1,523 | 17,105 | 18,628 |
| Consumption (TWh) | 5,296 | 12,546 | 17,843 |

**Source: Statnett [27]**

Other important input values are:

- Initial certificate storage: 12,1 TWh (13 TWh - 0,9 TWh) [20]
- Average certificate price in the previous year (2013): 17,8 øre/kWh [2]
- End value of certificates at the end of week 208: 16,89 øre/kWh [28]
- Certificate quotas for Norway and Sweden, as listed in Appendix A (in basecase only the values from 2014 are used)

The capacity for each of the power sources in this dataset did not add up to be the same as the values in Table 4-1. Therefore the percentage of green certificates, which the production asset receives, has been adjusted accordingly. Although there are 24 areas in the dataset, the percentages have been divided up by country. This turned out to be a lot easier and less time consuming than adjusting the production and consumption for each area individually, seeing as these areas do not match the areas used in reality. Because it is one joint market, this distribution will not have any effect on the simulation results. The division of percentages used in Basecase is shown below in Table 4-2. The complete document with input values for the green certificate market as used in the EMPS model, can be seen in Appendix B.

**Table 4-2: Percentages of green certificates the production asset receives**

| | Norway | Sweden |
|---|---|---|
| Biofuels (%) | 0 | 23 |
| Wind power (%) | 5 | 89 |
| Hydropower (%) | 85 | 0 |
| Consumption (%) | 140 | 61 |

Here the hydropower production in Sweden is set to 0 %. The reason for this is that the dataset created by SINTEF Energy Research did not include any new hydropower for the year 2020 in Sweden. Therefore, a higher number of certificates is allocated to Norway. Again, this will not have any effect on the results from the simulations. The firm-power consumption for Norway in the dataset was not high enough to match the consumption from Table 4-1. Consequently, the percentage that requires green certificates has been upped to more than 100 %, which is the easiest way to increase the consumption that has a quota obligation.

## 4.2 Different Test Cases

In this section the different cases tested in this thesis are presented. The demand for the simulated cases was calculated based on the estimated electricity consumption with quota obligations and the set quotas for each year (see Appendix A). Electricity consumption times the quota percentage equals the demand for each year, and to achieve these demand values the percentages again had to be adjusted in the EMPS model. These percentages were found by trial and error. The results for Norway and Sweden are shown in Table 4-3 and Table 4-4. The demand is calculated for both the original quotas and the increased new quotas as suggested in the change agreement.

**Table 4-3: Calculated demand that requires certificates for Norway**

| Year | Electricity consumption (TWh) | Quota | Demand (TWh) | New quotas | New demand (TWh) | Demand in EMPS % |
|---|---|---|---|---|---|---|
| 2014 | 76,7 | 0,069 | 5,2923 | | | 140 |
| 2015 | 80,1 | 0,088 | 7,0488 | | | 147 |
| 2016 | 79,9 | 0,108 | 8,6292 | 0,119 | 9,5081 | 148 |
| 2017 | 80,1 | 0,127 | 10,1727 | 0,137 | 10,9737 | 148 |

**Sources: Regjeringen [17], Energimyndigheten [20]**

**Table 4-4: Calculated demand that requires certificates for Sweden**

| Year | Electricity consumption (TWh) | Quota | Demand (TWh) | New quotas | New demand (TWh) | Demand in EMPS % |
|---|---|---|---|---|---|---|
| 2014 | 88,4 | 0,142 | 12,553 | | | 61 |
| 2015 | 93,2 | 0,143 | 13,328 | | | 61 |
| 2016 | 93,1 | 0,144 | 13,406 | 0,23 | 21,413 | 64 |
| 2017 | 93 | 0,152 | 14,136 | 0,246 | 22,878 | 64 |

**Sources: NVE; Energimyndigheten [2], [29], [30]**

### 4.2.1 Case 1: Increased Quotas, no Expansion

In this case the quotas have been set as the original quotas listed in Appendix A. The quotas and the demand for green certificates will then increase every year from 2014-2017. However, there is no expansion in production which will stay exactly the same as in 2014. It is therefore expected that the green certificate storage will decrease from 2015-2017 in this case, and it may possibly create a deficit of certificates.

### 4.2.2 Case 2: Lower Initial Certificate Storage

This case is exactly the same as case 1, however the initial certificate storage has been lowered to 5 TWh instead of 12,1 TWh. This will lead to a higher probability of deficit and should therefore have a big influence on the price levels. The calibration process that was demonstrated in section 3.4, was based on this case.

### 4.2.3 Case 3: Slow Expansion Rate for New Production

This case, and the following two cases, are inspired by an example made by NVE [7] where the expansion rate of new production in the certificate market differs. Here they have analyzed the storage development in three different scenarios for the years 2015-2020, while using the actual data from 2012-2014. The demand is based on the new proposed quotas for Norway and Sweden, and will be used in this case and all the remaining test cases.

In the first example it is assumed that the expansion of renewable production will be slow at first, at approximately 2,2 TWh/year for 2015-2017, and then increase to 3,8 TWh/year for 2018-2020. Their graphic results for the storage development for all three scenarios are shown below in Figure 4-2. The blue curve is the one that is relevant to this case.

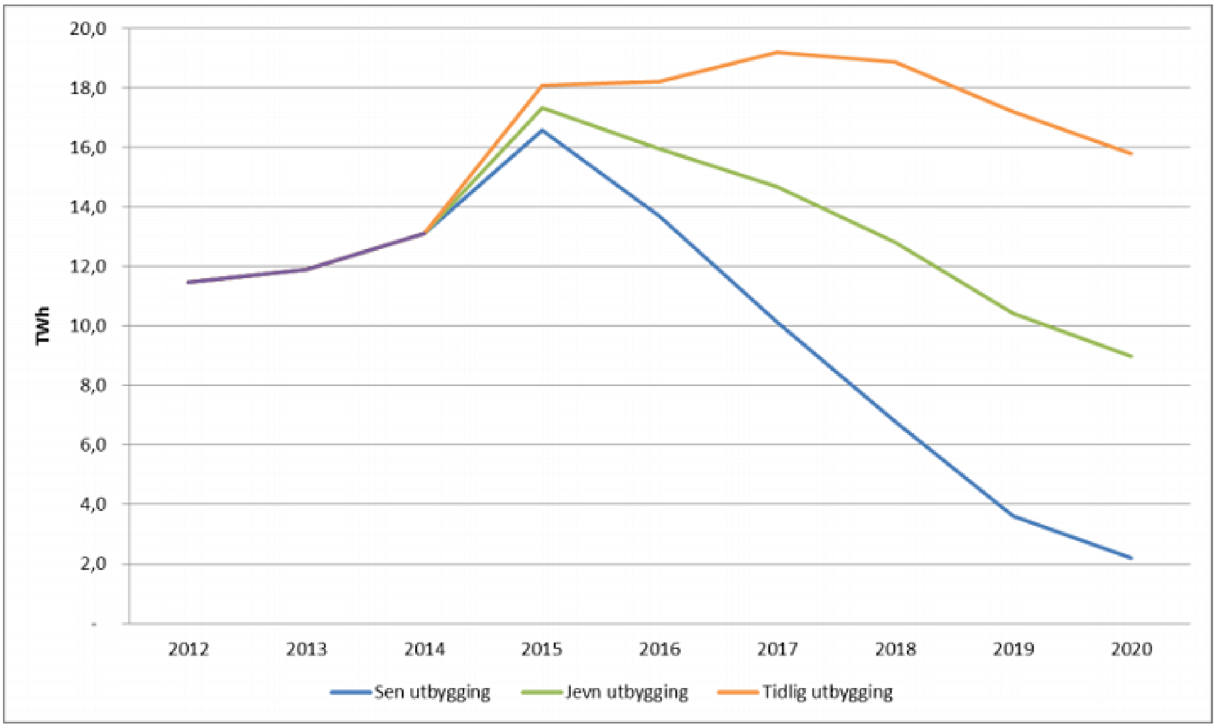



**Figure 4-2: Example by NVE for storage development in three different scenarios**
**Source: Energimyndigheten; NVE [7]**

In the dataset used in this thesis, the model simulates for a total of 4 years, and as a result this case only imitates NVEs' example for the years 2014-2017. The division of new production made here is 25 % to biofuels, 60 % to wind power and 15 % to hydropower. This is an approximation of the distribution of production from Table 4-1, and the exact values from the new division are shown below in Table 4-5.

**Table 4-5: Division of new production that generates certificates for slow expansion**

| | Norway | Sweden | Total |
|---|---|---|---|
| Biofuels (TWh/year) | 0 | 0,55 | 0,55 |
| Wind power (TWh/year) | 0,0264 | 1,2936 | 1,32 |
| Hydropower (TWh/year) | 0,33 | 0 | 0,33 |
| Total (TWh/year) | 0,356 | 1,844 | 2,2 |

### 4.2.4 Case 4: Even Expansion Rate for New Production

This case imitates the second scenario in NVEs' example, where it is assumed that there will be an even expansion of 3 TWh/year for all years up until 2020. The division of new production made here is the same as in case 3, and the exact values calculated are shown below in Table 4-6. NVEs' result for this example is shown by the green curve in Figure 4-2.

**Table 4-6: Division of new production that generates certificates for even expansion**

| | Norway | Sweden | Total |
|---|---|---|---|
| Biofuels (TWh/year) | 0 | 0,75 | 0,75 |
| Wind power (TWh/year) | 0,036 | 1,764 | 1,8 |
| Hydropower (TWh/year) | 0,45 | 0 | 0,45 |
| Total (TWh/year) | 0,486 | 2,514 | 3 |

### 4.2.5 Case 5: Fast Expansion Rate for New Production

This case imitates the third example by NVE, where it is assumed that there will be a fast expansion at first at approximately 3,8 TWh/year for 2015-2017, and then it decreases to 2,2 TWh/year for 2018-2020. The division of new production is the same as in the previous two cases, and the exact values calculated are shown below in Table 4-7. NVEs' result for this example is illustrated by the orange curve in Figure 4-2.

**Table 4-7: Division of new production that generates certificates for fast expansion**

| | Norway | Sweden | Total |
|---|---|---|---|
| Biofuels (TWh/year) | 0 | 0,95 | 0,95 |
| Wind power (TWh/year) | 0,0456 | 2,2344 | 2,28 |
| Hydropower (TWh/year) | 0,57 | 0 | 0,57 |
| Total (TWh/year) | 0,6156 | 3,1844 | 3,8 |

### 4.2.6 Case 6: Hydropower Expansion

Here the rate of expansion for new production is set to 3 TWh/year, like in case 4 with the even expansion rate. However, in this case only the production of hydropower is increased, while wind power and biofuels production stays the same as in 2014. The intention is to see how the price levels are affected and how the model reacts to uneven distribution between the production sources. The amount of certificates that should be generated from hydropower for each year is stated below in Table 4-8.

**Table 4-8: Green certificates generated from hydropower**

| Year | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|
| Certificates generated from hydropower (TWh) | 2,68 | 5,68 | 8,68 | 11,68 |

### 4.2.7 Case 7: Wind Power Expansion

Like in the previous case the expansion rate of new production here is 3 TWh/year. In this case the wind power is the only production source that is increased, while biofuels and hydropower stays the same as in 2014. Of the 3 TWh/year wind power expansion, 2 % is allocated to Norway and 98 % to Sweden, which was the percentage of division for certificates generated by wind power in 2014. The amount of certificates that should be generated each year is stated below in Table 4-9.

**Table 4-9: Green certificates generated from wind power**

| Year | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|
| Certificates generated from wind power in Norway (TWh) | 0,218 | 0,278 | 0,338 | 0,398 |
| Certificates generated from wind power in Sweden (TWh) | 11,02 | 13,96 | 16,9 | 19,84 |

### 4.2.8 Case 8: Biofuels Expansion

The rate of expansion for new production in this case is the same as in the previous two cases, at 3 TWh/year. However, only the production of biofuels is increased while the production of hydropower and wind power stays the same as in 2014. The amount of certificates that should be generated from biofuels each year in the simulations is stated below in Table 4-10.

**Table 4-10: Green certificates generated from biofuels**

| Year | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|
| Certificates generated from biofuels (TWh) | 4,7 | 7,7 | 10,7 | 13,7 |

### 4.2.9 Case 9: Equal Production and Consumption

In this case it is attempted to match the production of green certificates to the consumption every year so that they are equal. The consumption and production aimed for are the sums of some of the values calculated in Table 4-3 and Table 4-4, and they are shown below in Table 4-11. However, the values for 2014 were kept the same as in basecase, 17,8 TWh for consumption and 18,6 TWh for production. The division of the increased production is like in the previous cases, wind power 60 %, hydropower 15 % and biofuels 25 %.

**Table 4-11: Equal production and consumption values aimed for**

| Year | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|
| Production and consumption (TWh) | 18,63/17,84 | 20,38 | 30,92 | 33,85 |

# 5 Simulation Results

**Table 5-1: Comparison of simulation results from all cases**

| | Base-case | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 | Case 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Optimal feed-back factor | 1,000 | 1,000 | 1,050 | 1,055 | 1,050 | 1,045 | 0,860 | 1,055 | 1,150 | 1,100 |
| Average yearly certificates generated from hydropower production (TWh) | 2,74 | 2,74 | 2,75 | 3,23 | 3,42 | 3,59 | 7,16 | 2,75 | 2,75 | 3,63 |
| Average yearly certificates generated from biofuels production (TWh) | 4,67 | 4,67 | 4,67 | 5,58 | 5,80 | 6,10 | 4,73 | 4,68 | 9,17 | 6,46 |
| Average yearly certificates generated from wind power production (TWh) | 11,21 | 11,21 | 11,21 | 13,19 | 13,94 | 14,68 | 11,21 | 15,72 | 11,21 | 15,75 |
| Total average yearly certificates produced (TWh) | 18,61 | 18,61 | 18,61 | 22,00 | 23,16 | 24,37 | 23,10 | 23,14 | 23,14 | 25,80 |
| Average yearly consumption that requires certificates (TWh) | 17,85 | 20,34 | 20,34 | 25,63 | 25,63 | 25,63 | 25,63 | 25,63 | 25,63 | 25,63 |
| Balance (TWh) | 0,76 | -1,73 | -1,73 | -3,63 | -2,47 | -1,26 | -2,53 | -2,49 | -2,49 | 0,20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Average green certificate price (øre/kWh) | 16,89 | 16,89 | 24,97 | 37,96 | 27,16 | 21,31 | 20,62 | 28,12 | 23,23 | 19,87 |
| Highest average certificate price before final settlement (øre/kWh) | 16,89 | 16,89 | 39,41 | 89,44 | 46,78 | 25,35 | 29,74 | 50,67 | 35,63 | 24,36 |
| Lowest average certificate price before final settlement (øre/kWh) | 16,89 | 16,89 | 20,29 | 19,59 | 18,04 | 17,37 | 16,89 | 18,72 | 17,21 | 17,33 |

In most of the simulated cases the initial storage of 12,1 TWh turned out to be too high to create a probability for deficit and to produce different price scenarios. The initial storage was therefore lowered in many of the cases. In the cases where this was done, the values in Table 5-1 above are from the simulations performed with the lower initial certificate storage.

## 5.1 Basecase

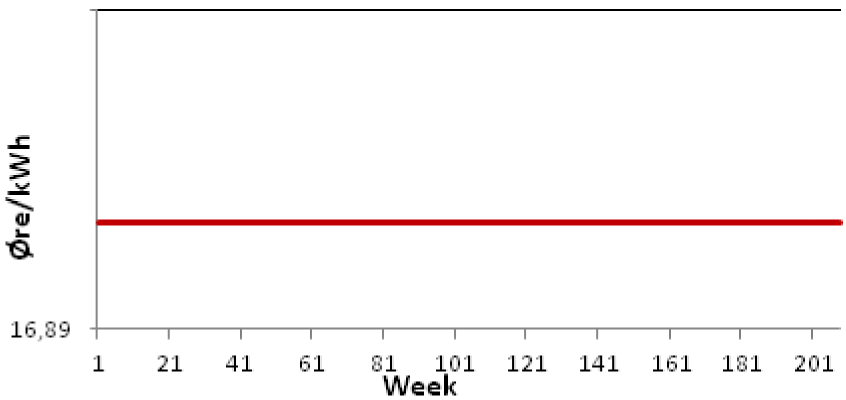



Figure 5-1: Green certificate prices for basecase

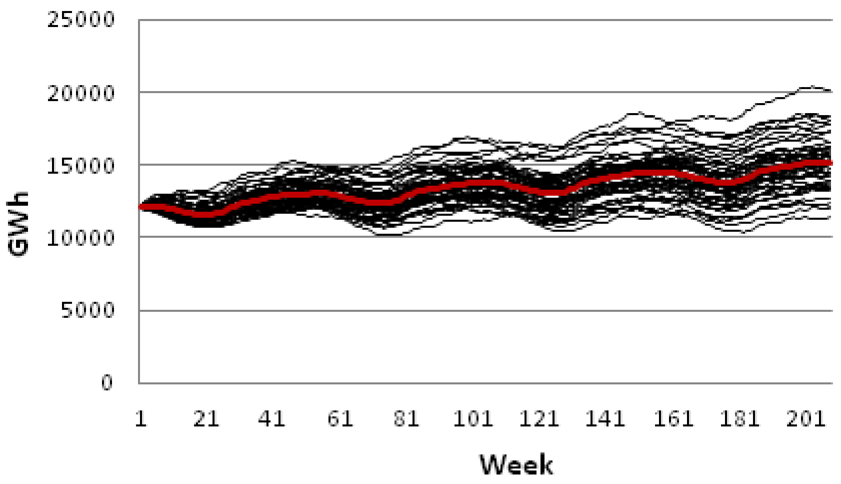



Figure 5-2: Green certificate storage for basecase

The initial storage of certificates in this case is very high at 12,1 TWh. Because the production is slightly higher than the consumption, there is a constant positive balance, and the storage will always increase in this case as seen in Figure 5-2. Accordingly, there will never be any probability of a deficit, and this is why the certificate prices, as seen in Figure 5-1, are constantly equal to the set end-value for certificates of 16,89 øre/kWh.

By looking only at the first year of the storage development, it is evident that it matches the progress in the real Norwegian-Swedish certificate market well. In week 52 the value is approximately 13 TWh, which was the real value at the end of 2014 as mentioned in section 2.9. By comparing the values in Table 4-1 and Table 5-1, it is evident that the total amount of certificates generated by the power sources in the simulation at 18,61 TWh, as well as the amount of consumption at 17,85 TWh, matches the real values at 18,63 TWh and 17,84 TWh, almost perfectly. This shows that the EMPS model works as intended in this case. The calibration factor did not actually matter in this case because of the high initial certificate storage, and the prices were the same no matter if it was turned up or down.

## 5.2 Case 1: Increased Quotas, no Expansion

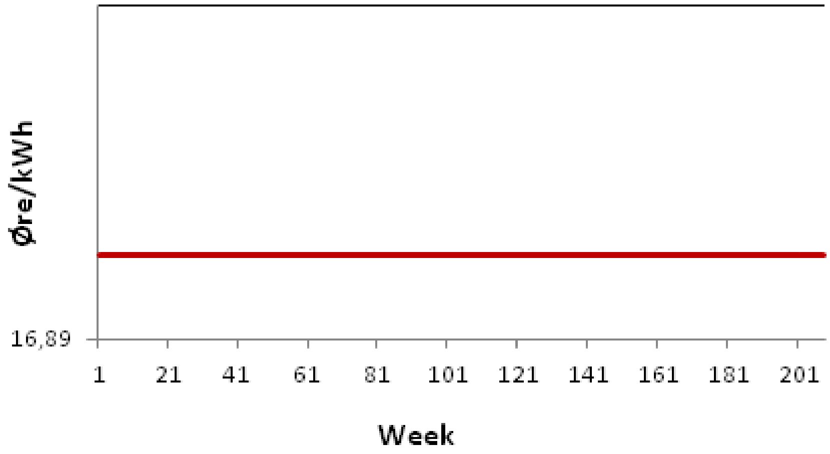



Figure 5-3: Green certificate prices for increased quotas, no expansion

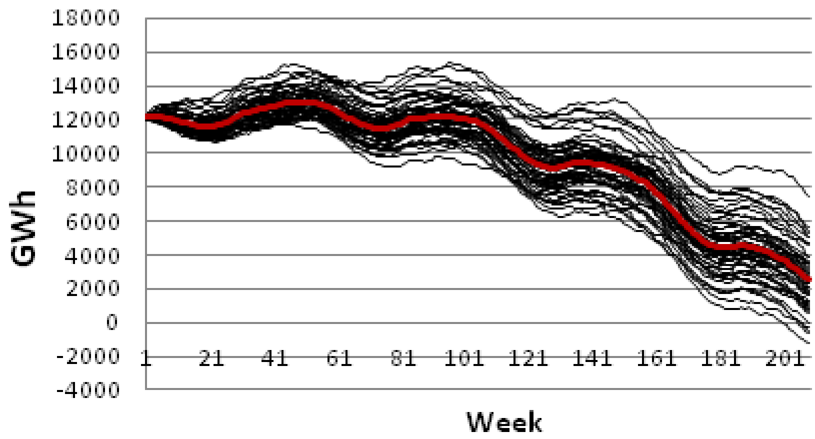



Figure 5-4: Green certificate storage for increased quotas, no expansion

Again, the prices does not vary in this case from the set end-value of 16,89 øre/kWh because of the high initial storage and therefore slim chances of a deficit. The storage however starts out as in basecase during first year, but after that it starts to decrease more and more, though a deficit never occurs until the very end in a few of the scenarios. This happens so late in the simulation that it has no effect on the certificate prices, which are already set for the end-value.

The results in this case are as expected since the only change from basecase is a higher consumption, which results in a negative balance. A higher consumption compared to the production will start to eat out of the certificate storage, which is what happens in Figure 5-4. The impact from calibration turned out to have no effect here either, just as in basecase.

## 5.3 Case 2: Lower Initial Certificate Storage

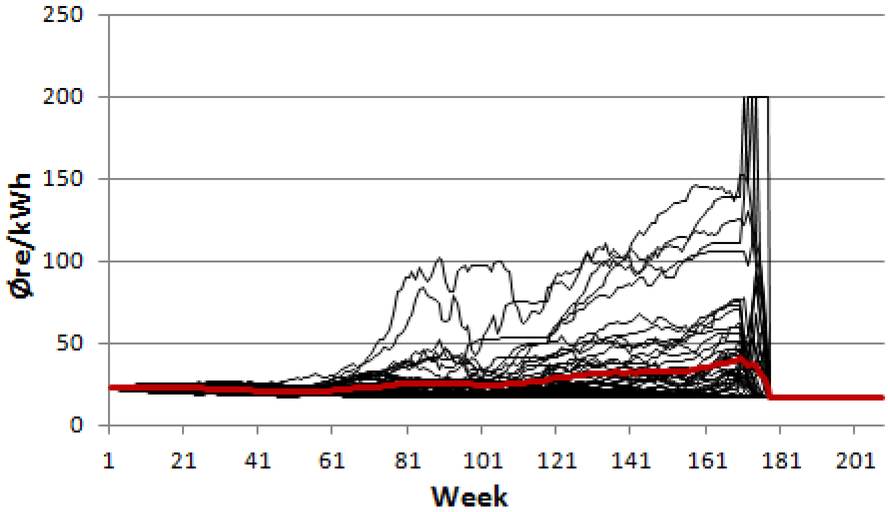



Figure 5-5: Green certificate prices for lower initial certificate storage

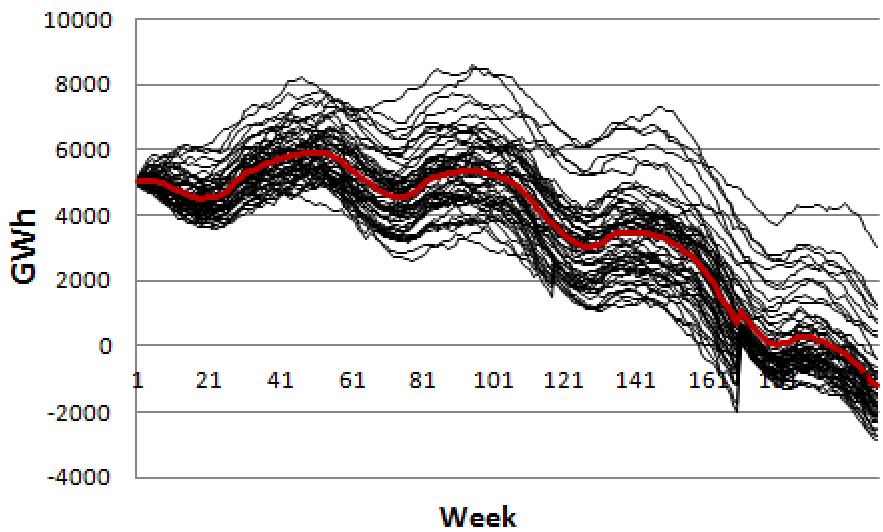



Figure 5-6: Green certificate storage for lower initial certificate storage

In this case the initial certificate storage was greatly reduced from the previous case, while the production and consumption remained the same. This obviously had a big impact on both the certificate prices and the certificate storage, as seen from Figure 5-5 and Figure 5-6. Here there is a high probability of a deficit in 2017, when the certificate storage drops below zero for the first time. The average green certificate price has increased by 8,08 øre/kWh from the previous case, and the highest and lowest certificate price before the final settlement increased by 22,52 øre/kWh and 3,4 øre/kWh.

At first the model foresees a deficit of certificates in the future, which is why the price scenarios differ in comparison to the previous case, when there were hardly no chances of a deficit. This probability increases after the first year, and the average price rises gradually up until the final settlement in week 170. By looking at the certificate storage in that week it is clear that a penalty is taken in a lot of the scenarios, either to avoid a deficit or because there are not enough certificates available. In the most extreme deficit scenarios, the prices shoot up to the set maximum value of 200 øre/kWh. After the final settlement the prices drop to the set end-value for certificates.

## 5.4 Case 3: Slow Expansion Rate for New Production

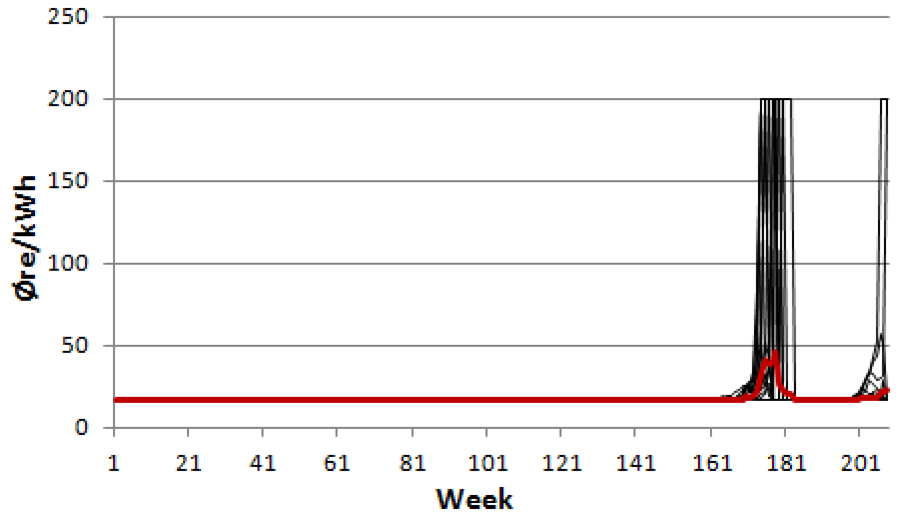



Figure 5-7: Green certificate prices for slow expansion

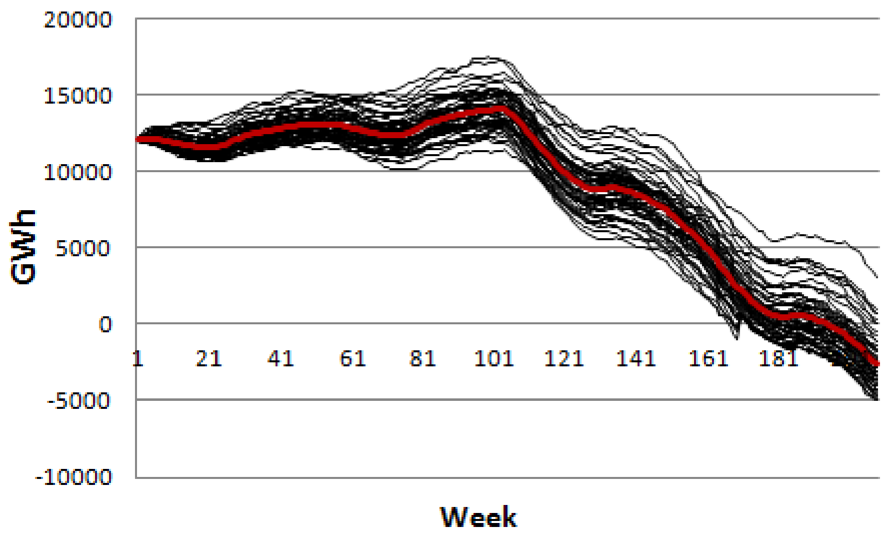



Figure 5-8: Green certificate storage for slow expansion

In this case it is apparent, from the certificate storage in Figure 5-8, that the consumption is much higher than the production of green certificates after 2015. However, it appears that the model is not able to predict a future deficit since the prices are constant in all scenarios up until the final year. In the final settlement, a penalty is taken in some of the scenarios which makes the average certificate price rise until it drops back to the end-value. It appears however that the deficit at the end of 2017 is so large that the average certificate price has a slight increase.

By looking at the figure of the certificate storage in this case, and the curve from NVEs' example as presented in section 4.2.3 and Figure 4-2, it is clear that the figures match up well. However, the curve in this case decreases a lot faster. By retrieving the output values from the simulation, it is found that the production increases with approximately 2,2 TWh each year as intended. The difference between this case and NVEs' example must then be caused by the amount of consumption that requires green certificates, which is higher here.

To obtain some more interesting scenarios regarding the price levels, a higher probability of deficit is required, so the initial storage needs to be lowered. It is therefore decreased from 12100 GWh to 5000 GWh, and the results are shown below in Figure 5-9 and Figure 5-10.

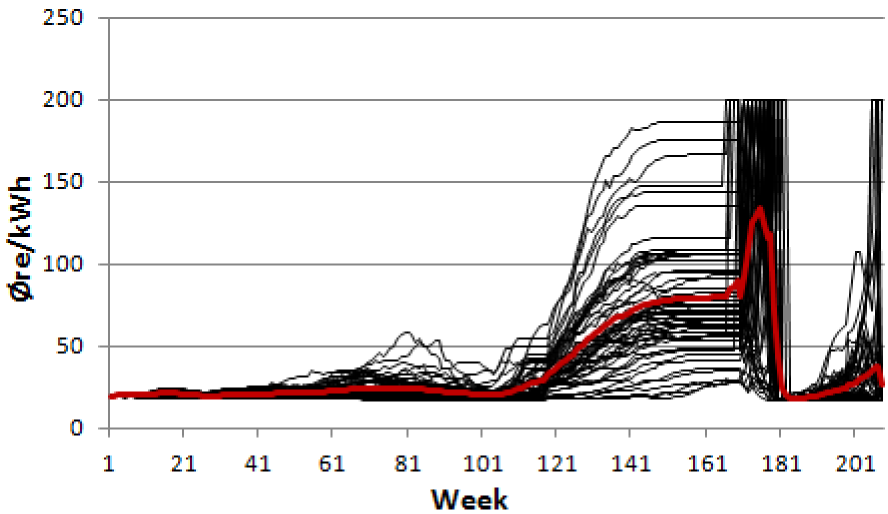



**Figure 5-9: Green certificate prices for slow expansion and lower initial storage**

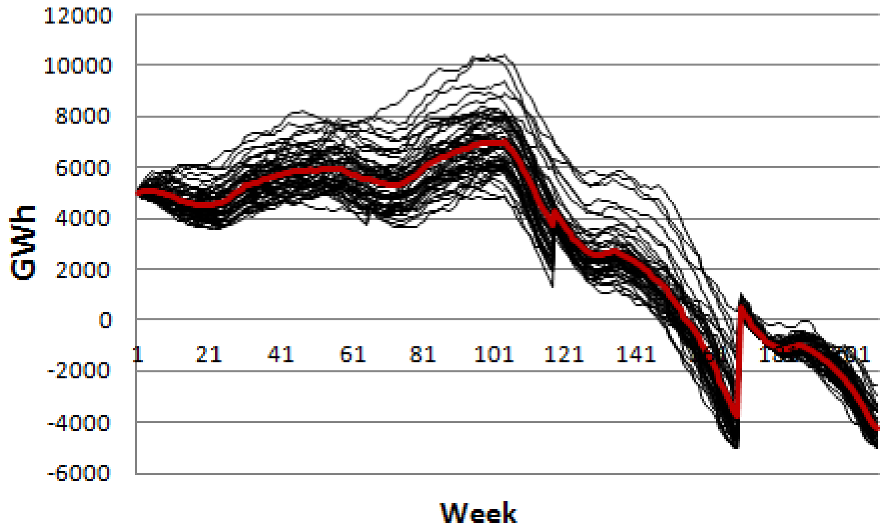


Figure 5-10: Green certificate storage for slow expansion and lower initial storage

With a lower initial storage the probability for a deficit becomes much higher, and the certificate prices then vary in the different scenarios from the start. During the first two years the probability of a deficit is small, and so the prices remain fairly even. From week 104 the demand increases drastically, and a penalty is taken in some of the scenarios during the settlement of this year. As a result, the average price increases considerably to a level of 89,44 øre/kWh before the final settlement. Here there is a huge deficit and, as shown by Figure 5-10, a penalty is taken in many of the scenarios. This leads to an even higher price level, before it drops down to the set end-value. The consumption is still very high, so the prices start to rise again towards the end of 2017.

## 5.5 Case 4: Even expansion rate for new production

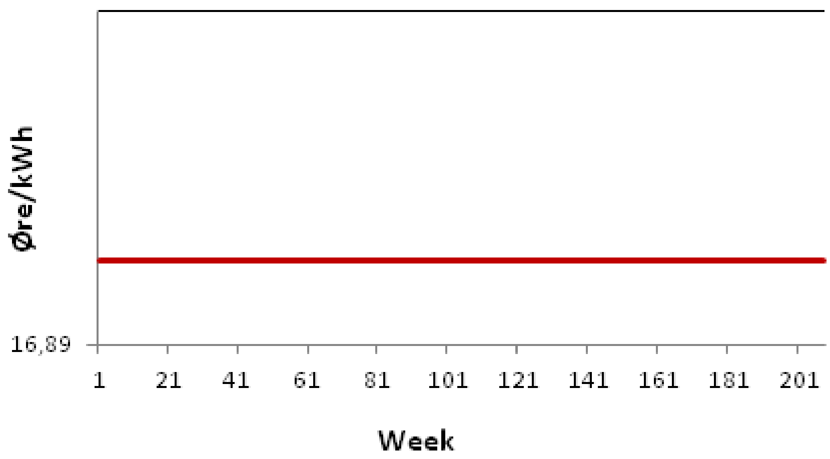


Figure 5-11: Green certificate prices for even expansion

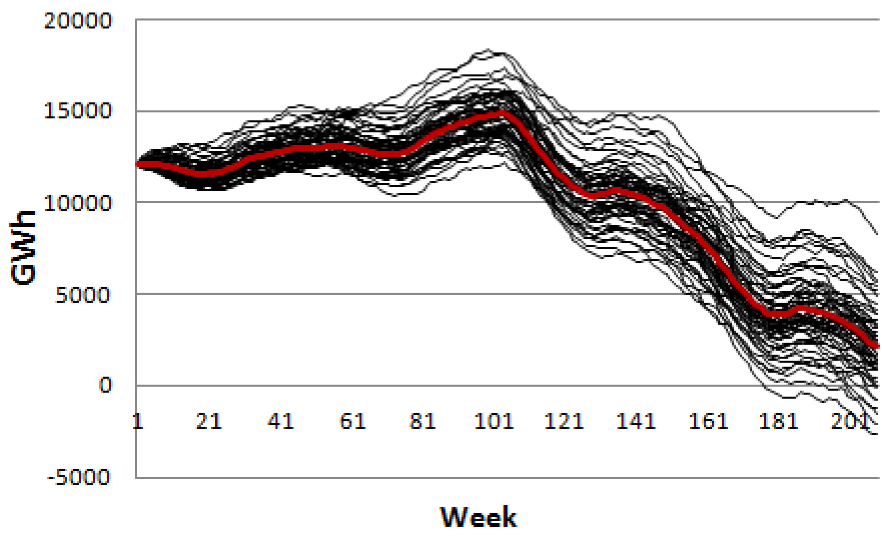


Figure 5-12: Green certificate storage for even expansion

In this case the consumption of green certificates is still a lot higher than the production after the first two years. However, the certificate storage does not decrease quite as rapidly as in the previous case. Nevertheless, the model is still not able to predict a deficit in the future, and the prices remain constant at 16,89 øre/kWh.

By comparing the certificate storage in Figure 5-12 with the example from NVE in Figure 4-2, they somewhat match up. However, the curve from this case decreases a lot more than the one in NVE's example. The output values retrieved from the simulation makes it clear that the total production increases by approximately 3 TWh/year as intended, so again the difference in the two cases must be the amount of consumption.

To create some more interesting scenarios for the price values, the initial storage is again lowered to 5000 GWh, and the results are shown below in Figure 5-13 and Figure 5-14.

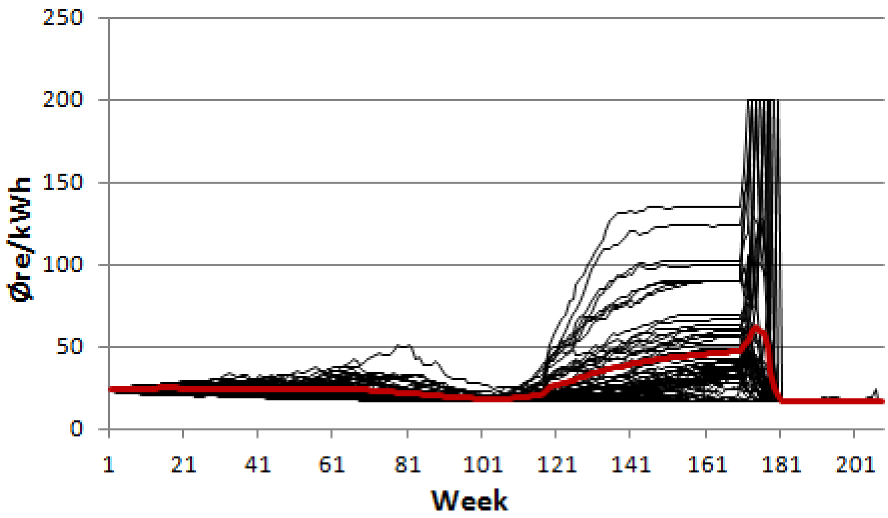



Figure 5-13: Green certificate prices for even expansion and lower initial storage

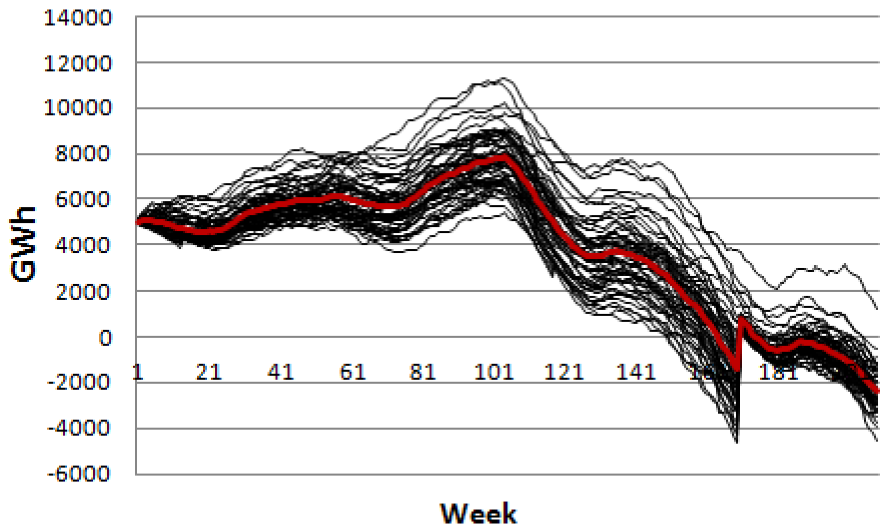



Figure 5-14: Green certificate storage for even expansion and lower initial storage

The lower initial storage leads to a higher probability of deficit, and the prices vary in the different scenarios. Like in the previous case the prices remain fairly constant during the first two years, where they converge to a slightly lower level of 18,04 øre/kWh before the next settlement in week 118. After that the prices rise in some of the scenarios and the average price climbs to 46,79 øre/kWh before the final settlement. Here there is a deficit in most of the scenarios and a penalty is generally taken. As a result, the prices increase further and then drops to the end-value after the settlement.

## 5.6 Case 5: Fast Expansion Rate for New Production

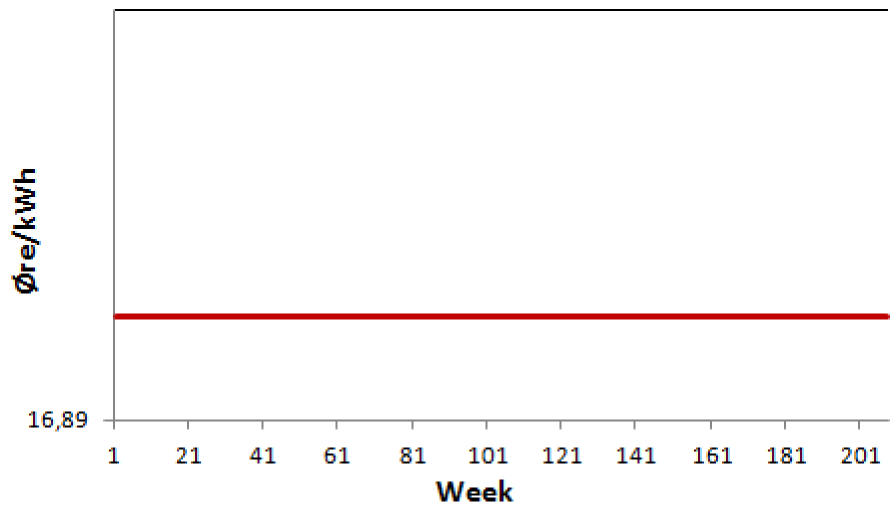



Figure 5-15: Green certificate prices for fast expansion

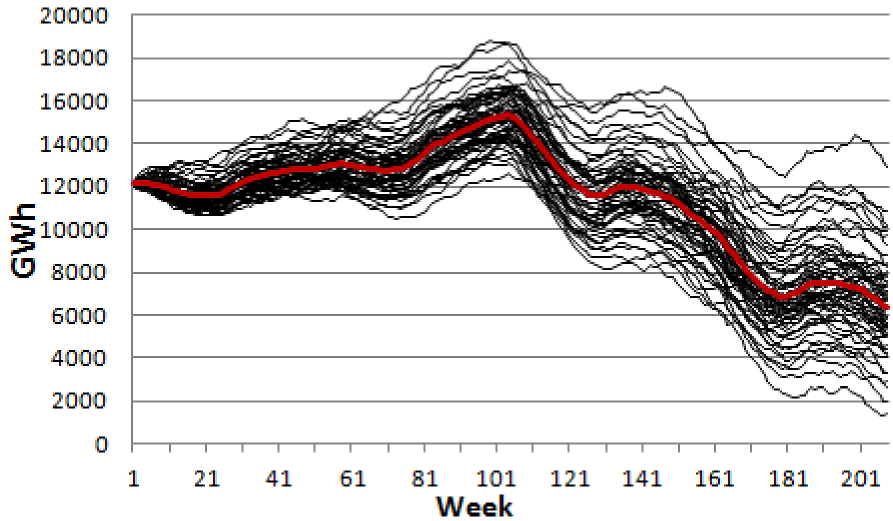



Figure 5-16: Green certificate storage for fast expansion

It is evident from the development of the certificate storage in Figure 5-16 that there will never be a chance of a deficit. The prices are therefore always equal to the set end-value of 16,89 øre/kWh.

By comparing the certificate storage in this case to the orange curve in NVEs' example in Figure 4-2, it is evident that they only match up until the end of 2014. By retrieving the output values for production from the simulation, they show that the total amount of certificates produced increases by approximately 3,8 TWh/year, which is what it was aimed for. The main difference must be the amount of consumption like in the previous two cases.

Because there were no price variations in this case, the initial storage is lowered to 5000 GWh in an attempt to create some more interesting scenarios. The results are shown below in Figure 5-17 and Figure 5-18.

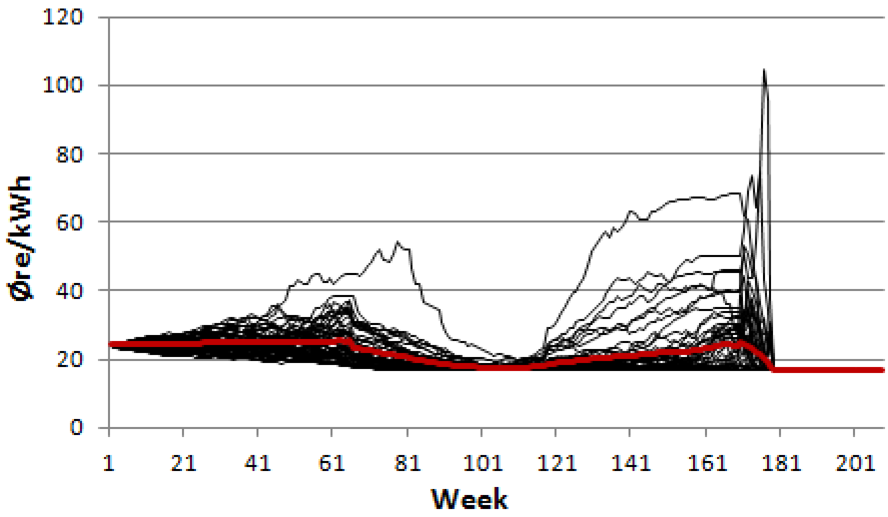



Figure 5-17: Green certificate prices for fast expansion and lower initial storage

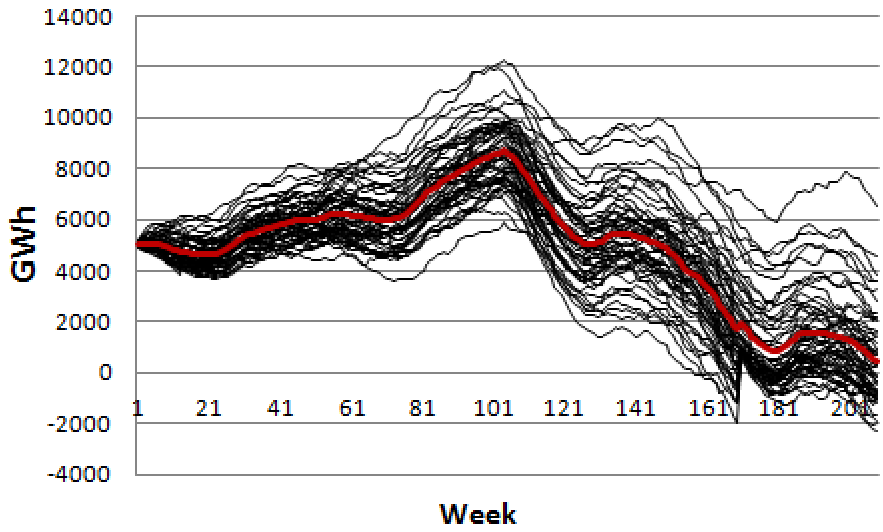



Figure 5-18: Green certificate storage for fast expansion and lower initial storage

By lowering the initial certificate storage, a probability for deficit in the future is seen by the EMPS model, which leads to price variations in the different scenarios. Here the prices are very stable up until the second settlement in week 66, where they drop slightly and converge towards a value of 17,37 øre/kWh during the second year. The prices then rise a little after the third settlement and towards the fourth. Here a penalty is taken in a few of the scenarios where a deficit occurs, but it is not enough to make a major change to the average price level. Afterwards the price drops to the set end-value for certificates.

## 5.7 Case 6: Hydropower Expansion

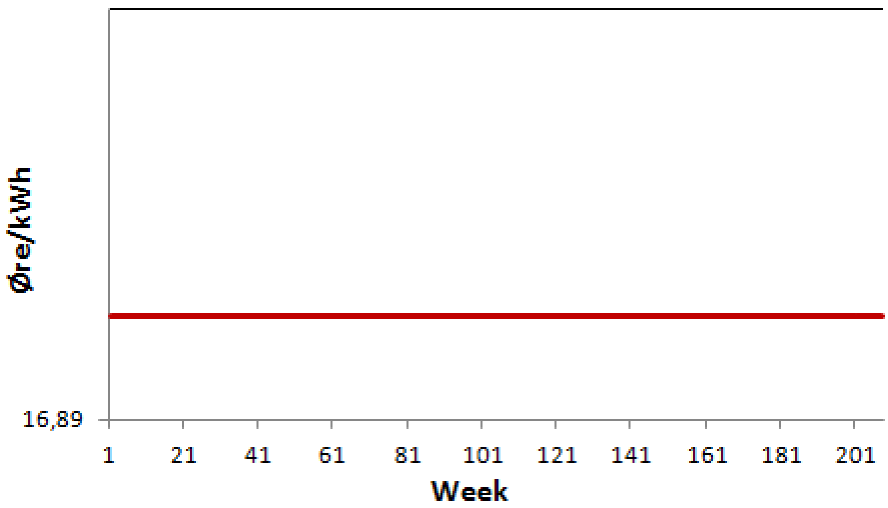



Figure 5-19: Green certificate prices for hydropower expansion

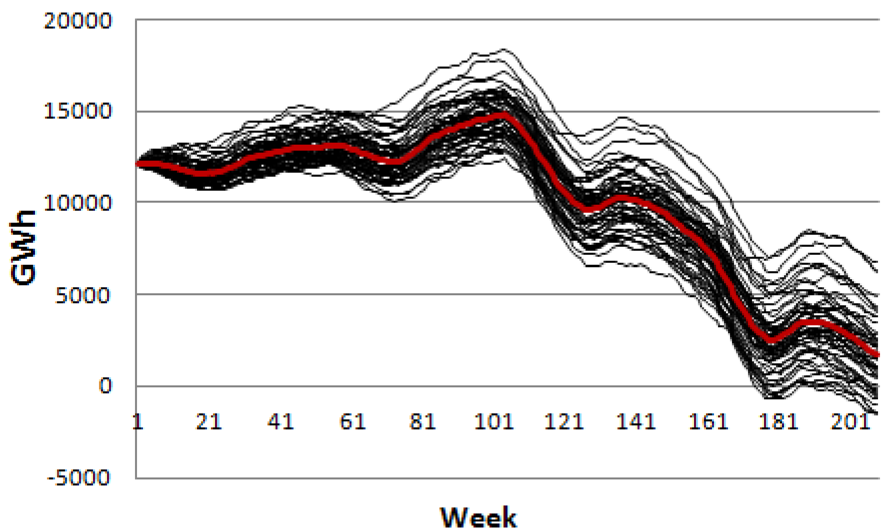



Figure 5-20: Green certificate storage for hydropower expansion

In this case there is no probability for a deficit in any of the scenarios until the final year and after the final settlement. Hence, there is no variation in the certificate prices, which remain constant at 16,89 øre/kWh as seen in Figure 5-19.

The rate of expansion is the same in this case as in case 4, and the total average yearly amount of certificates produced, as well as the balance, is about the same. By comparing the certificate storage figures in the two cases, it is obvious that they are very similar. However, the storage drops a lot more around the settlement weeks here than in case 4. A reason for this could be that there is slightly less production in this case, with 0,06 TWh.

To get some more interesting price scenarios, the initial certificate storage is lowered from 12100 GWh to 5000 GWh. The results are shown below in Figure 5-21 and Figure 5-22.

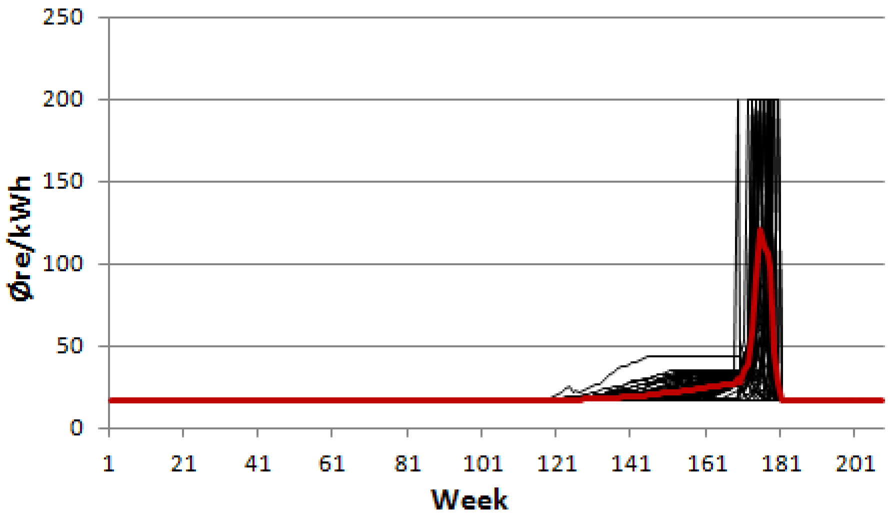



Figure 5-21: Green certificate prices for hydropower expansion and lower initial storage

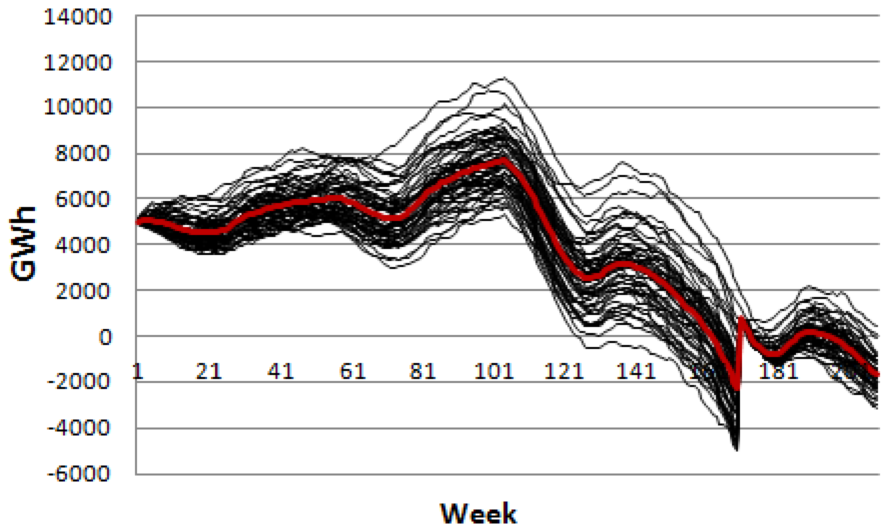



Figure 5-22: Green certificate storage for hydropower expansion and lower initial storage

To get a reasonable figure for the certificate storage, the calibration factor had to be reduced a lot, to 0,860 compared to 1,050 in case 4. This might be a reason why the certificate prices in all scenarios remain constant until after the third settlement. After this a probability for deficit is predicted when the certificate storage starts to decrease. The certificate prices then starts to spread out and increase towards the final settlement and to a value of 29,74 øre/kWh. Here a penalty is taken in many of the scenarios, and as a result the prices skyrocket. Afterwards they drop back down to the end-value.

## 5.8 Case 7: Wind Power Expansion

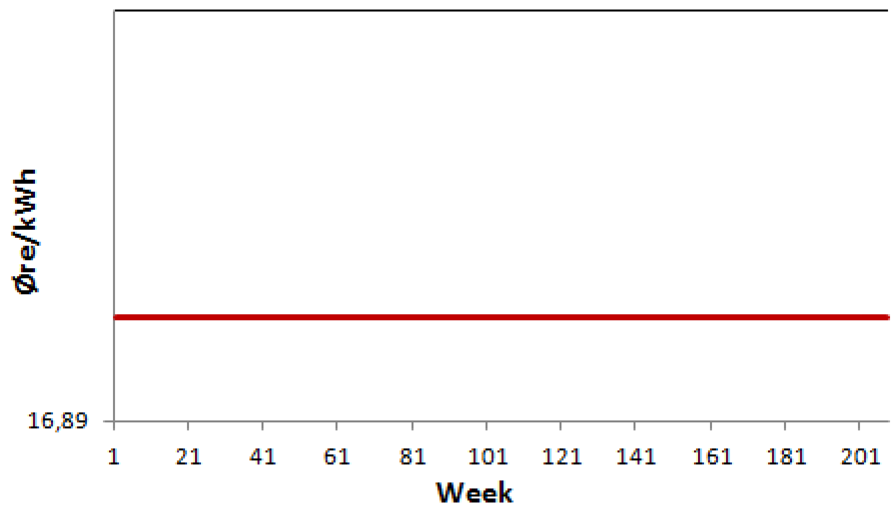



Figure 5-23: Green certificate prices for wind power expansion

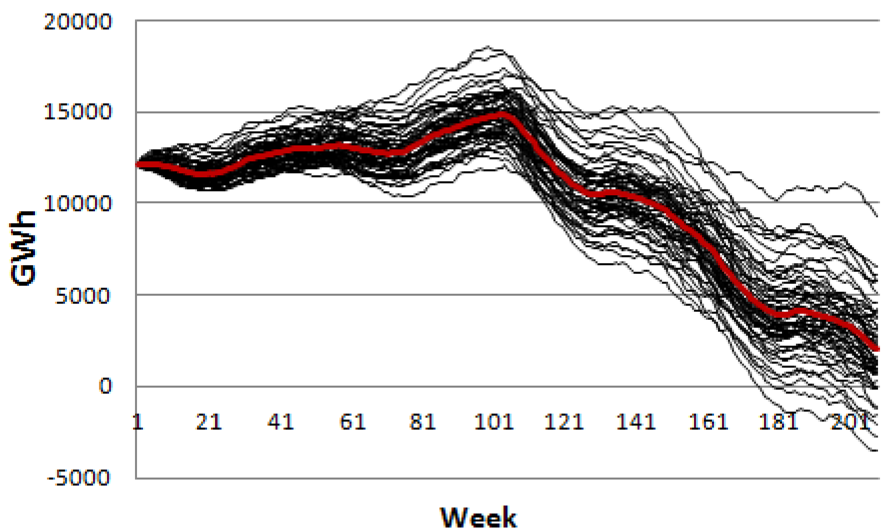



Figure 5-24: Green certificate storage for wind power expansion

Like in the previous case, there is no probability for a deficit in any scenarios until the final year and after the final settlement, as seen in Figure 5-24. The certificate prices then remain constant at the set end-value throughout the simulation, as seen in Figure 5-23.

The amount of wind power expansion in this case equals the even expansion rate of 3 TWh/year. The total amount of certificates produced is 23,14 TWh here, compared to 23,16 TWh in case 4. By comparing the certificate storage figures from both cases, they appear to be almost completely identical apart from minor deviations in a few of the scenarios.

Because of the constant certificate prices above, the certificate storage is again lowered to 5000 GWh in an attempt to get some variation. The results are shown below in Figure 5-25 and Figure 5-26.

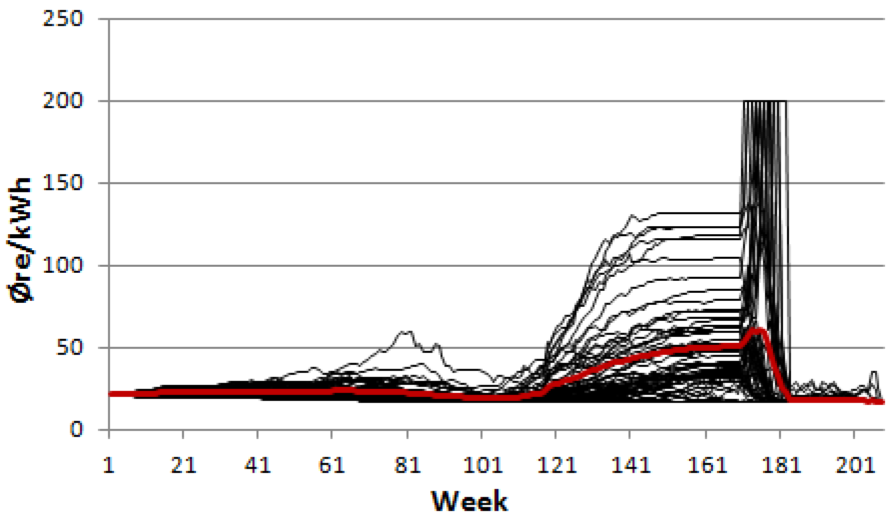



**Figure 5-25: Green certificate prices for wind power expansion and lower initial storage**

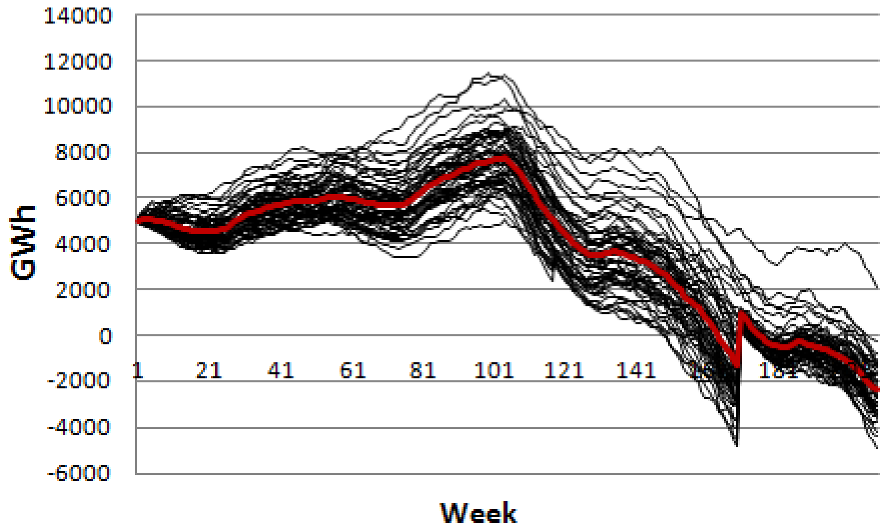



Figure 5-26: Green certificate storage for wind power expansion and lower initial storage

The lowered initial storage leads to higher probability of a deficit, and as a result the prices vary throughout the entire simulation. By comparing these results to the ones in case 4, it becomes clear that they are almost completely the same here as well.

The prices are very even during the first two years, where they converge to a somewhat lower level of 18,72 øre/kWh before the third settlement. In case 4 this value was at 18,04 øre/kWh. After that the average price rises to 50,67 øre/kWh before the final settlement, compared to 46,78 øre/kWh in case 4. Here there is a deficit in most of the scenarios and a penalty is usually taken. The prices then increase further and drops to the end-value after the final settlement. However, there is a slightly higher variability in a few of the scenarios in this case after this settlement compared to case 4.

## 5.9 Case 8: Biofuels Expansion

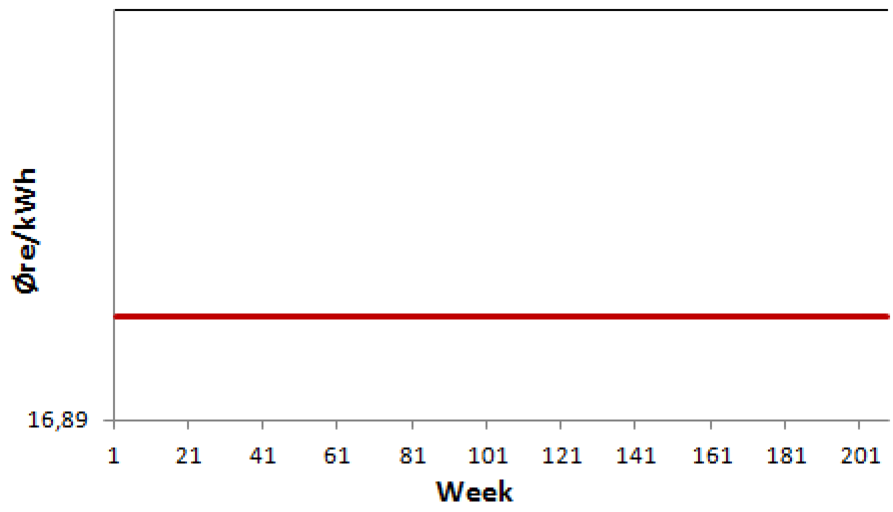



Figure 5-27: Green certificate prices for biofuels expansion

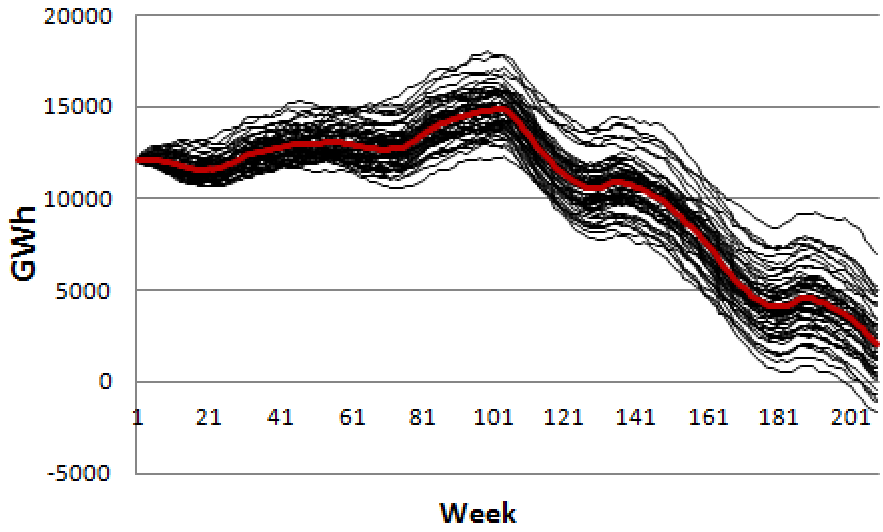



Figure 5-28: Green certificate storage for biofuels expansion

Like in the previous cases there is no probability of a deficit until the very end of 2017, and as a result the certificate prices remain constant at the end-value of 16,89 øre/kWh, as seen in Figure 5-28.

The amount of biofuels expansion in this case equals the total amount of expansion in case 4. The total amount of certificates produced is 23,14 TWh here, compared to the previous 23,16 TWh. By comparing the certificate storage in the two cases it becomes apparent that they are very similar. The only noticeable difference is that the amount of variation in the different scenarios is slightly reduced here.

To get a more interesting case when it comes to price values, the certificate storage is reduced to 5000 GWh like in the previous cases. The results from the simulation are shown below in Figure 5-29 and Figure 5-30.

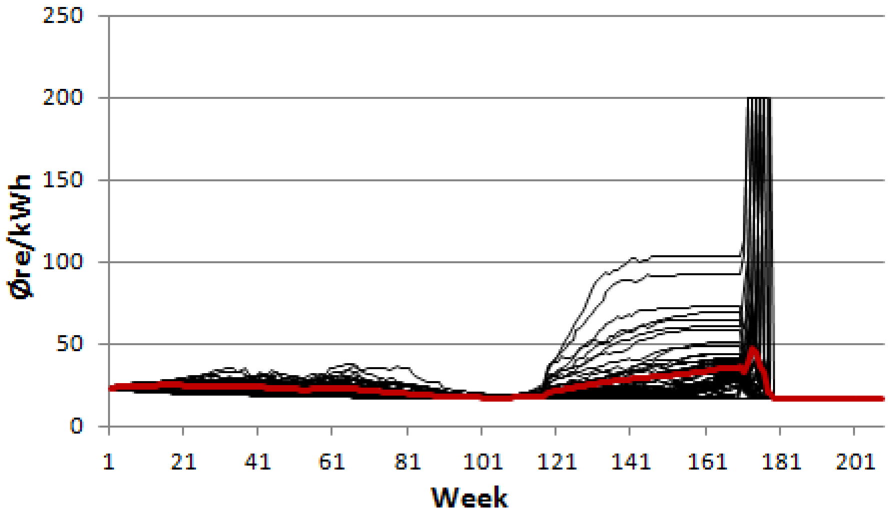



Figure 5-29: Green certificate prices for biofuels expansion and lower initial storage

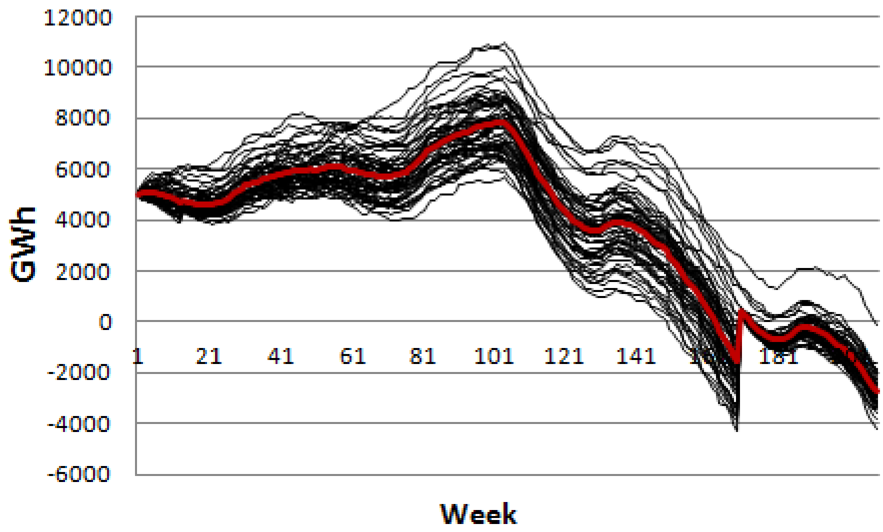



Figure 5-30: Green certificate storage for biofuels expansion and lower initial storage

To get a reasonable figure for the certificate storage the calibration factor had to be increased a lot, to 1,150 compared to 1,050 in case 4. However, by comparing Figure 5-14 and Figure 5-30 it is evident that the differences in the certificate storage in the two cases are small. Like before the most noticeable thing is that there is slightly less variation in the different scenarios in this case.

By comparing the certificate prices with the prices in case 4, they seem to have the same development. As seen in Figure 5-29 the curve is very even during the first two years where it converges towards a value of 17,21 øre/kWh before the third settlement. After that there is a large probability of deficit, and as a result the prices spread out and rise towards the final settlement. It never gets as high as in case 4 however, with an average maximum price of 35,63 øre/kWh before the settlement. Afterwards the prices drop to the set end-value.

## 5.10 Case 9: Equal Production and Consumption

Because it was attempted to make the production equal to the consumption in this case, the initial certificate storage was lowered to 5000 GWh right away. If it was higher, there would not be any probability of a deficit and the prices would remain constant at the end-value, as encountered in many of the previous cases.

The values obtained from the simulations are presented below in Table 5-2. It shows that the values for production and consumption from 2015-2017 are quite close, but with a minor deficit in 2015 and surplus in 2016-2017. The graphic results are shown below in Figure 5-31 and Figure 5-32. To get a reasonable figure for the green certificate storage, the feed-back factor had to be turned up quite high, to 1,100.

**Table 5-2: Simulated production and consumption per year**

| Year | Production (TWh) | Consumption (TWh) |
|---:|---:|---:|
| 2014 | 18,61 | 17,85 |
| 2015 | 19,08 | 19,72 |
| 2016 | 31,12 | 30,99 |
| 2017 | 34,50 | 33,96 |

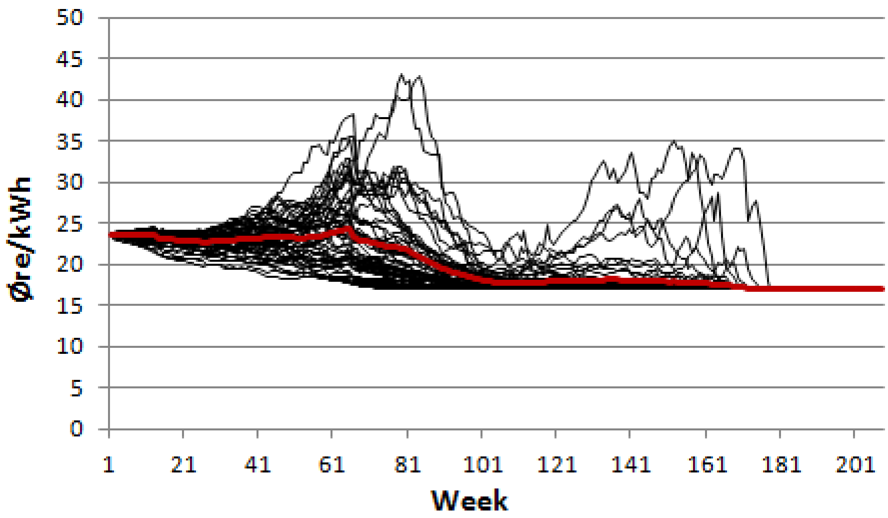



Figure 5-31: Green certificate prices for equal production and consumption

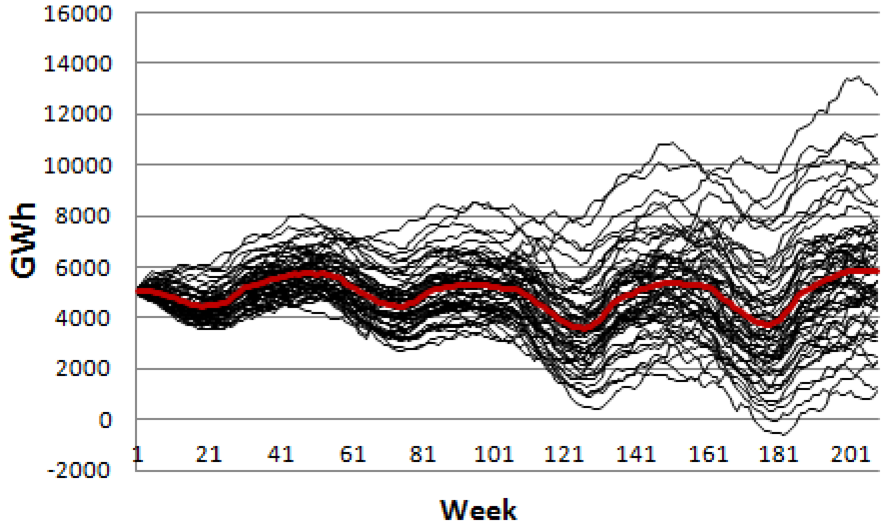



Figure 5-32: Green certificate storage for equal production and consumption

By looking at the green certificate storage in this case, it shows that the system is reasonably balanced, with an average surplus of 0,2 TWh. There is a minor buildup of certificates in the years with a surplus and a minor decrease when there is a deficit.

The certificate prices remain fairly stable during the first year and up until the second settlement. Here the average price is at its highest with a value of 24,36 øre/kWh. Then there is a small drop and the prices decrease towards a value of 17,33 øre/kWh before the final settlement. After that they all drop to the end-value.

# 6 Discussion

Price volatility in the green certificate market is undesirable, so the ideal result would be to have a constant average price in the cases where the price develops differently in the 57 scenarios. However, the average price is not a variable in the EMPS model, so it will never be a totally straight line.

The best price curves from the simulations in this thesis are found in case 5 with the fast expansion, and case 9 with the equal production and consumption. These are also the cases with the best balances and some of the lowest average certificate prices. Basecase also has a fairly good balance, but the initial storage is so high that there are no price variations. When simulating in the EMPS model it is therefore important that the certificate storage is low enough for the model to see a possibility of deficit in the future, which is proven in case 2.

At the present time the green certificate storage is quite large at 13 million certificates. Even though the EMPS model does not see a chance of deficit unless the market balance is extremely negative, there could still be a risk of deficit scenarios in the real market. The producers own a lot of the certificates that are in the current storage, but as long as the prices remain low like they are at present, they might not want to sell them. As a result, enough certificates might not be available in the market, which could lead to increasing price levels.

A trend that appears in many of the simulated cases is the tendency for the prices to remain fairly constant and converge towards a low value before the third settlement. The quota obligation increases a lot from 2016, and as a result many of the prices shoot up towards the final settlement. Consequently, the average price is not even and the results are not entirely perfect. A reason for this development could be that it is a challenge for the model to "tune in" the right amount of penalty when the deficit occurs so far in the future and the penalty fee is so variable.

When it comes to case 3, 4 and 5 with the different expansion rates, they show how the certificate balance can influence the price levels in the EMPS model. Case 3 has the least amount of production and huge deficit of certificates, which leads to very high certificates prices. The average certificate price has a value of 37,97 øre/kWh in this case. Case 5 has the largest amount of production and thus less deficit, and as a result the average certificate price is considerably lower at 21,31 øre/kWh.

The results are clearly more ideal when there is less probability of a huge deficit or surplus in the market. This is also true for the real market. It is expected that the certificate storage will increase to about 15 million in 2015, but in 2016 the quotas will be increased drastically (assuming that the change agreement is enacted), and it seems unlikely that the expansion rate will be able to keep up. As a result the certificate storage will start to decrease. If it gets really low the market will start to stress, it might be hard to obtain enough certificates and the price levels will increase.

When comparing case 3, 4, and 5 to the example made by NVE, the figures of the certificate storages correspond to some extent. The main difference is that the consumption that requires green certificates in the simulated cases in this thesis is a great deal higher. The reason for this could be that some calculation errors are made. It could also be the fact that the numbers used here to calculate the demand are retrieved from a different source than NVEs' source, and they could therefore be quite different.

The results from case 6, 7 and 8, that focused on hydropower expansion, wind power expansion and biofuels expansion, turned out to be a bit different from one another. The curves for the certificate storages looks reasonably similar and the balances are about the same, but the certificate prices behaves differently. Hydropower expansion has the lowest average price but also the most extreme price curve. Wind power expansion has the highest average price, while biofuels expansion had the most even and ideal price curve of the three cases.

The expansion rate is the same in case 6, 7 and 8 as it is in case 4, and the balances are approximately the same. However, the price values from case 4 falls somewhere in between case 7 and 8, and it shows how an uneven distribution of production may affect the price levels in the simulations.

Because biofuels are dependent on price, higher certificate prices will lead to an increase in the production of biofuels. This happens in both case 6 and 7, but only in the last year of the simulations. Because the prices are higher during the final settlement in case 6 than in case 7, the production of biofuels is also slightly higher in this year, even though the input values are the same. This makes the average production of biofuels a little higher in case 6, as presented in Table 5-1.

Hydropower is a zero-cost energy source, and can like biofuels be adjusted in response to power prices. In the EMPS model it is dependent on both the strategy calculation and the different realizations of climate variables. For that reason the hydropower prices vary for each year in case 7 and 8, even though the manual input values are constant.

It turns out that the three cases needs three completely different calibration factors in order to produce reasonable results. The hydropower case has the lowest factor of 0,860, the wind power case has the middle value with a factor of 1,055, and the biofuels case needs a very high factor of 1,150. This might be a reason as to why the price scenarios are so different in the three cases.

By turning the feed-back factor down in the hydropower case, the demand seen in the strategy calculation is lower, which leads to lower price levels. However, when a deficit eventually occurs the prices skyrocket. In the wind power case the demand seen is higher, and as a result the prices will be higher from the start, but not rise quite as high when a deficit occurs. In the biofuels case the demand seen is very high, but because the production of biofuels can be adjusted in response to power prices, the prices are lower than in the wind power case. This feature will regulate the prices throughout the simulations, which is why the prices in the biofuels case is more ideal than the two others.

When it comes to the calibration factor itself, it does not appear to be a particular adjustment pattern, by looking at the results from the test cases in this thesis. If such a trait exists is uncertain, but to find out more specific testing is needed.

All in all, it seems like 2015 will be a very important year regarding the future of the Norwegian-Swedish certificate market. The regulators have decisions to make about quota changes, depreciation rules and a suggestion for an extended end date for new production. A lot of investment decisions also needs to be made, which will be crucial for whether the common goal will be met or not. The end date for new production to be eligible for certificates is approaching rapidly, and at the same time the certificate prices are extremely low. This combination makes the future of the green certificate market very exciting, and perhaps the EMPS model can be used to predict some of it.

# 7 Conclusion

The main objective of this master thesis has been to analyze the Norwegian-Swedish certificate market in the EMPS model by adjusting and updating a realistic dataset for the Nordic power market. The historic values from the real certificate market were used as inputs and as a basis for the simulations. 10 different cases have been tested and analyzed, where the focus was particularly on factors that affect the green certificate price levels and price fluctuations.

At the present time the green certificate storage is quite large at 13 million certificates. The results obtained from the simulations in this thesis however, showed that this value is too high for the EMPS model to see any probability of a deficit in the near future, unless the market balance is extremely negative. Nevertheless, in the real market it could still be difficult to obtain enough certificates if the actors holding the certificates refuse to sell them because of low prices.

By lowering the initial certificate storage a probability of deficit occurred in the simulations, and as a result the prices would vary in each of the different scenarios. These results obtained by the EMPS model seems to correspond well to theoretical findings about the green certificate market. It appears that the certificate storage will increase to a value of around 15 million in 2015. However, the quotas will be increased drastically from 2016 and the storage will probably start to decrease, depending on the expansion rate of new production.

The most even prices and the best results were achieved when the balance was closest to zero, that is to say when the difference between the production and consumption of certificates was as low as possible. Thus, the expansion rate of new production will greatly influence the green certificate prices in the market.

This was demonstrated in case 3, 4, and 5 where the expansion rate was set to slow, even and fast. The slow expansion rate lead to a huge deficit and an average price level of 37,96 øre/kWh, while the fast expansion rate had less of a deficit, and consequently a lower average price level of 21,31 øre/kWh.

Attention was also given to the different types of production in the simulations (hydropower, wind power and biofuels), and how they affect the certificate price levels. The balances and certificate storages turned out to be very similar, but the price levels were quite different. The case with only hydropower expansion ended up having the lowest average certificate price, but also the most extreme price curve. The wind power expansion case had the highest price levels, while the biofuels expansion case had the most even price curve and thus the most ideal results.

A reason for these differences in the simulations could be that biofuels are dependent on price, while hydropower is a zero-cost energy source, and they can both be adjusted in response to power prices. Also, the three cases needed completely different calibration factors in the EMPS model in order to produce reasonable results, and this might have had too big of an effect on the prices.

Overall it looks like 2015 will be a very significant year regarding the future of the Norwegian-Swedish certificate market. A lot of regulatory decisions are to be made, as well as decisions regarding new investments. This affects whether the common goal will be met or not and how the certificate prices will develop in the future. It is uncertain how it is going to play out, but with more work and testing the EMPS model may perhaps be able to predict some of it.

## 7.1 Future Work

The simulations carried out in this thesis were performed in version 9.3 of the EMPS model. However, the implementation has now been updated to the newest version of the model, 9.6, so that the user's operational datasets can be applied without special modifications. It is therefore recommended that any further testing of the green certificate market should be done in the most updated version of the model.

In this thesis it was only possible to simulate over a period of 4 years. This restraint should be removed or extended so that simulations could include more historical data, as well as forecasting scenarios further into the future. It should be noted however that this might lead to very long computation times.

The inputs can also be divided up more detailed by area, and not by country like it was done in this thesis. However, if the same dataset is used as a basis it will be very time consuming and have no effect on the actual results. Nevertheless, if such a change were to be made, it would make it easier to perform minor and more specific changes to the test cases.

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# Appendix A: Quotas

**Table 1: Norwegian quotas**

| | Updated proposition for new quotas (nov.2014) | NVEs proposition for new quotas from the progress review | Today's quotas |
|---|---|---|---|
| 2012 | | | 0,03 |
| 2013 | | | 0,049 |
| 2014 | | | 0,069 |
| 2015 | | | 0,088 |
| 2016 | 0,119 | 0,092 | 0,108 |
| 2017 | 0,137 | 0,11 | 0,127 |
| 2018 | 0,154 | 0,128 | 0,146 |
| 2019 | 0,173 | 0,145 | 0,165 |
| 2020 | 0,197 | 0,17 | 0,183 |
| 2021 | 0,196 | 0,17 | 0,182 |
| 2022 | 0,196 | 0,169 | 0,181 |
| 2023 | 0,195 | 0,169 | 0,18 |
| 2024 | 0,193 | 0,168 | 0,179 |
| 2025 | 0,186 | 0,167 | 0,176 |
| 2026 | 0,174 | 0,158 | 0,164 |
| 2027 | 0,156 | 0,146 | 0,151 |
| 2028 | 0,131 | 0,126 | 0,132 |
| 2029 | 0,109 | 0,107 | 0,113 |
| 2030 | 0,09 | 0,089 | 0,094 |
| 2031 | 0,072 | 0,071 | 0,075 |
| 2032 | 0,054 | 0,054 | 0,056 |
| 2033 | 0,036 | 0,036 | 0,037 |
| 2034 | 0,018 | 0,018 | 0,018 |
| 2035 | 0,009 | 0,009 | 0,009 |

**Table 2: Swedish quotas**

| | Proposed new quotas from the progress review | Today's quotas |
|---|---|---|
| 2003 | | 0,074 |
| 2004 | | 0,081 |
| 2005 | | 0,104 |
| 2006 | | 0,126 |
| 2007 | | 0,151 |
| 2008 | | 0,163 |
| 2009 | | 0,17 |
| 2010 | | 0,179 |
| 2011 | | 0,179 |
| 2012 | | 0,179 |
| 2013 | | 0,135 |
| 2014 | | 0,142 |
| 2015 | | 0,143 |
| 2016 | 0,23 | 0,144 |
| 2017 | 0,246 | 0,152 |
| 2018 | 0,262 | 0,168 |
| 2019 | 0,276 | 0,181 |
| 2020 | 0,266 | 0,195 |
| 2021 | 0,25 | 0,19 |
| 2022 | 0,235 | 0,18 |
| 2023 | 0,222 | 0,17 |
| 2024 | 0,205 | 0,161 |
| 2025 | 0,184 | 0,149 |
| 2026 | 0,161 | 0,137 |
| 2027 | 0,14 | 0,124 |
| 2028 | 0,124 | 0,107 |
| 2029 | 0,108 | 0,092 |
| 2030 | 0,091 | 0,076 |
| 2031 | 0,071 | 0,061 |
| 2032 | 0,053 | 0,045 |
| 2033 | 0,037 | 0,028 |
| 2034 | 0,021 | 0,012 |
| 2035 | 0,013 | 0,008 |

# Appendix B: Complete Document for the Green Certificate Market Used in Basecase

```
; Groenne sertifikater;
;
; Sertifikatparameter;
Oppgjoeruke; Start sertifikat lagerbeholdning (GWh); Maximal sertifikat pris (ore/kWh);
Maximal sertifikat lager (GWh); Null magasin level (%); Antall straff scenarier
14; 12100; 200; 20000; 20;;
;
3; Sluttverdi;
Loepenr.; Magasinlevel (GWh); Sertifikatverdi (ore/kWh);
1 ;-5000; 16.89;
2; 0; 16.89;
3; 5000; 16.89;
4; 10000; 16.89;
;
1; Sertifikatpriser;
Loepenr.; Uke; Pris (ore/kWh);
1; 0; 17.8;
;
0; UkePrisVekt;
Loepenr.; Uke; Vekt;
1; 26; 1;
2; 52; 1;
;
0; Straffverdi;
Loepenr.; Uke; Verdi (ore/kWh);
1; 520; 10;
2; 520; 15;
;
12; Produksjon;
Loepenr.; Delomraade; Typenr.; Navn; Sluttuke; Andel (%);
1; 21; 13; Ny bioenergi; 52; 23
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2; 21; 13; Ny bioenergi; 104; 23

3; 21; 13; Ny bioenergi; 156; 23

4; 21; 13; Ny bioenergi; 208; 23

5; 22; 13; Ny bioenergi; 52; 23

6; 22; 13; Ny bioenergi; 104; 23

7; 22; 13; Ny bioenergi; 156; 23

8; 22; 13; Ny bioenergi; 208; 23

9; 23; 12; Ny bioenergi; 52; 23

10; 23; 12; Ny bioenergi; 104; 23

11; 23; 12; Ny bioenergi; 156; 23

12; 23; 12; Ny bioenergi; 208; 23

;

0; Forbruk;

Loepenr.; Delomraade; Typenr.; Navn; Sluttuke; Andel (%);

1; 1; 30; Flex Forbruk; 520; 0

;

1; Kvoteplikt;

Loepenr.; Sluttuke; Kvote Delomr.1 (%); Kvote Delomr.2 (%);

1; 208; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 6.9; 14.2; 14.2; 14.2; 14.2; 14.2; 14.2; 14.2; 14.2; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0;

2; 104; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 8.8; 14.3; 14.3; 14.3; 14.3; 14.3; 14.3; 14.3; 14.3; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0;

3; 156; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 10.8; 14.4; 14.4; 14.4; 14.4; 14.4; 14.4; 14.4; 14.4; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0;

4; 208; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 12.7; 15.2; 15.2; 15.2; 15.2; 15.2; 15.2; 15.2; 15.2; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0;

;

60; Fastkraft;

Loepenr.; Delomraade; Dellastnr.; Navn; Sluttuke; Andel (%);

```
1; 3; 1; Nor-sorost; 52; 140;
2; 3; 1; Nor-sorost; 104; 140;
3; 3; 1; Nor-sorost; 156; 140;
4; 3; 1; Nor-sorost; 208; 140;
5; 4; 1; NOR-HALLING; 52; 140;
6; 4; 1; NOR-HALLING; 104; 140;
7; 4; 1; NOR-HALLING; 156; 140;
8; 4; 1; NOR-HALLING; 208; 140;
9; 5; 1; NOR-TELEMARK; 52; 140;
10; 5; 1; NOR-TELEMARK; 104; 140;
11; 5; 1; NOR-TELEMARK; 156; 140;
12; 5; 1; NOR-TELEMARK; 208; 140;
13; 6; 1; Nor-sorland; 52; 140;
14; 6; 1; Nor-sorland; 104; 140;
15; 6; 1; Nor-sorland; 156; 140;
16; 6; 1; Nor-sorland; 208; 140;
17; 7; 1; Nor-vestsyd; 52; 140;
18; 7; 1; Nor-vestsyd; 104; 140;
19; 7; 1; Nor-vestsyd; 156; 140;
20; 7; 1; Nor-vestsyd; 208; 140;
21; 8; 1; Nor-vestmidt; 52; 140;
22; 8; 1; Nor-vestmidt; 104; 140;
23; 8; 1; Nor-vestmidt; 156; 140;
24; 8; 1; Nor-vestmidt; 208; 140;
25; 9; 1; Nor-midt; 52; 140;
26; 9; 1; Nor-midt; 104; 140;
27; 9; 1; Nor-midt; 156; 140;
28; 9; 1; Nor-midt; 208; 140;
29; 10; 1; Nor-helge; 52; 140;
30; 10; 1; Nor-helge; 104; 140;
31; 10; 1; Nor-helge; 156; 140;
32; 10; 1; Nor-helge; 208; 140;
33; 11; 1; Nor-troms; 52; 140;
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34; 11; 1; Nor-troms; 104; 140;

35; 11; 1; Nor-troms; 156; 140;

36; 11; 1; Nor-troms; 208; 140;

37; 12; 1; Nor-finnmark; 52; 140;

38; 12; 1; Nor-finnmark; 104; 140;

39; 12; 1; Nor-finnmark; 156; 140;

40; 12; 1; Nor-finnmark; 208; 140;

41; 17; 1; Sver-on1; 52; 61;

42; 17; 1; Sver-on1; 104; 61;

43; 17; 1; Sver-on1; 156; 61;

44; 17; 1; Sver-on1; 208; 61;

45; 20; 1; Sver-nn2; 52; 61;

46; 20; 1; Sver-nn2; 104; 61;

47; 20; 1; Sver-nn2; 156; 61;

48; 20; 1; Sver-nn2; 208; 61;

49; 21; 1; Sver-most; 52; 61;

50; 21; 1; Sver-most; 104; 61;

51; 21; 1; Sver-most; 156; 61;

52; 21; 1; Sver-most; 208; 61;

53; 22; 1; Sver-mvest; 52; 61;

54; 22; 1; Sver-mvest; 104; 61;

55; 22; 1; Sver-mvest; 156; 61;

56; 22; 1; Sver-mvest; 208; 61;

57; 23; 1; Sver-syd; 52; 61;

58; 23; 1; Sver-syd; 104; 61;

59; 23; 1; Sver-syd; 156; 61;

60; 23; 1; Sver-syd; 208; 61;

;

60; Vindkraft;

Loepenr.; Delomraade; Serienr.; Navn; Sluttuke; Andel (%);

1; 6; 1; Nor-sorland; 52; 5;

2; 6; 1; Nor-sorland; 104; 5;

3; 6; 1; Nor-sorland; 156; 5;

4; 6; 1; Nor-sorland; 208; 5;
5; 7; 1; Nor-vestsyd; 52; 5;
6; 7; 1; Nor-vestsyd; 104; 5;
7; 7; 1; Nor-vestsyd; 156; 5;
8; 7; 1; Nor-vestsyd; 208; 5;
9; 8; 1; Nor-vestmidt; 52; 5;
10; 8; 1; Nor-vestmidt; 104; 5;
11; 8; 1; Nor-vestmidt; 156; 5;
12; 8; 1; Nor-vestmidt; 208; 5;
13; 9; 1; Nor-midt; 52; 5;
14; 9; 1; Nor-midt; 104; 5;
15; 9; 1; Nor-midt; 156; 5;
16; 9; 1; Nor-midt; 208; 5;
17; 10; 1; Nor-helge; 52; 5;
18; 10; 1; Nor-helge; 104; 5;
19; 10; 1; Nor-helge; 156; 5;
20; 10; 1; Nor-helge; 208; 5;
21; 11; 1; Nor-troms; 52; 5;
22; 11; 1; Nor-troms; 104; 5;
23; 11; 1; Nor-troms; 156; 5;
24; 11; 1; Nor-troms; 208; 5;
25; 12; 1; Nor-finnmark; 52; 5;
26; 12; 1; Nor-finnmark; 104; 5;
27; 12; 1; Nor-finnmark; 156; 5;
28; 12; 1; Nor-finnmark; 208; 5;
29; 17; 1; Sver-on1; 52; 87;
30; 17; 1; Sver-on1; 104; 87;
31; 17; 1; Sver-on1; 156; 87;
32; 17; 1; Sver-on1; 208; 87;
33; 18; 1; Sver-on2; 52; 87;
34; 18; 1; Sver-on2; 104; 87;
35; 18; 1; Sver-on2; 156; 87;
36; 18; 1; Sver-on2; 208; 87;

37; 19; 1; Sver-nn1; 52; 87;

38; 19; 1; Sver-nn1; 104; 87;

39; 19; 1; Sver-nn1; 156; 87;

40; 19; 1; Sver-nn1; 208; 87;

41; 20; 1; Sver-nn2; 52; 87;

42; 20; 1; Sver-nn2; 104; 87;

43; 20; 1; Sver-nn2; 156; 87;

44; 20; 1; Sver-nn2; 208; 87;

45; 21; 1; Sver-most; 52; 87;

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47; 21; 1; Sver-most; 156; 87;

48; 21; 1; Sver-most; 208; 87;

49; 22; 1; Sver-mvest; 52; 87;

50; 22; 1; Sver-mvest; 104; 87;

51; 22; 1; Sver-mvest; 156; 87;

52; 22; 1; Sver-mvest; 208; 87;

53; 23; 1; Sver-syd; 52; 87;

54; 23; 1; Sver-syd; 104; 87;

55; 23; 1; Sver-syd; 156; 87;

56; 23; 1; Sver-syd; 208; 87;

57; 24; 1; SVER-S-OWP; 52; 87;

58; 24; 1; SVER-S-OWP; 104; 87;

59; 24; 1; SVER-S-OWP; 156; 87;

60; 24; 1; SVER-S-OWP; 208; 87;

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12; Vannkraft;

Loepenr.; Delomraade; Modulnr.; Navn; Sluttuke; Andel (%);

1; 1; 1078; Kraft2020; 52; 85;

2; 1; 1078; Kraft2020; 104; 85;

3; 1; 1078; Kraft2020; 156; 85;

4; 1; 1078; Kraft2020; 208; 85;

5; 6; 6086; Kraft2020; 52; 85;

6; 6; 6086; Kraft2020; 104; 85;

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7; 6; 6086; Kraft2020; 156; 85;
8; 6; 6086; Kraft2020; 208; 85;
9; 7; 7124; Kraft2020; 52; 85;
10; 7; 7124; Kraft2020; 104; 85;
11; 7; 7124; Kraft2020; 156; 85;
12; 7; 7124; Kraft2020; 208; 85;
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