This report describes the results of the project "Assessment of the power situation 2021-2022", which SINTEF Energi has carried out on behalf of OED. The report consists of four main parts. The first part deals with magazine allocation in the autumn of 2021. We have compared observed magazine allocation in southern Norway from week 36 until the end of the year with a calculated socio-economically optimal allocation for the same period. In addition, we have investigated the price consequences of the two new cables to Germany and Great Britain respectively, i.e. NordLink and North Sea Link. The second part examines how different types of magazine restrictions affect magazine allocation and prices, and what benefit these restrictions might have exemplified in an extreme event. Part three deals with the significance of the rationing price for magazine disposal. In the last part, the research prototype model FanSi is tested on some of the cases from the other parts.

1 introduction

This is the final report from the report "Assessment of the power situation 2021-2022" carried out by SINTEF Energi. The power situation 2021-2022 is challenging and the OED wants a thorough review of the causes, as well as an assessment of the risk that similar situations may arise in the future. The study focuses in particular on assessing the magazine disposal. Assessment of the power situation is made with, among other things, model simulations using the interconnection model. The study is divided into four parts and will look at the present situation, future risk, possible measures and in part four, an alternative protype Market model model called fansi is used for some of the same analyzes as in the other parts of the report is carried out with the interconnection model.

Part 1:

a) observed magazine management compared to a socio -economically optimal handling

b) Norwegian power exports and influences on electricity prices

Part 2: Future Security Security

Part 3: Consequences of possible measures

Part 4: Testing of FanSi model

Work on part 1 was completed in September 2022 and documented in a separate report1. This final report includes the entire project including the results of part 1. After part 1 of the project was completed, we have become aware of and gained access to data that may indicate that some parts of the modeling of Sweden have some weaknesses with regard to the power flow. This can affect the results of the first part and especially the assessment of the magazine disposal. No changes have been made based on this in the final report and the modeling of Sweden is as before.

4 Observed magazine disposal and possible explanations

4.1 Observed magazine disposal

Figure 1 shows the minimum, maximum and average magazine filling for Southern Norway7 for the years 1995 to and including 2021, gathered with magazine filling 2021. The figure illustrates that there was a significant drainage of magazines in 2021 compared to previous years. Note that our analysis period is week 36/2021 to week 2/2022, and that the magazine filling had already been quite low in week 36 which is the start of our analysis period.

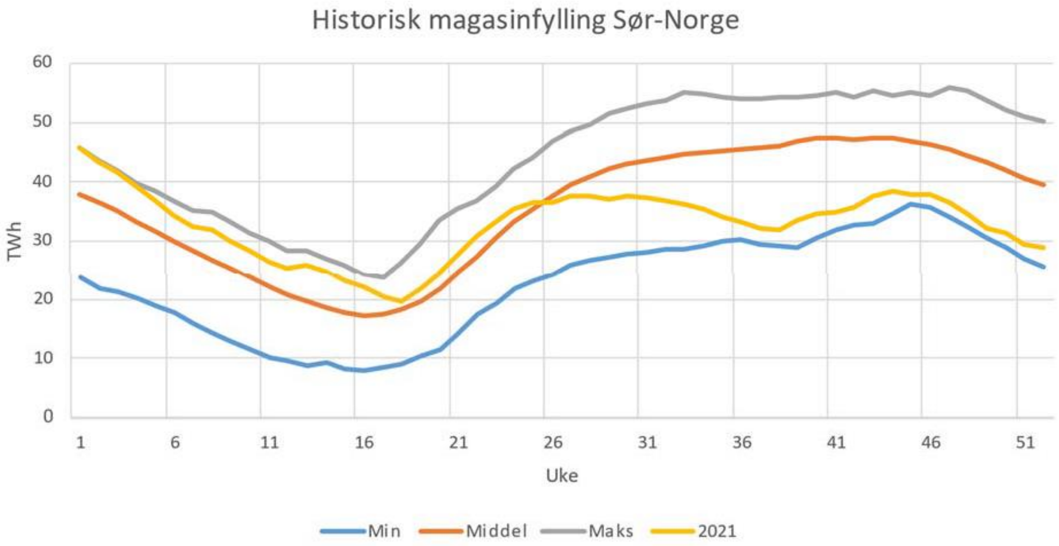


Figure 1: Magazine filling in Southern Norway - Minimum, maximum and average 1995 - 2021, as well as observed magazine filling 2021, based on NVE Magazine Statistics8

4.2 Increase to magazines

Intention to magazines is important to explain the development of magazine filling. Figure 2 shows the inflow in Southern Norway for 2021 compared to average, smallest and highest registered weekly for the period 1981-2021. We see that the inflow is smaller than average and down to the minimum number of statistics in the period from week 23 to week 38. This coincides with the period when the 2021 magazine filling is reduced from being above average in the statistics to getting down to the minimum fill rate in the statistics. The low inflow during this period is obviously an important explanation for the degree of filling down during that period.

If, on the other hand, we look at the period afterwards, e.g. From week 39 onwards, the inflow is significantly larger than average. Normally, this would indicate that the fill rate should approach the average magazine filling somewhat. However, such a normalization of the fill rate did not happen.

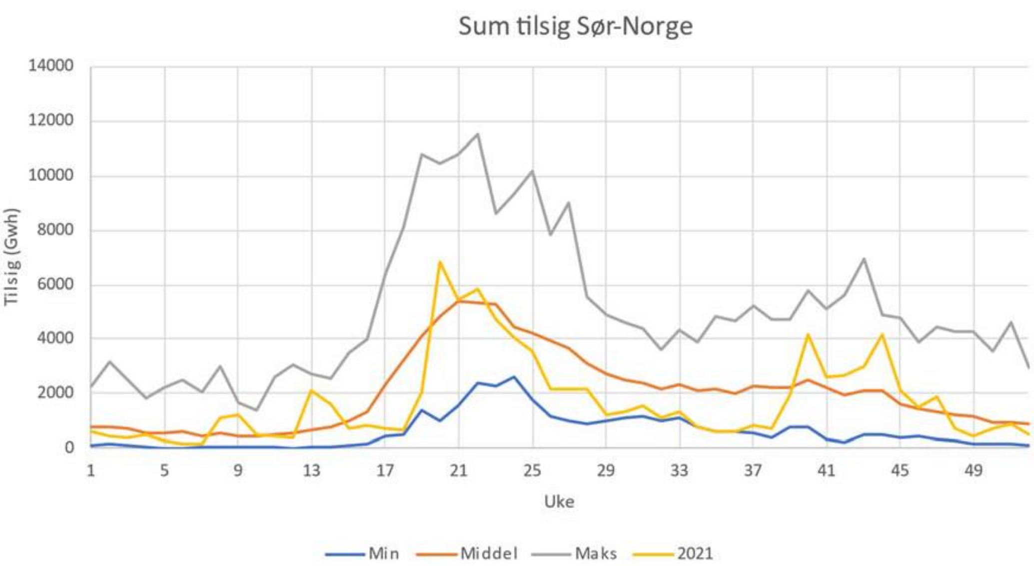


Figure 2: Total inflow to Southern Norway in the autumn of 2021 compared to mine, means and max for the period 1981-2021.

4.3 Power prices outside the Nordic

Another important factor in explaining the magazine disposal is the development in power prices outside the Nordic region. Here we use the term prices in Germany as an example of power prices and expectation of price developments outside the Nordic region. The price in the other exogenous current markets (ie those modeled with price and transmission capacity to the Nordic region) had the same development because they are governed by the same external factors, where the gas price is the most important. Figure 3 shows how the term prices in Germany for delivery times until the end of 2022 developed during the autumn/winter 2021. Term prices can be interpreted as the market's expectation for future German spot prices. It is likely that Norwegian players' expectations of the same prices do not differ much from this.

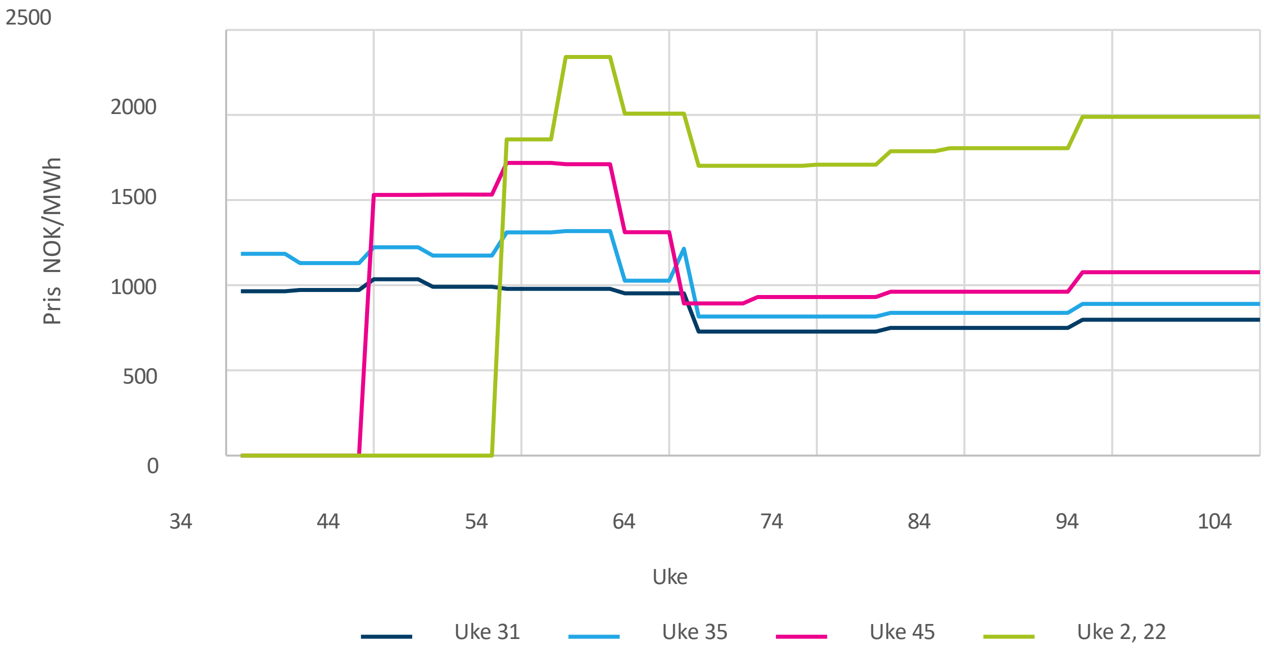


Figure 3: Development of German term prices in the autumn of 2021 (week 31, 35, and 45) and winter 2022 (week 2, 2022). A curve (eg week 35) shows the term price in week 35 for deliveries from week 36/2021 and out 2022. Source: Market data received from NVE.

In particular, two things are important when explaining the magazine disposal for flexible Norwegian hydropower: 1) Term prices are increasing during the autumn. The dark blue curve (week 31) is lower than the light blue (week 35) lower than the pink (week 45) which in turn is lower than the green (week 2, 2022). This shows that the market has constantly underestimated what is going to happen. 2) The second observation is that the market constantly thought that prices will be lower in time, this is especially clear in the fall of 2021 and especially at the pink curve. The basket has a peak in the next few weeks and then falls again throughout the year.

The power producers want to use the water so that one produces when the price is highest. The price forecasts are therefore crucial to whether one wants to save the water or produce in the current week. With such a price forecast as outlined in Figure 3, it will be optimal to produce/export a lot during the autumn of 2021, when the price is highest. It is constantly believed that prices at the start of the period are higher than the price further ahead. Ie Hydropower and water stored in magazines have their highest expected value in the first/current week. In addition, the general price level rises constantly which can lead to a delay of updating forecasts and water values. When the price is constantly rising, it can quickly become so that the water values based on previous information are obsolete before using them. This means that you underestimate the water value and the price ahead and end up producing more than you should.

4.4 Reviews

By 2021, the fill rate was reduced from being above average before week 26 to going below average and further down to the minimum fill rate in the statistics up to week 38. An important explanation for this reduction in relative filling rate is that the inflow was much lower than average in it the period it happened.

The fill rate then remained low in 2021, despite the fact that the inflow was higher than normal and despite the fact that a typical should be more careful to use the magazine water when the fill rate is low. An important explanation for this happened is the development of expected future price in Europe. In the fall of 2021, one expected the price to decrease somewhat from the current price level in the current week during the spring of 2022, and the expected price reduction increased throughout the year in 2021. Thus, it was optimal to produce relatively much even though the magazine filling was low. This may explain that the magazine filling remained low even if the inflow was greater than average.

Whether production was higher or lower than what was socio -economically optimally investigated in the following.

13.6.2 Trade abroad forward

As the power market is regulated now, it is the hourly rates on the power exchange that are crucial for trade between land. This is a trade regime that has been gradually developed over several decades. As explained above, such a system makes us vulnerable to the scarcity of power in our neighboring countries, with high prices as we have seen in southern Norway in 2021 and 2022 as a result. However, under more normal circumstances, with plenty of power available in our neighboring countries, such a trade regime can provide gains that also benefit Norwegian consumers.

It is difficult to predict how the energy situation is in our neighboring countries in the medium and long term. One possible scenario, which was ahead before the energy crisis 2021/22, was that for long periods there will be a lot of power available in our neighboring countries. In that case, it is conceivable that Norway will import very cheap power for long periods and reduce the need for development in Norway. Long periods of very cheap power in our neighboring countries may be due to the fact that more power generation has been developed than what is in demand. The price that is realized in their markets can then be so low on average that it is difficult to achieve at least as low an average price in the Norwegian power market.

Such a development, with little or no power development in Norway in the future, is problematic for several reasons. Without power development in Norway, the power surplus will be reduced and in the worst case we can have a power deficit. NVE estimates that the greater the surplus Norway has, the more likely it is with lower prices in Norway than in our neighboring countries. Power development and thus maintaining our surplus of power can thus contribute to competitive prices in the Norwegian market. At least as important is that without a power surplus in the normal year we will put ourselves in a very vulnerable situation if our neighboring countries in the future have a lack of energy in the future.

Another possible scenario is that the operation of the intermediate country connections is less linked directly to the daily prices of the power exchange. Seen from our neighboring countries, they want access to effects during periods when it does not blow in them. They can then pay for just this, and they may be entitled to import when such a need arises regardless of the daily prices in the markets. At the same time, from a Norwegian standpoint, there may be a desire for access to cheap wind power. It may also be appropriate to access their flexible power, to the extent that they have built it up, when we are in a dry year. Can such a trade regime, which differs from today's trade regime, help to decouplate the two markets in the two markets, and is it beneficial that this happens? How do we ensure national control over our water resources, not least in dry years, if it is the case that a neighboring country gets the option to import power when they themselves are most in need of it? We do not know of any thorough analysis of the advantages and disadvantages of such a scenario, but now that there are ongoing reforms in the UK and the EU, among others, this and similar scenarios may become relevant.

In general, it is in Norway's interest to act both in the short term and in the long term. In the future, more analysis environments are expecting a tighter power balance in Norway. If it occurs, it will mean a greater need for imports in dry years. At the same time, there may be gains associated with exports in wet years, including Would we avoid trapped power and very low prices during certain periods. The short -term trade can also be beneficial for Norway, as we can import one day it blows on the continent and export one day it is quiet on the continent.

Similarly, it is in other countries' interest to trade with us. If Norway has net power surplus in a normal year, we will be able to offer relatively affordable force to the outside world. Furthermore, Europe needs to sell large amounts of power when it blows, and the need for imports when it does not blow. In this way, there is potential for a win-win situation in trade abroad.

However, today we do not know what the trade regime will look like in a few years. Given possible changes in the system, it is important that Norway promotes its own interests and conveys solutions that we as a nation are best served with. As a rule, trade will be in both parties' interest. This means that Norway has a common interest with the outside world to come up with good solutions that serve both parties. In today's geopolitical situation with war in Ukraine and Russia's threading of gas supplies to Europe, there is extra good reason to be explicit that together we must agree on any new conditions for trade. Then it is important that other countries also follow the common rules that we follow. Among other things, it may be in Norway's interest that the countries we trade with also create price areas in our own country and at the same time do not limit the power flow from the outside world to Norway.

5 Quantitative analyzes of magazine disposal in the fall of 2021

5.1 Introduction

In this chapter, we try to answer whether the magazine filling was lower in the autumn of 2021 than was optimal, taken into account the observed price and inflow development. In this assessment, we are based on analyzes with the interconnection model. The starting point is that the interconnection model gives the socio -economically optimal disposal of the magazines.

Our analysis period starts in week 36, ie after the fill rate in Southern Norway has been reduced from above average to descending to the minimum fill rate in the statistics. However, in the following period, which we analyze, the inflow was greater than normal. Nevertheless, the degree of filling kept down to the minimum in the statistics.

To the greatest extent possible, we have used the analysis scheme described in the method chapter:

• We have calculated an optimal strategy for hydropower for week 36 and week 45. Corresponding datasets were not available for weeks before week 36, and therefore our first strategy calculation for the dataset is in week 36.

• We have then simulated the power system and the magazine disposal with the weather statistics for the year 2021. In each week we used the last updated strategy, ie the strategy calculated for the data set adapted to week 36 at all weeks from week 36 until the update in week 45, and The strategy calculated for the dataset adapted to week 45 thereafter. In the Simulations Weekly Week, however, we have used the actual European prices and the actual transmission capacities for countries modeled with exogenous price and an exchange capacity in the dataset.

5.2 Calibration

First, we examine what the calibration of the model means for calculated optimal magazine disposal, in that we compare the magazine disposal at an a a) manual calibration and a b) automatic calibration. For this, we use the dataset that is adapted for week 36, without updating the strategy for future weeks and without the use of observed prices and transmission capabilities during the simulations.

Calibration is done in the following two ways:

a) Manual calibration - a qualitative assessment based on the simulated magazine disposal and prices. The following criteria are considered for i.a. Magazine filling shown in Figure 4:

in. Utilizes magazine capacity well,

II. little flood,

III. Small rationing risk,

IV. Relatively flat average price trend during the tapping season.

Our understanding is that the actors who use the interconnection model are normally based on a qualitative calibration based on the sizes mentioned above.

b) Automatic calibration - the simulated magazine disposal that maximizes the expected socio -economic surplus. This is an objective criterion that from a theoretical point of view is correct. However, this assumes that all sizes of the model are properly estimated (eg consumer elasticities, rationing price) and that modeled uncertainties describe mathematically correct all risk that the magazines should be disposed of with regard to.

Figure 4 shows probability distributions for different magazine fillings for Southern Norway for different weeks through the autumn of 2021, when simulating with all the weather in the statistics (1981 - 2021). The figure on the left shows the results with a manual calibration, while the figure to the right shows the results with an automatic calibration. Typically, this type of percentiles at the sub

-area level is used as part of assessment in the manual/qualitative calibration. It is clear from the percentiles that the magazine filling will be somewhat lower with the automatic calibration.

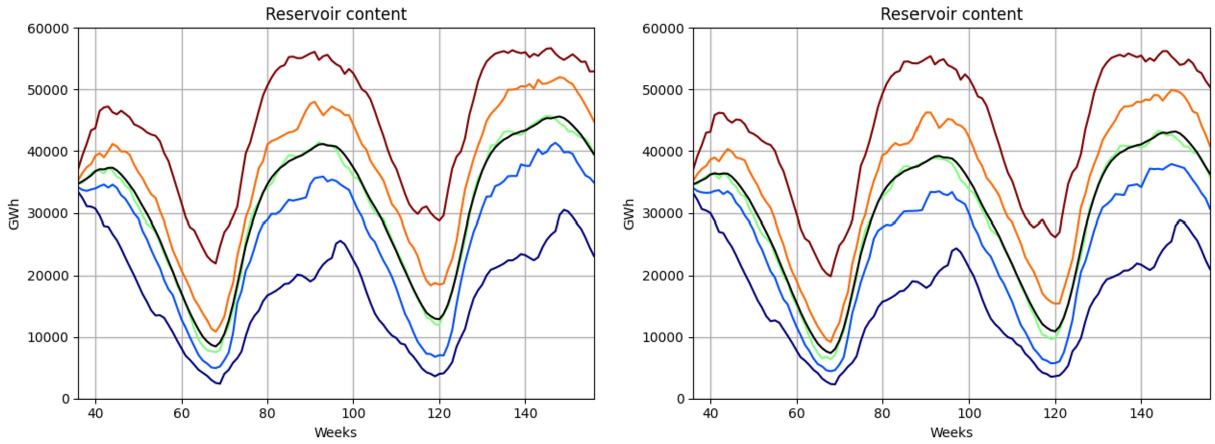


Figure 4. Percentage (0%, 20%, 50%, 80%, 100%) and average (black) for simulated magazine filling in Southern Norway with manual/qualitative calibration a) (left) and automatic/maximum socio -economic surplus calibration b) (to the right)

The manual calibration provides marginally larger socio -economic profits for Norway, while the automatic calibration (per construction) provides the highest socio -economic surplus in sum for all the areas for which the model calculates power prices.

While Figure 4 is a probability distribution for magazine filling when simulating all years in the weather statistics, in the rest of this document we will focus on the simulation that represents the year 2021 in the statistics.

5.3 Lower limit for optimal magazine disposal

Ideally, we should have had one updated data set for each week throughout the planning period with updated assumptions, so that the model could calculate an updated strategy for each week based on what was known for different weeks. For our analyzes, we only have updated interconnection model data sets available for week 36, and week 45 in 2021 as well as week 2 in 2022.

Figure 5 shows how the price of a term contract for Germany with delivery Q1 2022 has developed through the autumn of 2021.

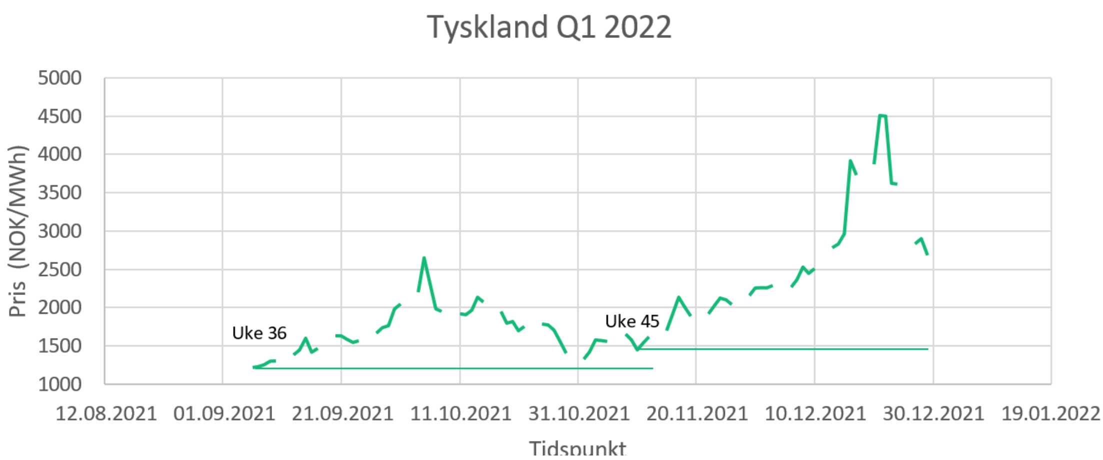


Figure 5: Price development in the autumn of 2021 on a schedule contract for Germany with delivery in Q1 2022. Source: Market data received from NVE.

We notice that week 36 (September 6) and week 45 (November 8) are both very close to the two times in the period when the term price (expected future price in Europe) is the lowest. Ie That the exogenous prices used to calculate the strategy from week 36 to week 44 in our analysis are lower than what the actual term prices were during this period. Too low term price in input provides too low water values from the strategy calculation. Water values based on the assumptions in week 36 will therefore be lower than if water values had been calculated new with updated data sets for each week between week 36 and week 45. For low water values provide too high simulated production, and thus for low magazine filling. Our simulations therefore provide a lower limit on what was the optimal fill rate in different weeks in the autumn of 2021, and in practice the optimum fill rate should be higher than the lower limit.

In that consequences, we compare the fill rate for the magazines in Southern Norway with this lower limit for optimal filling degree.

5.4 Results

The results of the analyzes are shown in Figure 6 and Figure 7, comparing the magazine filling with simulated optimal magazine filling (at the end of each week) for the two calibrations mentioned earlier in the report. The results with the manual/qualitative calibration are marked as "simulated a)", while the results of automatic calibration are marked as "simulated b)".

In the past, we have shown that the manual calibration provides a somewhat higher expected magazine filling than the automatic calibration. From Figures 6 and 7 we see that the manual calibration also provides higher magazine filling in a simulation of weather statistics for the year 2021.

We see from Figure 6 that observed magazine filling in the first period (week 36 onwards) is first equally with or above the simulated lower bounds, but that it is then below in weeks 44 and 45.

Before we simulated with the updated strategy from week 45 onwards, we updated the starting magazines. Thus, there is no deviation between simulated and observed magazine filling at the start of the new simulation period starting in week 45. From Figure 7, we see that observed magazine filling is below the simulated lower limits throughout the period from week 45 onwards.

The calculated lower limit is a more "extreme" limit the further from the starting point you are because you have followed the strategy without updating for a long time. At the end of the first period (Figure 6) and the second period (Figure 7), the model results indicate that more in Southern Norway has been produced than what is calculated as optimal with our models and input data.

The deviation in magazine filling and aggregated production throughout the period is just under 1 TWh for the first period and in excess of 1 TWh for the last period. This corresponds to just under one week of average inflow to the magazines from the inflow statistics for the respective periods.

The model shows the calculated lower limit for the optimal fill rate. The optimum fill rate will therefore be higher than this limit. This assessment assumes that other sizes (which the actors constantly update, such as short -term forecasts) have not provided significant information that should affect the water values during the period.

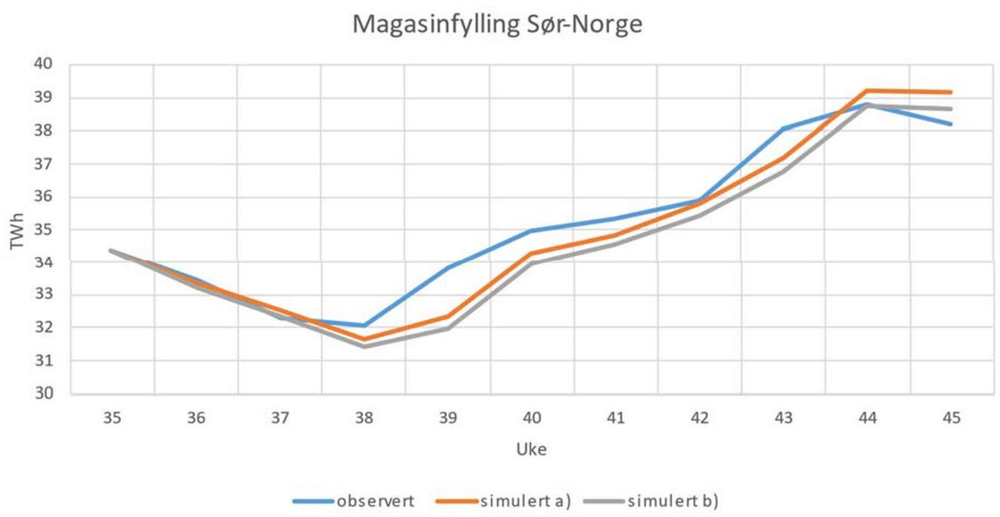


Figure 6: Simulated the lower limit for magazine filling at the end of the week compared to observed filling for week 36 and forward.

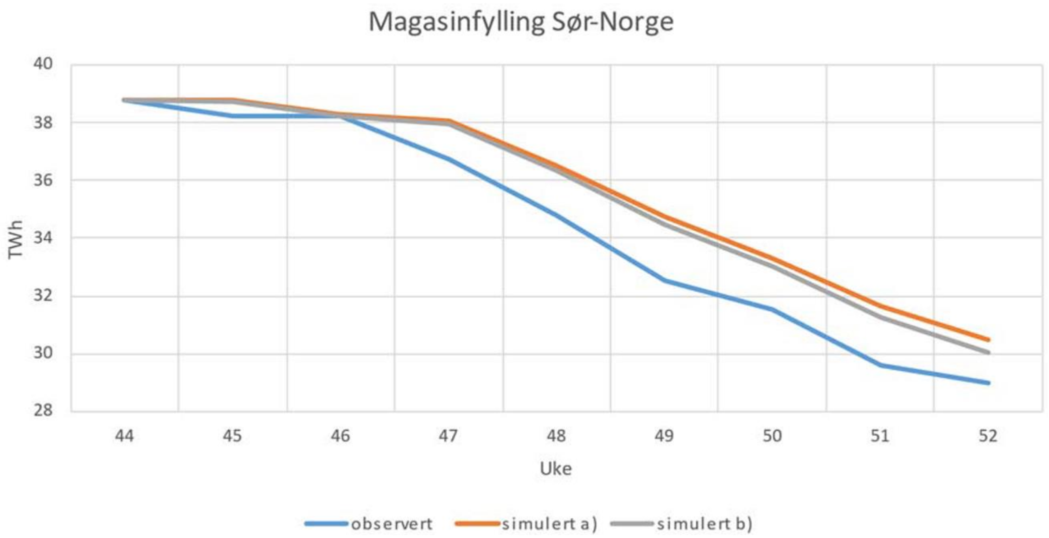


Figure 7. Simulated the lower limit for magazine filling at the end of the week compared to observed filling for week 45 and forward.

5.5 Summary of quantitative analysis of optimal versus observed magazine disposal

Based on the analyzes, we draw the following main conclusions:

• Rising European term prices in the autumn of 2021, together with an expectation of "normalization" further in the future, is an important reason for high production and thus exports from Norway. As a consequence, the fill rate remained low for the rest of the year (down to the minimum in the statistics), although the inflow was slightly above average from week 36 onwards.

• Our calculations based on our models, as well as Dataset from NVE updated with available information, nevertheless indicate that the magazines were tapped down somewhat more than what the special price trend would indicate.

5.6 Meaning of risk of disposal of hydropower magazines

The interconnection model maximizes the expected socio -economic profits. This provides an optimal adjustment if a neutral attitude towards risk. However, our analysis has shown that production the last part of 2021 was somewhat larger in Southern Norway than the model calculated as a socio -economically optimal production. In the analyzes presented above, we have not explicitly taken into account risk management. If a calibrates the model based on magazine disposal, which is common with manual calibration, instead of socio -economic profits used for automatic calibration, then the calibration will indirectly also take into account risk.

6 consequences of cables to Germany and the UK

6.1 Method of analysis

The interconnection model is also used to assess how the cables for Germany (Nordlink) and the UK (North Sea Link) affected the magazine disposition and electricity price in Norway in the fall of 2021. To investigate this we have made simulations with and without the aforementioned cables, and then we have compared The results for the two simulations.

Since we are to investigate the price consequence especially for the year 2021, it would be ideal to update the dataset and strategy9 week for week in the fall of 2021 based on what was available information for different weeks. This has not been possible within the framework of the project. We have therefore chosen not to update the strategy during the analysis period. We have also assumed that the future development in European prices from week 36 2021 to week 25 2022 was known information. The prices for the rest of the planning periods are as originally assumed in week 36, see Figure 10.

6.2 Results for magazine disposal

The results for optimal magazine filling in Southern Norway are shown in Figure 8 and Figure 9. The analyzes are based on simulations with automatic calibration. It is clear from the figures that the magazines are drained further into the case where the cables are included (Figure 8) than in the case where the cables are not included (Figure 9). For example, compare the average magazine filling just before the spring flood. The reason for this is that one has the opportunity to import more when there is little inflow if the cables exist, and therefore one can drive the magazines further down.

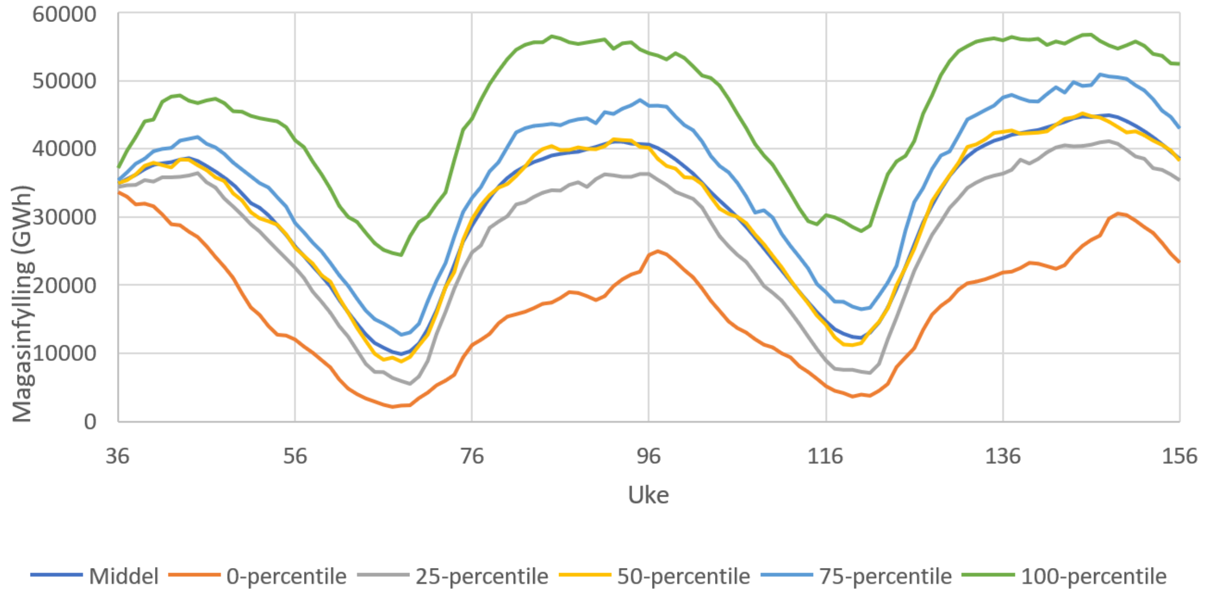


Figure 8. Percentage (0%, 25%, 50%, 75%, 100%) and average (black) for simulated magazine filling in southern Norway with existing cables against Germany and UK.

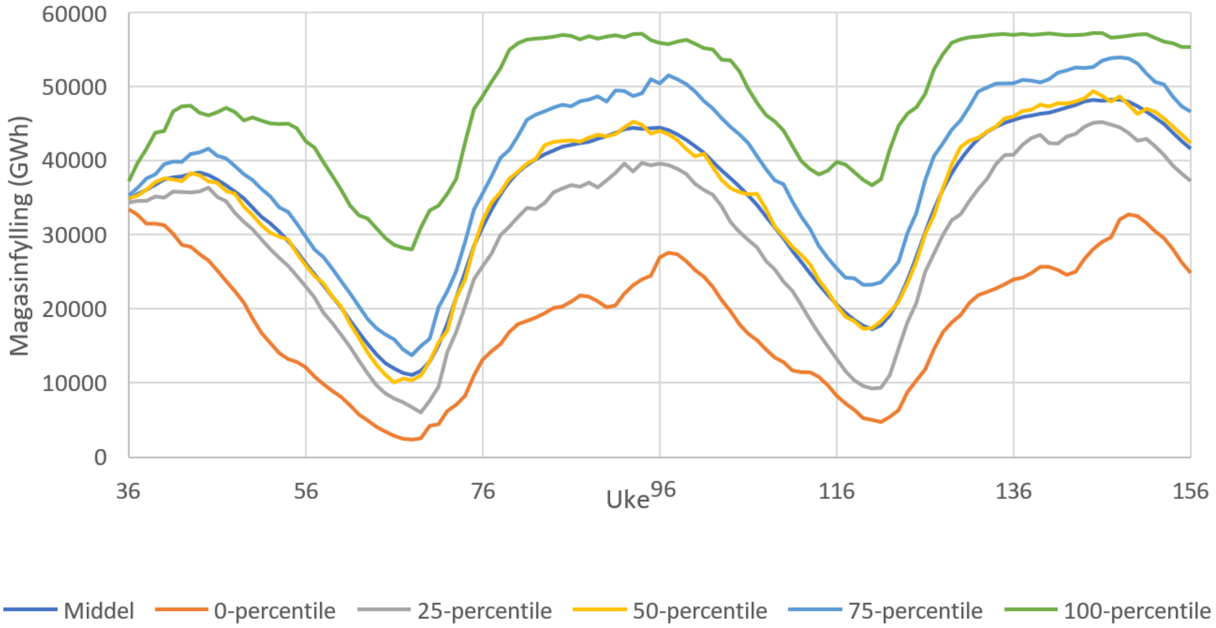


Figure 9. Percentage (0%, 25%, 50%, 75%, 100%) and average (black) for simulated magazine filling in Southern Norway without existing cables against Germany and the United Kingdom.

6.3 Results for power prices

Table 2 shows the results for power prices in price range NO1 (Eastern Norway) for simulations with and without cables to Germany and the United Kingdom. The prices in the various sub -areas in Southern Norway are quite similar and we have chosen to show only the price for NO1, which represents the largest consumption area in Southern Norway.

As mentioned, these types of analyzes will always have limitations and weaknesses. In this case, for example, it can be argued that the mistake made by treating the exogenous prices that determine is greater for the case with cables than the case without cables because the significance of the exogenous prices is somewhat greater. In addition, there are always limitations and weaknesses in both the model apparatus and the dataset that mean that the analysis cannot be perfect. Among other things, because of this, we show the results for two different calibrations for the model (qualitative manual calibration, and automatic calibration for maximum socio -economic surplus), to illustrate an outcome room of the analyzes from different calibration, and to substantiate what is the general trend in the results.

The table shows average prices for all years and weeks during the planning period together with the specific result for autumn 2021. The results show that the price in Eastern Norway in the autumn of 2021 is in the order Two cables. However, there is great variation in the price consequence depending on the year and time of the year. The variety is greatest around the end of the tapping season. The calculations are made with the condition that you know what the exogenous prices are going to be. The same assumption is used for both cases with and without cables.

Table 2. Results for price consequences of cables to the UK and Germany. Simulated prices (ear/kWh) in NO1 for different cases.

Type result strategy with cables without cables difference (%)

Week 36–52, 2021 a) Qualitative calibration 124.7 109.4 14.0

Week 36-52, 2021 b) Max socio -economic profits 124.9 99.0 26.1

All scenarios and weeks a) qualitative calibration 88.2 71.2 23.8

All scenarios and weeks b) max socio -economic profits 88.4 83.9 5.4

There is reason to believe that the price consequence of the cables of Germany and the United Kingdom (measured in ear/kWh) is larger in this analysis than if one had used exogenous prices based on a year with more common power prices in Europe.

7 Risk of similar events

Developments in the power market from the autumn of 2021 until today are extreme if you compare the price variations in the approx. 30 -year -old history of the power market, but also if one compares with what players in the power market have assumed in their short -term and long -term price forecasts.

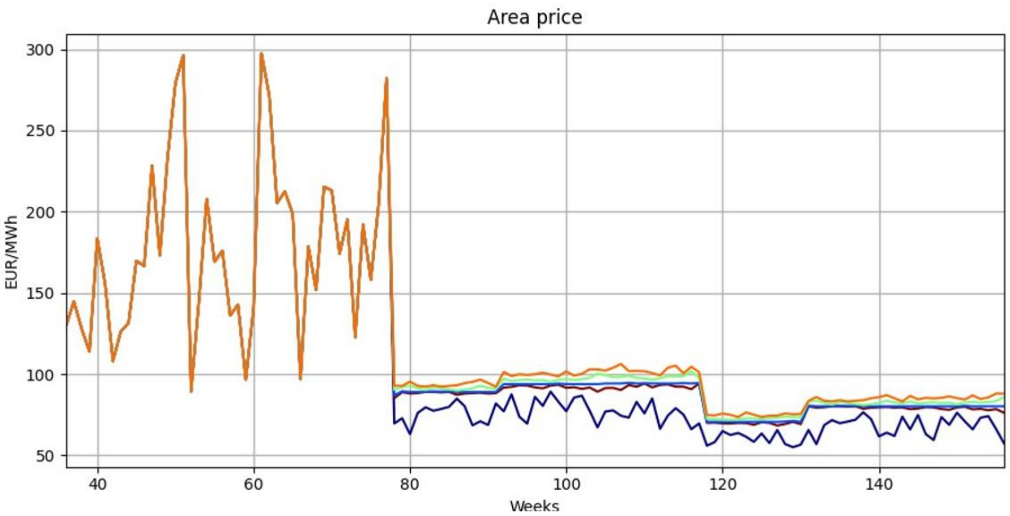


Figure 10: Price for Germany, observed from week 36, 2021 to week 25, 2022 (ie week 77 in the figure). Percentiles (0.25, 50, 75, 100 and average) for forecasted prices, seen from week 36, for the rest of the period.

An example of the large short -term variations that have been shown in Figure 10. For week 36/2021 to week 26/2022 (ie week 77 in the figure) are realized market prices. From week 78 the price forecast in NVE's data set from week 36, 2021. We see that the observed prices at the start of the planning period, week 36-77, have varied much more than the outcome room for prices after week 77.

Another example is Statnett's long -term market analysis from October 2020. There is an outcome room for gas prices from between 15 to 25 to 25 EUR/MWh for the period 2030-2040. When the report was made, the price in the Futures market for gas was 18 EUR/MWH. On the date of August 24, 2022, however, the gas price was almost 300 EUR/MWH.

The above examples illustrate that what has happened last year is far beyond what has been assumed to be the outcome room of the most important explanatory variable at the power price during the period, ie the gas price. We assume that most, if not all, players in the power market have done the same underestimation of the outcome room.

Underestimation of uncertainty affects different types of decisions. Underestimation of the long -term (many years ahead) Price security affects the investment decisions while underestimation of the more short -term price security affects the magazine disposal. Would it be decided to build the aforementioned cables if one had included a probability that what has happened to the gas price could occur in the calculations that formed the basis for decision? We do not decide on it, but expect the probability that one had added such an event and how long it comes to last will be part of the assessment. Risk of a type of HILP (HIGH -Impact -Low -Probable) event is difficult to estimate and does not necessarily have a major impact on an optimal strategy due to the low probability, but can lead to extreme situations when it appears.

Underestimation of the short -term price safety means that the magazine capacity is utilized more than would be done if greater price security was included. In general, flexible hydroelectric power plants will have higher water value at greater price security, especially at low filling degree. But the structure of the price security also has something to say.

Fundamental market models are largely used by most players in the power market. Several of these models have been good at including weather -related uncertainty, but it has been less focused on other types of uncertainty even though the interconnection model was expanded to handle a type of exogenous price uncertainty in 2010. Focus has been on weather safety because it has been And probably the most important in the Nordic power market is still in normal situations. But also because it has been relatively easy to quantify. Both variation and probability can be quantified based on historical observations. Other types of uncertainty, such as gas prices, have had less focus. If historical prices had been used as a starting point to say something about the future, the uncertainty would still be underestimated.

We believe that what has happened in recent years will in the future increase the focus on modeling uncertainty for more underlying factors. However, in some cases it will be a challenge to include this uncertainty in quantitative models, at least with existing methodology/functionality. Such extreme events that we have experienced in recent years are events with very little probability, but where the consequences can be great and partly unacceptable. There will always be combinations of events that are unable to predict or quantify. Such types of events may need measures and schemes in addition to and outside the power market.

Magazine restrictions can be regarded as a remedy that helps to some extent reduce the consequences of some such unforeseen/non -modeled events affecting the operation of the system. This will be investigated in more detail in the next chapter. Investment in several cables is in isolation, risk -reducing in relation to weather -related uncertainty/variety and other unfavorable events in the Nordic system. The weather -related utility is clear with the model tools used for decision support. But more cables also increase the impact on the Nordic power market of what is happening outside the Nordic region. The risk this entails is not included in the quantitative tools in the same way.

8 magazine restrictions

In this part of the report, we look at the consequences of introducing restrictions on the magazine disposal beyond what lies in current licensing conditions. In the surveys we use the interconnection model and NVE dataset from week 36, 2021 but updated with observed exogenous prices and exchange capacities for the period week 36, 2021 - week 25, 2022 (see also Appendix A). Because we use the interconnection model, the analyzes of magazine restrictions will not include any consequences in balance markets, system stability, etc.

The calculations are carried out based on the manual calibration, but with new water value calculation for each case.

SINTEF has also previously assessed the consequences of restrictions on magazine disposal, see Flatabø et al 10. In 2003, it was concluded that all the restriction designs that were tested on average resulted in higher prices due to greater flood losses and reduced production. All the extra restrictions reduced the socio -economic profits. As expected, this is from the theory, as an optimization problem will always result in poorer lens function if adding new restrictions. But a few of the restrictions resulted in marginal rationing.

The power system and the electricity market have changed significantly since 2003, among other things, the proportion of unregulated renewable production has increased and the connection between the Nordic and Europe has grown stronger. The price level now is also much higher than it was the last time such analyzes did. In addition, we are now trying to quantify the possible benefit of the magazine restrictions if an event (outcome of lines) occurs that has not been planned for. We analyze whether there is a difference between whether the restrictions are linked to individual magazines or whether they can be placed freely to a greater extent. Finally, we examine whether there is a difference between whether the restrictions are designed as "hard" or "soft" restrictions. Hard magazine restrictions are magazine restrictions that must be met, ie that the disposal must be planned in advance so that the restriction is adhered to for all years. A soft restriction only means that you cannot drain from the magazine if the filling is below the requirement at a given time, but you do not need to dispose of this in advance of the restriction period.

8.1 Restrictions per area

First, we test the consequence of restrictions at one -magazine level11 in the interconnection model. That is, the requirement is defined at the sub -area level and the model can even distribute the requirement for the individual magazines in the sub -area in such a way that it costs as little as possible for the system. Such a requirement is not available today, but can be implemented for a geographical area e.g. in that the requirement is purchased at an auction and then continuous trade in trade in shares of the magazine requirement.

In order to trade with magazine requirements, the actors must calculate the value of the requirements. The players have p.t. Not decision support tools that make it possible to plan the operation in relation to magazine restrictions that apply to the sum of selected individual magazines. It is possible to implement in the tools used, but because these types of sum restrictions do not exist today, no functionality is implemented to handle it in today's decision support tool.

The single -magazine restriction we test is defined as follows:

- The restriction applies from the start of each year to week 11. Ie. The restriction applies to the weeks 53-63 and 105-115 in simulation. The purpose is that this will help to make more water in the magazines available for production towards the "spring bin" which is approx. week 17.

- In sum, the requirement is 8 TWh, ie 14.1 % of the magazine capacity in Southern Norway, which is distributed proportionally with the magazine capacities in each sub -area in Southern Norway. No magazine requirements are defined for other parts of Norway than Southern Norway.

Results for price and magazine handling

The following figures illustrate the effect of a single -magazine restriction. Figure 11 shows the main effect on magazine disposal. The figure shows a comparison of simulated minimum magazine and average magazine filling for the cases with and without the restrictions as well as the restriction inserted. Figure 12 and Figure 13 show all percentiles for simulated magazine filling in Southern Norway.

Simulated minimum filling in week 63 (last week of restriction in year 2) increases from 4.1 TWh in the case without the restrictions to 8.1 TWh in the case with restrictions, see 0 -percent in Figure 11. The average magazine filling for the first spring culination is 9.9 TWh and 10 TWh respectively For the cases without and with the restrictions, see the lowest point for the average filling for reference case and case with restriction in Figure 11.

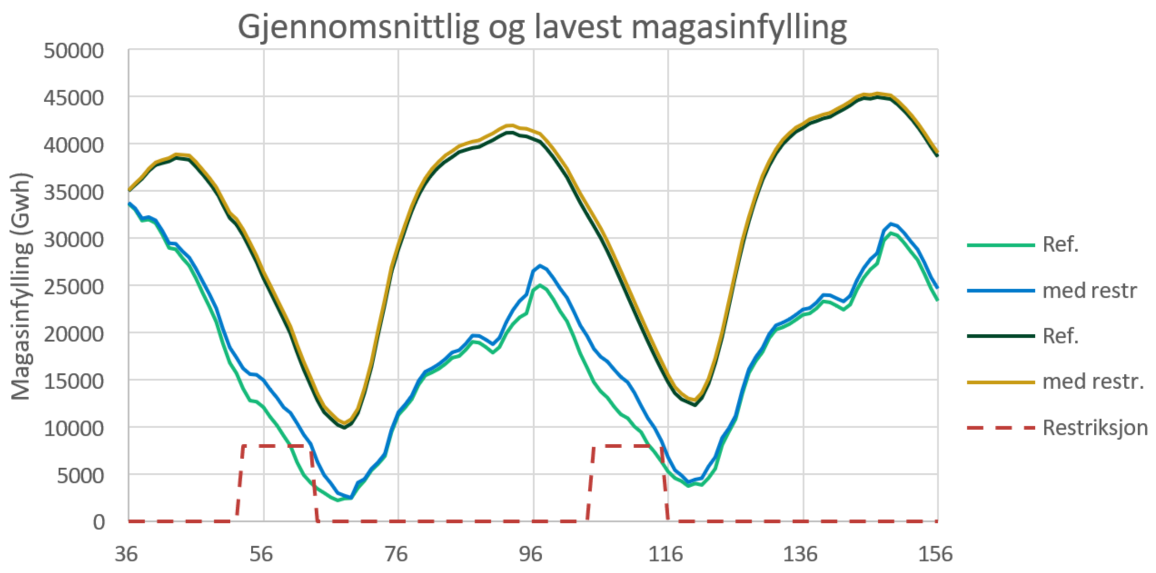


Figure 11: Comparison Magazine Handling in Southern Norway of 0 -parsentiles and Average for Case with ("With Restr.") And without magazine restrictions ("Ref.").

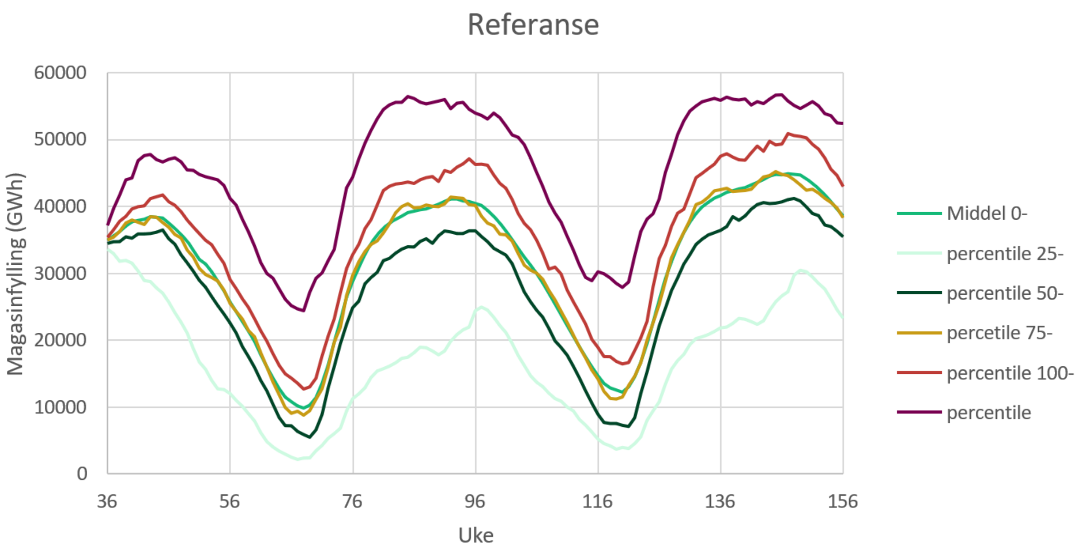


Figure 12: percentiles (0, 25, 50, 75 and 100) and average for simulated magazine filling in Southern Norway without magazine restrictions.

With single -magazine restriction

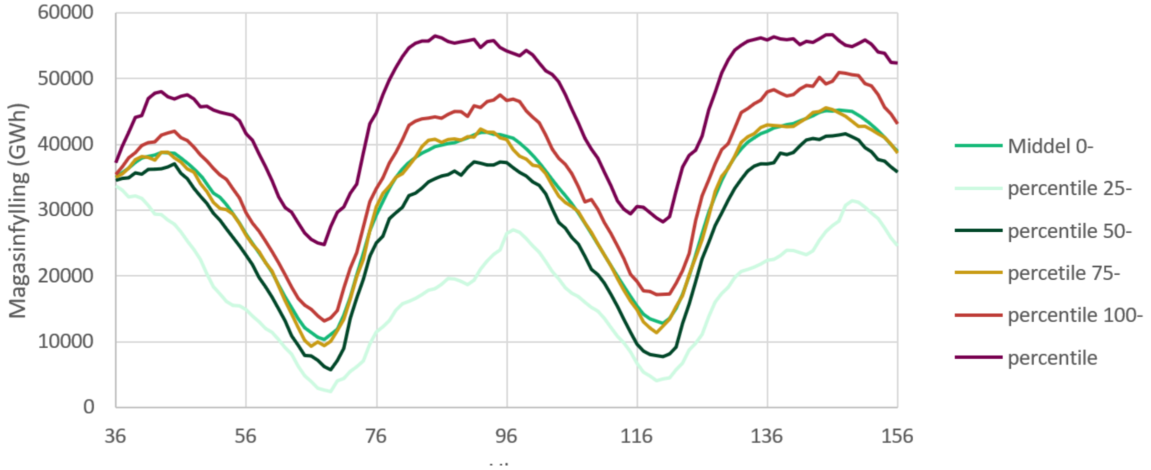


Figure 13: percentiles (0, 25, 50, 75 and 100) and average for simulated magazine filling in Southern Norway with minimum restrictions at one -magazine level.

Figure 14 shows percentiles of simulated prices for the case without single -magazine restrictions. Prices for the case with restrictions are shown in Figure 15. The calculations show that the socio -economic profits are reduced by NOK 314 million in total for the entire planning period if the magazine restrictions are introduced at one -magazine level. The planning period is from week 36 in 2021 to week 51 in 2023 (week 156).

The average price for the entire planning period then increases from 88.4 to 88.7 øre/kWh for sub -area Ostland. In addition, a clear fall of the highest price percentage can be observed at the end of the restriction period in case with single -magazine restriction.

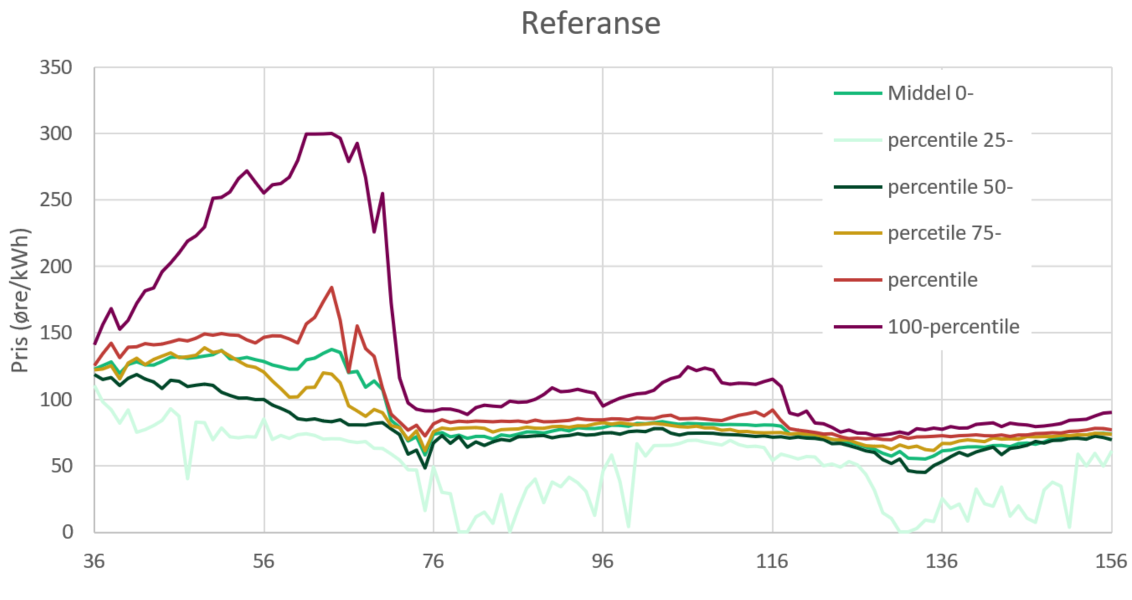


Figure 14: percentiles (0, 25, 50, 75 and 100) and average for simulated prices in Sub -area Ostland in reference case (without extra magazine restrictions).

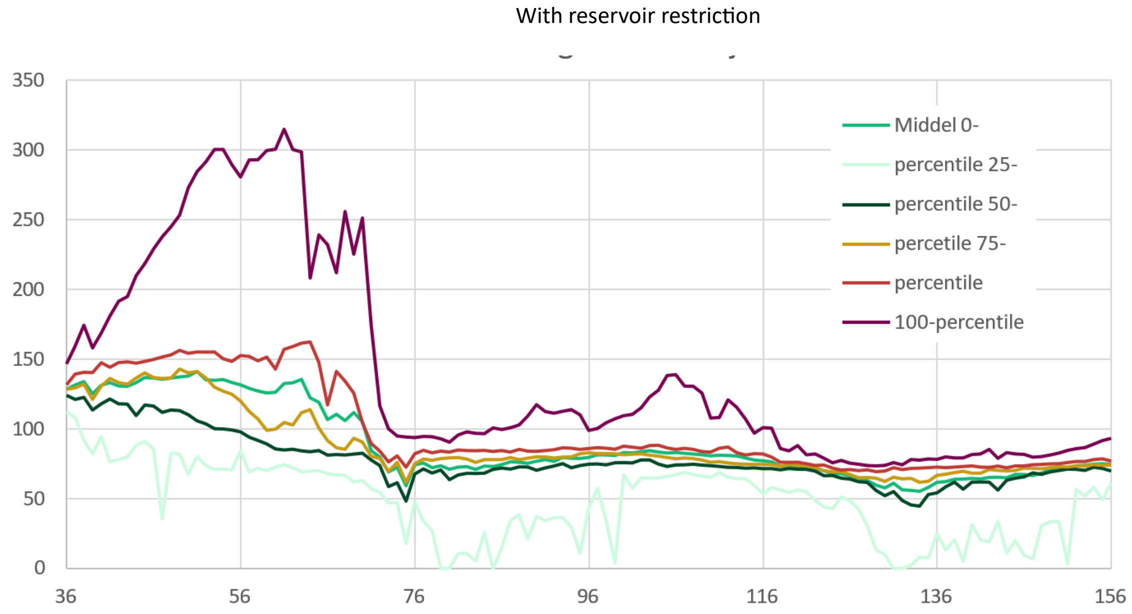


Figure 15: percentiles (0, 25, 50, 75 and 100) and average for simulated prices in Sub -area Ostland with single -magazine restrictions.

8.2 Restrictions on individual magazines.

This chapter describes the result of simulations where the magazine restrictions are linked to individual magazines. The requirement is the same as in the previous chapter, ie a minimum of 8 TWh in total for Southern Norway for the period week 1 - week 11 each year during the planning period. We have chosen to put the individual magazine restrictions on the 24 largest magazines in Southern Norway sorted by stored energy. Blåsjø is the largest of these magazines with a storage capacity of about 7.8 TWh, black water in the Sira -Kvina system is the second largest with a storage capacity of about 2.9 TWh. In order to achieve the requirement of 8 TWh, these magazines must have a minimum requirement for filling of 25 % of maximum magazine filling during the restriction period, if we assume the same percentage requirements for filling in the selected magazines. A requirement for 25% filling narrows production flexibility from the largest magazines, which can have significant consequences beyond the social economy and rationing that we illuminate afterwards.

We have looked at two different cases. In the first case, the individual magazine restrictions are defined as hard, that is, one must plan in advance to comply with the restrictions. In the second case, the restrictions are defined to be soft, which means that you do not need to plan ahead of the restriction period, but the tapping must stop if you are below the claim during the period.

Figure 16 shows a comparison of simulated minimum magazine for the various restriction cases together with the case without restrictions, ie the reference case without special restrictions, case with restrictions defined at one -magazine level, and the two new cases with individual magazine restrictions. Simulated lower magazine levels are raised for all the restriction cases and we see that the hard magazine restrictions raise the magazine more than the soft restrictions. Observations are as expected. In week 64, the hard restrictions raised the minimum magazine with 5.4 TWh compared to the case without restrictions. The case with single -magazine restrictions results in a maximum increase of 4.8 TWh for week 62 while the soft restriction gives a maximum increase of 4.7 TWh for week 64.

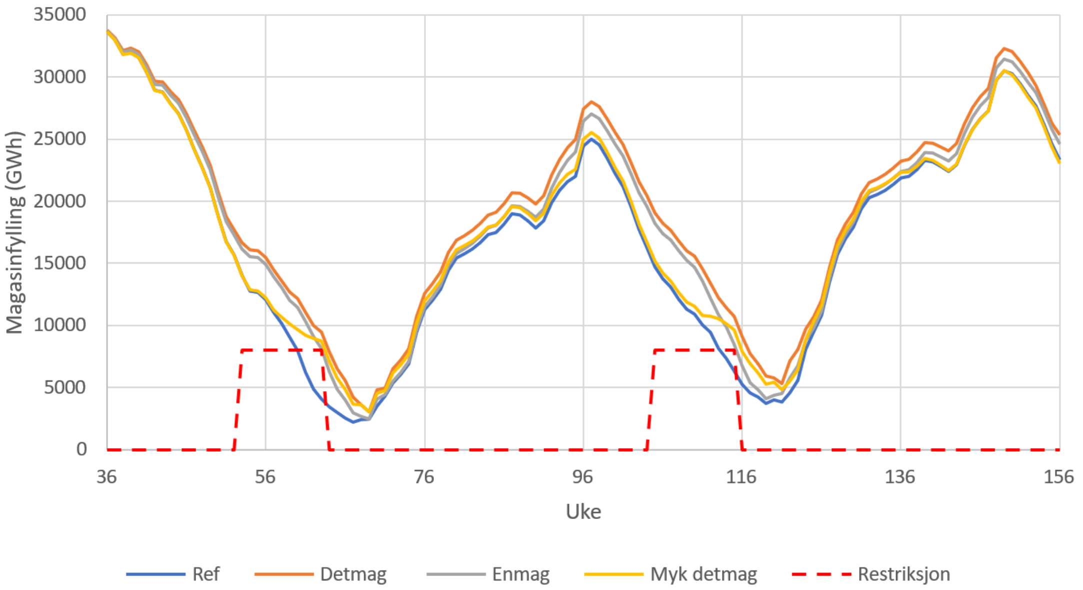


Figure 16: Simulated minimum magazine in Southern Norway for the original case along with three cases with three different magazine restrictions (ref = without restrictions, enemag = restriction on the entire area, not on single magazine, soft detecly single magazine).

Figure 17 shows percentiles for simulated prices in the section Ostland for the case with hard individual magazine restrictions. Prices rise significantly for over half of the simulated scenarios at the end of the first tap period. This is because the restrictions limit production ability. Possibly model -technical properties/weaknesses, which make you not see the restriction in time, also contribute to this. As is well known, the interconnection model is not a formal optimization model, but a model that uses formal optimization with several levels of heuristics to arrive at the solution. We will return to this in the chapter that deals with fansi12 results.

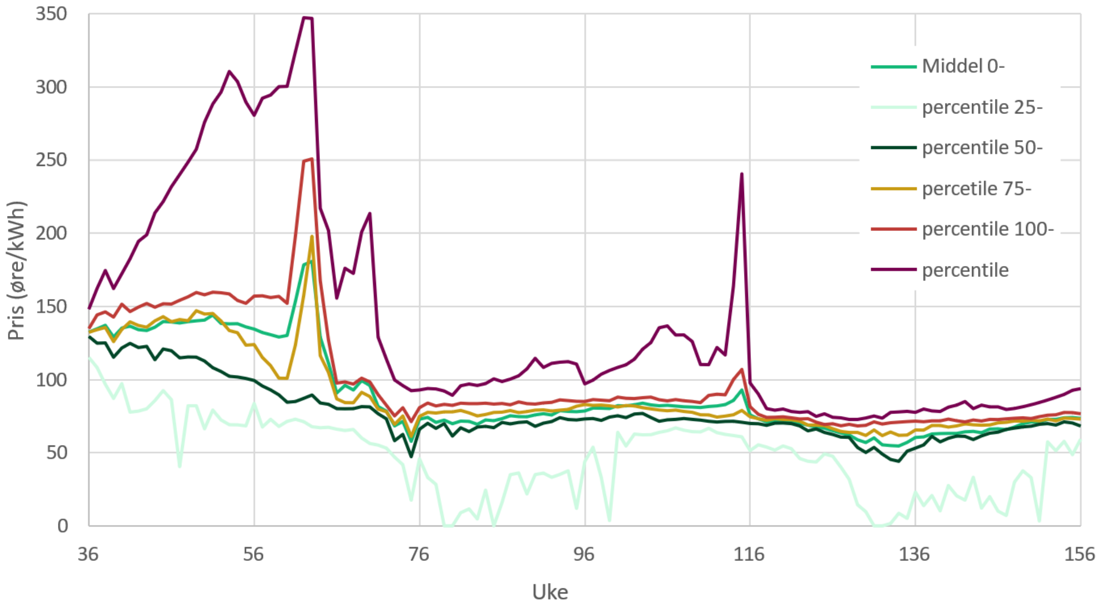


Figure 17: Percentage of simulated prices in Sub -area Ostland for the case with hard individual magazine restrictions.

Figure 18 shows simulated average prices for all restriction cases. The single -magazine restrictions result in a general increase in the price level during the winter period and slightly lower prices after the restriction period is over. The hard individual restrictions result in a slightly higher increase in the winter price in advance of the restriction period, significantly higher price increases at the end of the restriction period and a decline in price after the restriction period is over. The soft restrictions do not change the price change in advance of the restriction period, but the highest price increase during the restriction period and lower prices after the restriction period is over. In summary, one can say the one -magazine restrictions produce less price consequences because you then have a greater flexibility to place stored water where it costs at least. The one -magazine restriction provides the lowest minimum filling, but the requirement is complied with for all types of restriction.

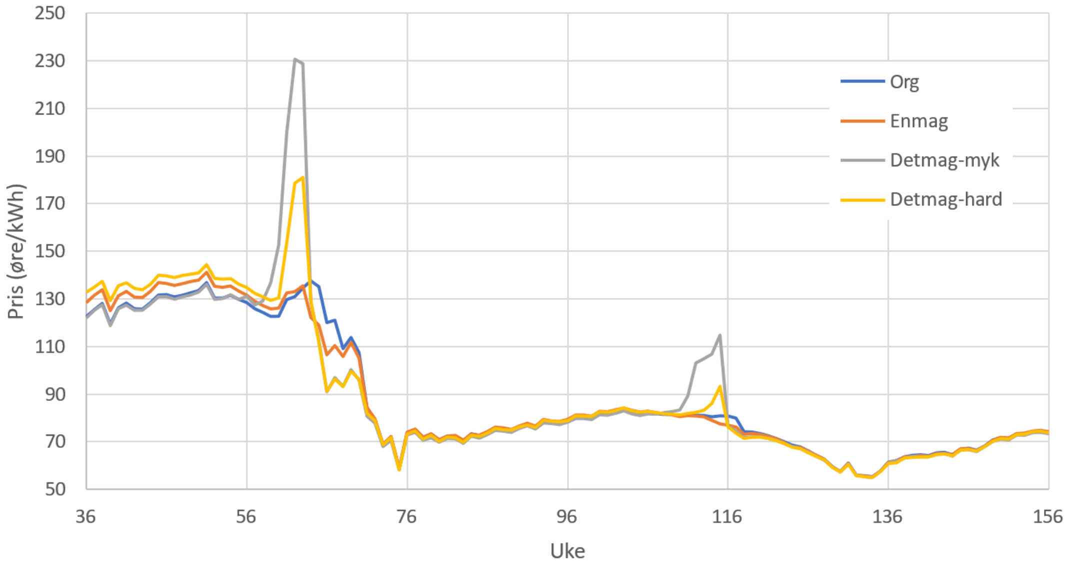


Figure 18: Comparison of simulated average prices for price range of Ostland for the various restriction cases. (Ref = without restrictions, one -magic = restriction on the entire area, not on single magazine, damag -soft = soft restrictions on single magazine, Detmag -hard = hard restrictions on single magazine).

In parallel simulations with a relatively short planning horizon (week 36-156), the value of the magazine fillings at the end of the planning period will constitute a not insignificant value and must be taken into account in a comparison of the socio -economic profits for the various cases. When comparing case with and without magazine restrictions, this value can make a larger difference between the cases. Based on how the restrictions are defined, the technical calculation of socio -economic profits has some properties in the valuation of the final magazine that is specific when compared to the case with hard individual magazine restrictions with the other cases. We have therefore chosen not to focus on the differences in socio -economic profits in the results presented except for the case with single -magazine restrictions as shown in the next chapter.

The calculations of socio -economic profits we have made where we try to correct for the said property indicate that the individual restrictions cause greater socio -economic losses than the single -magazine restrictions and that the hard individual restrictions cause the greatest loss.

Quantification of socio -economic cost with various restrictions is best done by means of series simulation due to the following:

- Any discrepancies between starting magazine and final magazine are divided by the number of years because the final magazine is equal to the starting magazine for the next year in the series simulation except for the first year. The importance of any deviations is therefore much smaller than for parallel simulation where starting magazine and final magazine are different for all the years.

- If you simulate twice, you can take the final magazine from the first simulation and use as a starting magazine for the next series simulation. There will then be no deviation between start and final magazine.

- A series simulation is typically done for a static symmetrical system where the water values at the start of the first week of the year are equal to the values at the end of the last week of the year. Start magazine and final magazine are then valued based on the same water value.

We have therefore performed a series simulation based on the last year in the NVE dataset. For the dataset, the series simulation shows that even without magazine restrictions, you will have more than 8 TWh at the end of week 11 (see Figure 19), which is the last week of the restriction period. Therefore, the restriction is not binding, and the series simulation therefore does not provide any costs for the various restrictions. Based on this, we can conclude that a minimum magazine restriction of 8 TWh from week 1 to week 11 for Southern Norway is not a very strict restriction in a normal situation. This also supports previous observations, where only the lowest percentages for magazine management are raised.

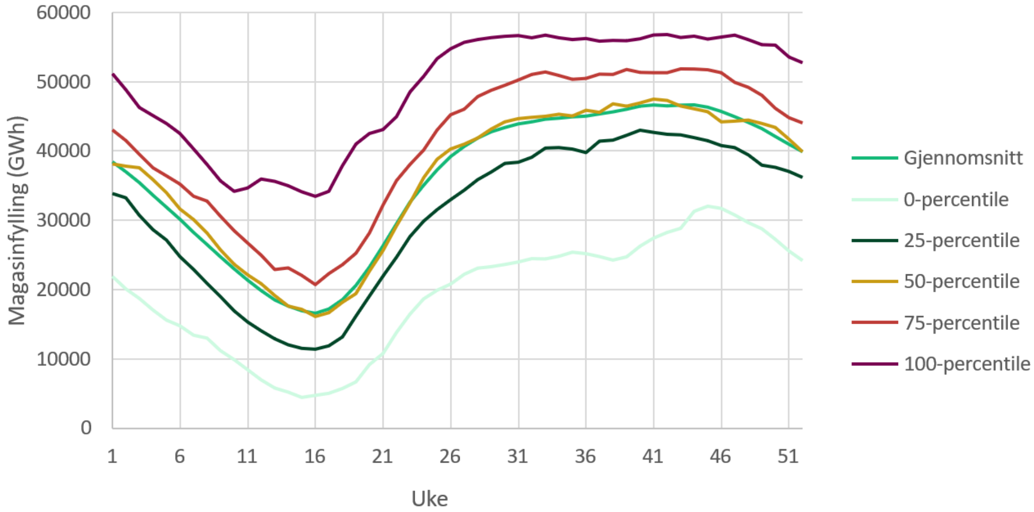


Figure 19: percentiles (0, 25, 50, 75 and 100) and average for simulated magazine filling in Southern Norway for a series simulation for the year 2023 in the NVE dataset.

8.3 Magazine restrictions and a non -scheduled event

In an optimization model, extra (binding) restrictions will always provide a poorer lens function. Extra magazine restrictions therefore provide a lower calculated socio -economic surplus in the interconnection model. Sometimes, however, additional assessments must be made because not all factors can be taken into account in the model. For example, the model with all imaginable fakes does not have. In the data set we have used, the modeled uncertain factors are weather safety based on the History 1981-2021, and uncertainty in the exogenous prices outside the Nordic

Prices increase when introducing magazine restrictions. We can estimate the socio -economic cost of the restrictions by comparing calculated socio -economic profits with and without the restrictions. For the case with one -magazine restrictions, this cost is estimated at NOK 314 million.

The utility of the magazine restrictions is linked to both the uncertainty modeled, e.g. Uncertainty in inflow, in addition to providing a "insurance" against some types of events that are not represented in the model. It is impossible to know what the market players include in events/considerations in the decisions that eventually give the market price. Due to the complexity of the problem, the actors depend on decision -making models such as the interconnection model and in these types of models, there will be many types of events and uncertainties that will not be directly taken into account. These may be events with very little probability, but with major consequences. In the interconnection model, one can indirectly include consideration for some such incidents by calibrating the model qualitatively with regard to magazine disposal instead of socio -economic profits.

Here we exemplify the utility of magazine restrictions for an event with little probability. The incident is that all cables between Norway and Denmark, Norway and England and Norway and Germany are inaccessible from week 64 to 69. The example is as follows: We have magazine restrictions from week 53 to week 63, and the outcome happens the week after that the restriction ceases. Here we do not consider the probability that this may happen, but quantifies the utility of the restriction given that it happens.

In the calculations we use the case with magazine restrictions at one -magazine level. We make simulations with and without restrictions in combination with and without outcomes on the above -mentioned cables. The various cases are then defined as follows:

Ref

Ref outfit as ref but simulated with the outcome of cables. Water values from the ref case. Ref -MRESTR as a ref but with single -magazine restrictions.

Ref -Med -Restrap as a ref -Mrestre but simulated with outcomes, water values.

from ref -Mrestr Caset.

Figure 20 shows simulated average prices for the four cases. We see, as is also shown earlier, that the average price increases in advance of the restriction period for the cases with restrictions. If the outcome occurs, prices increase more without restrictions than with restrictions. With restrictions, you have higher magazine filling when the outcome occurs, thus avoiding high prices in the dry years. In the wet years, however, the higher magazine filling along with the outcome will result in reduced exports and lower prices.

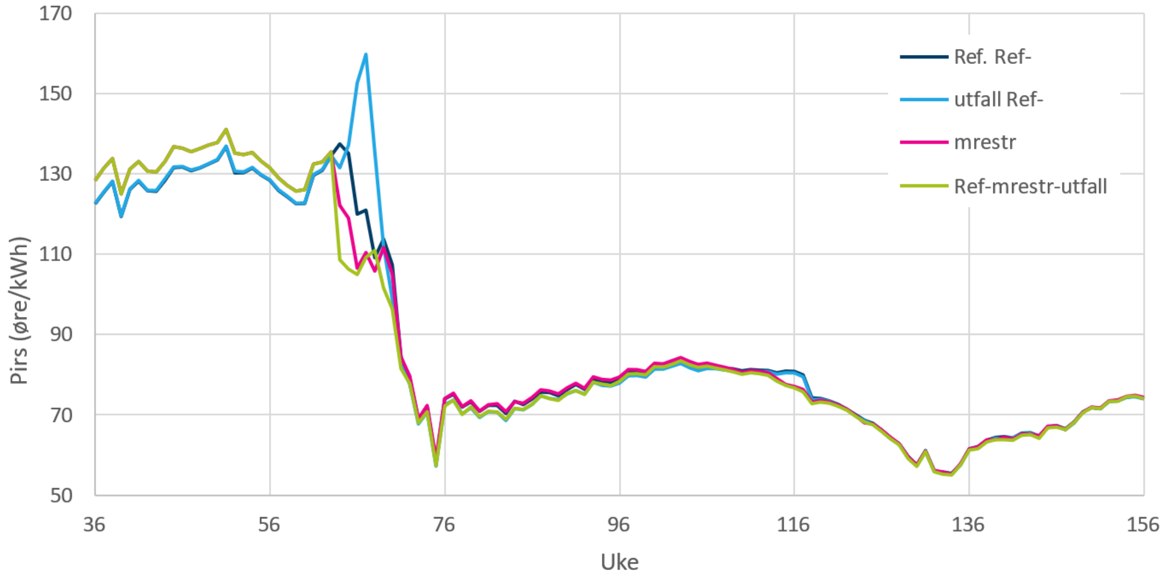


Figure 20: Simulated average prices. Ref: Without restriction, without outcome, refractory: Without restriction, with outcome, ref - Mrestr: With restriction, without outcome, ref -MRESTR's outcome: with restriction, with outcome. Restrictions are specified for the entire area, and not on specific magazines.

Table 3 shows the inflow years that result in the highest increase in the price as a result of the cable failure. We see that the year 1986 gives the biggest increase in the price both with and without magazine restrictions. The magazine restrictions result in a significant reduction in the consequences of the given cable outcome.

Table 3 Simulated maximum increase in price as a result of the outcome of the cables for the inflow years with the largest price increase. The year in the table refers to the year for the second year during the planning period (week 53-104).

Without reservoir restriction		With reservoir restriction	
Year	Price change (øre/kWh)	Year	Price change (øre/kWh)
1986	623.8	1986	524.4
2003	532.8	1985	259.1
1996	470.7	1996	132
1985	380.7	2013	95.7
2013	336.9	1999	18.8
1994	262.8	2004	9.4
1982	128.3	2016	8.1
2010	50.3	2015	7.3
1987	47.5	1981	6.3
2015	15.3	2019	5.4
2021	6	2006	5.2

Figures 21 and Figure 22 show the price change as a result of the outcomes of the cables for all the year. As shown in the table above, the highest change is observed for the 1986 lasting year.

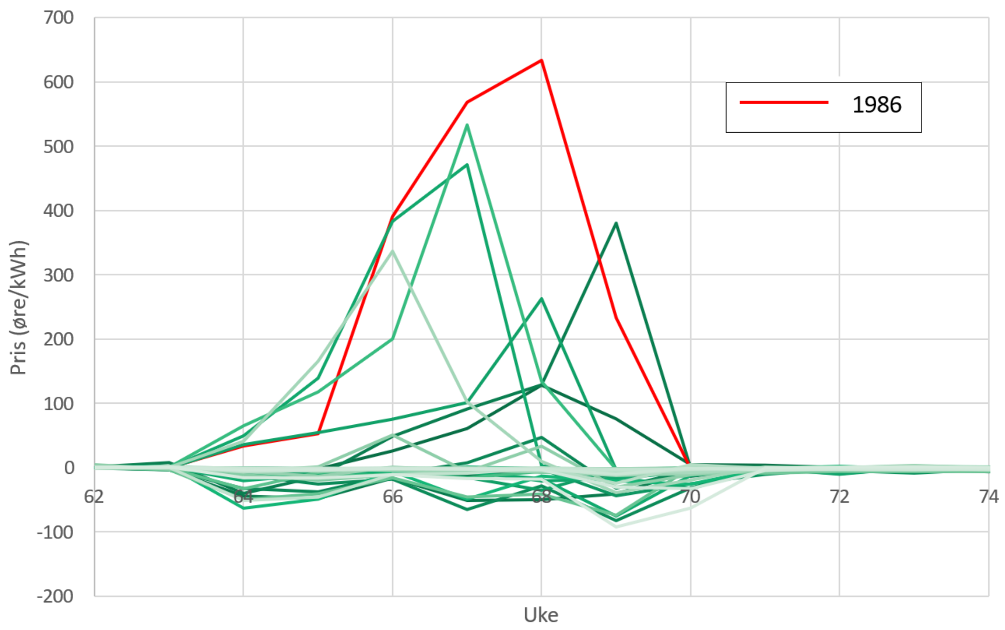


Figure 21: Change in price due to outcomes on cables for the cases without magazine restrictions. A curve per year.

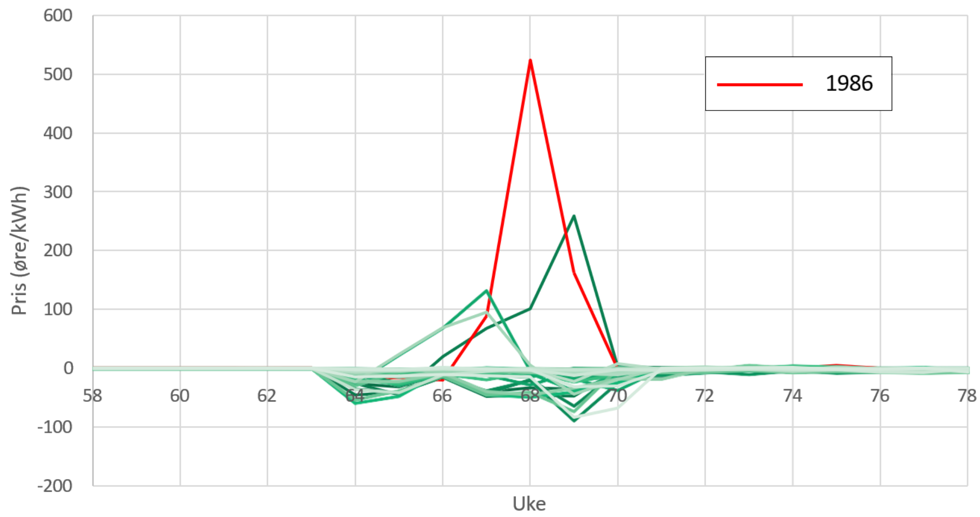


Figure 22: Change in price due to outcomes on cables for the cases with magazine restrictions. A curve per year.

Given that the outcome of the cables occurs, the socio -economic benefits of the magazine restrictions are calculated at NOK 312 million. The restrictions provide an insurance against line outcomes in the dry years. For this case, the "insurance premium" is NOK 314 million for the entire planning period.

9 consequences of increased rationing price

Recent high prices have changed many players' estimates of what price one will get for production in a rationing situation. One has also received new information on how much consumption changes as the market price increases from normal (consumption price elasticity). These sizes are important input to the market models because they affect the utility of saving the water for periods of a strained power situation. Hydropower manufacturers face a stochastic decision problem when determining production, where at any time they weigh the probability of floods and associated loss of water against the probability of dry years and associated high prices. In this problem, the sizes of the high prices will have something to say for the assessment and thus the magazine disposal. There is no public information on the rationing price and it is up to the actors to make their own estimates themselves.

The purpose of the subsequent calculation is to quantify, using an example, what the rationing price and the consumption's price elasticity have to say for the magazine disposal. NVE has also updated its estimates of these sizes after 2021.

In the original dataset, the ration price is set at xx øre/kwh. In addition, some industrial consumption has been defined in the various sub -areas that are assumed to disconnect at a price of yy øre/kWh. A price elasticity function on ordinary consumption is also defined which means that about 7 % of the consumption at "normal price" is switched off before reaching the rationing price. Simulated maximum price shown in Figures 14 and 15 is much lower than the rationing price.

We have done a test where we increase the rationing price by a factor of three, 7 % reduction in ordinary consumption is reached first at the new rationing price and the aforementioned industrial consumption is switched off at a price three times higher than originally assumed.

In the test, the dataset from week 36, 2021 is used with the forecasts that one had at that time. In these calculations, we have used automatic calibration based on the maximization of socio -economic profits for both cases. Figure 23 shows a comparison of simulated average prices for section Ostland. We see that with an assumed higher rationing price and changed price elasticity, the average price level increases somewhat at the start of the period while it is slightly lower just before the coming spring flood. This is as expected and is due to the fact that with a higher rationing price it is optimal to be somewhat more cautious about using the water during the winter period as shown in Figure 24. The consequence of running out of water in the magazines is greater. The largest change in the minimum filling is for week 54 which has 2.8 TWh higher minimum filling in the simulation with increased rationing price. This is a fairly similar raising of minimum magazine, which is observed for one -magazine restriction and hard individual restrictions, see also Figure 16.

Although, as shown in Figure 14 and Figure 15, the rationing price of the original simulation is not changed, the rationing price may still affect the magazine disposition because in strategy-

/Water value calculations also consider other possible outcomes for inflow, wind and temperature than those used in the simulations.

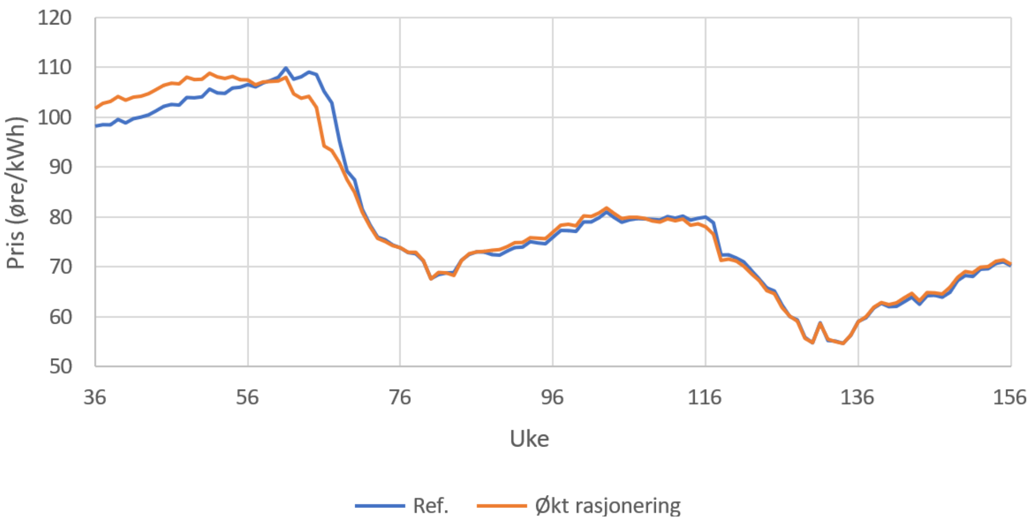


Figure 23. Simulated average prices for sub -area Ostland with original rationing price compared to the case with increased rationing price.

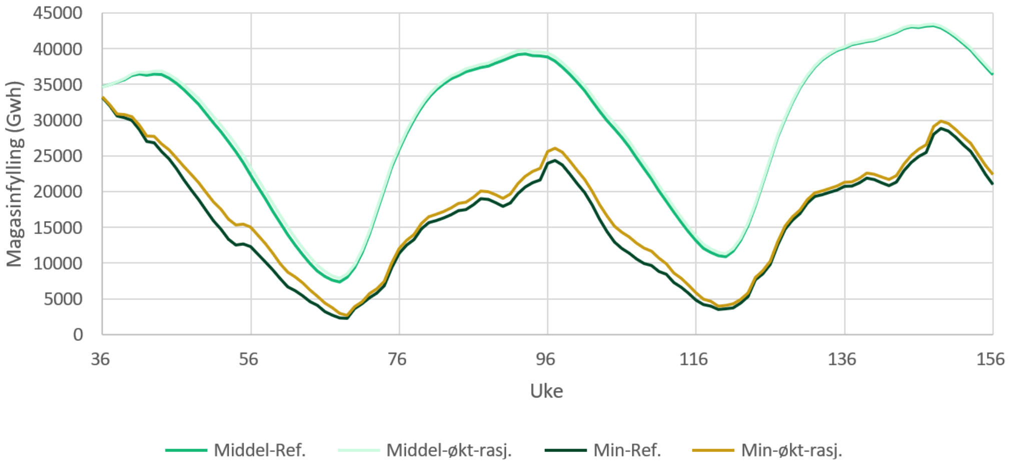


Figure 24. Simulated magazine filling (average and minimum) for southern Norway for case with original and case with increased rationing price.

10 testing of FanSi

10.1 About FanSi

Fansi13 is a research prototype market model that solves the same hydro -thermal planning problem as the interconnection model. The model was developed in the IPN project "Stochastic optimization model for the Nordic countries with individual water values and web restrictions" (FOVN) ended in 201614. Since then, the prototype has been used in several research projects carried out by SINTEF Energy (such as KPN PRIBAS15, IPN SUMEFIFT16, IPN WATERFLY17, KSP Hydroconnect18, EU Openentrance19).

FanSi runs on the same data sets as the interconnection model. In short, FanSi major benefits and a disadvantage have gathered with the interconnection model. The benefits are 1) a better modeling of short -term variability and flexibility and 2) a formal optimization of long -term magazine management, while the disadvantage is longer rain time.

The solution methodology means that the short -term flexibility of the watercourses is better utilized than in the interconnection model, for example, FanSi can optimize the short -term operation of pump power plants or similar operations for batteries. The standard version of the interconnection model can only handle seasonal pumping, but there is also a prototype version of this model that includes the inward -in -week optimization for pumps and batteries (EMPSW). FanSi uses to a much greater extent than the interconnection model formal optimization and thus provides more consistent performance changes for changes in assumptions (eg new power lines). The model does not depend on calibration and the results are thus much more than the interconnection model regardless of the user.

In the above research projects, the FanSi model is used on different versions of a dataset for Northern Europe developed at SINTEF. The data sets are run in series simulation mode that is typically used when simulating the operation of a future system where the current state (read the magazine filling today) to the system is not considered to be important. The analyzes in this report are run on the NVE's dataset and simulated in parallel simulation mode. Parallel simulation is used when conducting analyzes based on a known state. Both simulation mode and dataset are therefore new in relation to what has been the focus of previous tests.

For the dataset used in this report, the calculation time in FanSi was 1 day and 8 hours. The model is then run on a relatively powerful machine20 with the following parameter setting:

- 3 hours of time resolution in (Master) week problem (the same as used in the interconnection model)

- week's resolution in the scenariova

- 52 weeks long scenario fan

- 14 scenarios in the fan

- Planning period Week 36–156, 41 inflow years (the same as used the interconnect model)

- FanSi is run with parallel processing with the use of 61 threads, which means that 4 inflow years can be calculated in parallel.

- Cplex is used as LP solves.

The IPN project Rocket21, concluded in 2022, has analyzed possible methods to reduce the rain time of the FanSi methodology. For further information, refer to the final report of the project22.

10.2 Comparison: FanSi - the co -operation model for reference case

We run fans on the same reference case from week 36, 2021 with the original forecasts for exogenous prices and exchange capacities.

Results

Figure 25 shows a comparison of simulated magazine filling in Southern Norway. We see that the fans tap the magazine more than the interconnection model. The figure compares the manual calibration of the interconnection model. Minimum gauge filling from FanSi is 1.1 TWh in week 68 while the interconnection model provides 2.4 TWh in week 69.

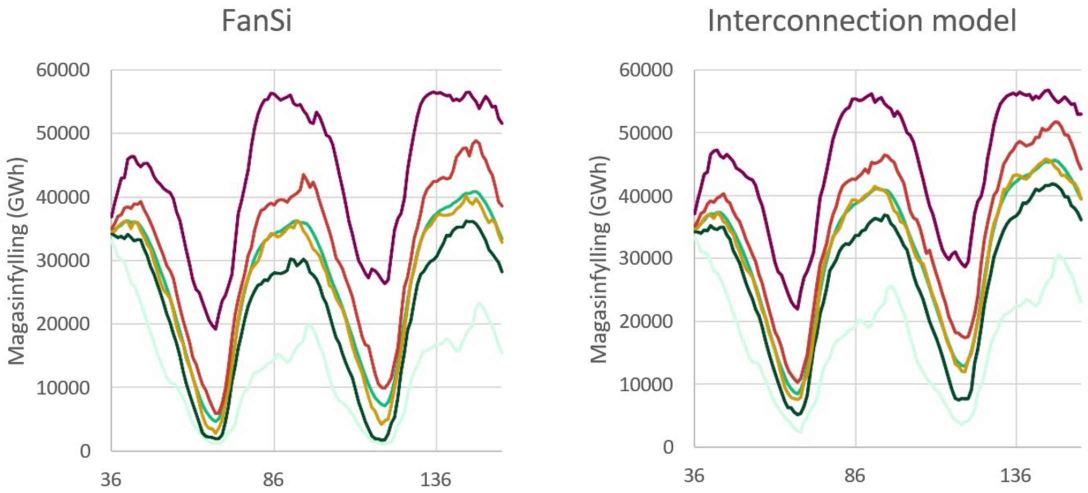


Figure 25. Comparison of simulated magazine filling Southern Norway with fansi (left) and the interconnection model (right). Percentiles (0%, 25%, 50%, 75%, 100%) and average (green).

Figure 26 shows simulated sum average magazine filling in southern Norway, Northern Norway and REST (Sweden + Finland) for two different calibrations with the interconnection model (EMP's manual calibration and empecal - automatic calibration) compared to the FanSi simulations. The most obvious difference is that the magazine disposition from FanSi for Southern Norway is significantly lower than the two different simulations with the interconnection model. More detailed key figures from the simulations with the interconnection model (manual calibration) and FanSi are shown in Appendix B. FanSi provides greater hydropower production for the planning period and less flood. Because FanSi have lower magazine filling, especially in southern Norway, it is logical that you get less flood loss. Some of the difference is also due to the fact that FanSi is a formal optimization model that manages to better utilize the relationships in the watercourses

Average reservoir filling

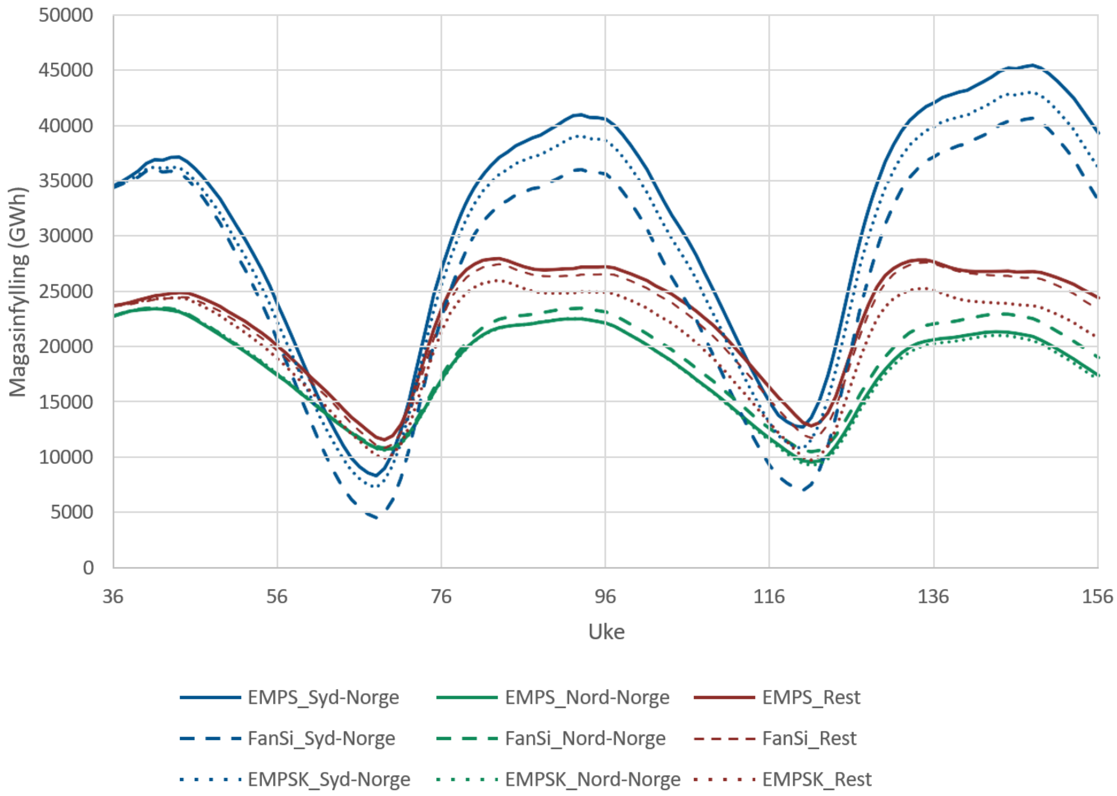


Figure 26. Simulated average magazine filling for two different calibrations with the interconnection model (EMPS and Emposk) and a simulation with fans.

Figure 27 compared simulated prices for sub -area Ostland for the same case from week 36. We see that the FanSi model gives an average of lower prices than the interconnection model, but that in the driest years the FanSi model gives a higher maximum price. This is logical based on what we have seen from the magazine disposal. FanSi is located with lower filling and in the driestest years you have less production that produces higher prices.

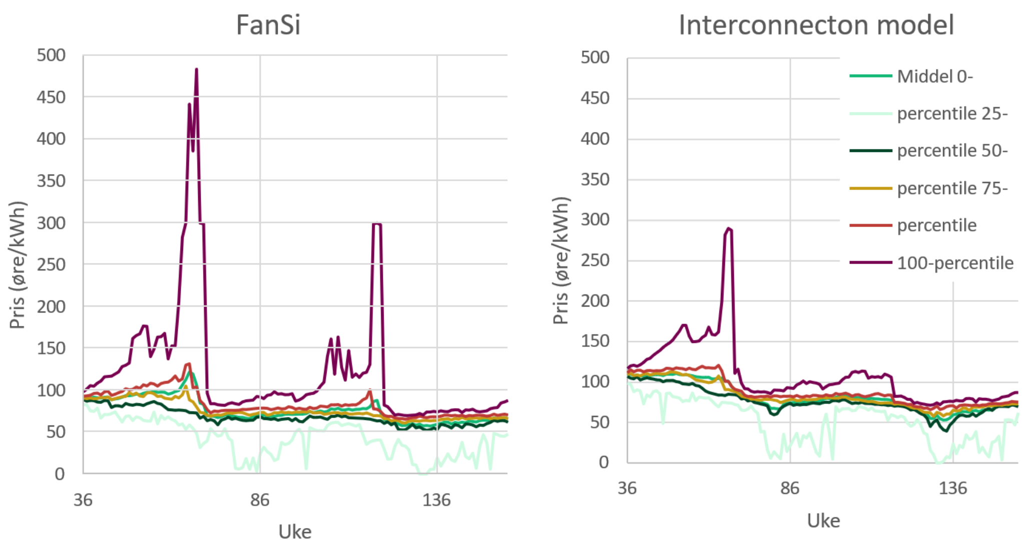


Figure 27. Comparison of simulated prices in Ostland with fansi (left) and the interconnection model (right). Percentiles (0%, 25%, 50%, 75%, 100%) and average (green).

Figure 28 shows the simulated average price for some selected sub -areas in the model. Prices are shown from both fansi and the interconnection model with a manual calibration. Fansi provides lower prices for all sub -areas except for Sub -area Ostland in the "Spring Knip". The other sub -areas in Southern Norway have almost the same average price as a sub -area Ostland.

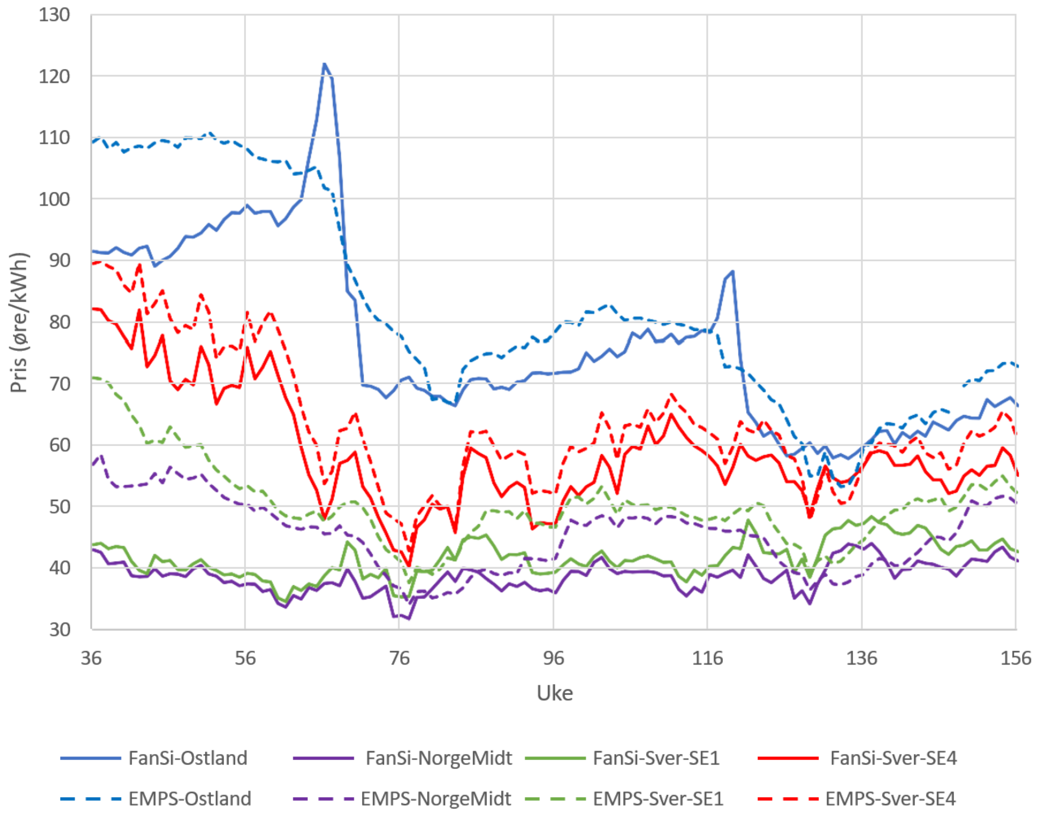


Figure 28. Simulated average price for different sub -areas using the interconnection model and fans.

The results show that FanSi are running the magazines, especially in Southern Norway, more down than what we think most users of the interconnection model would have chosen as an optimal strategy. FanSi does what is optimal for the uncertainty and associated risk that the model sees. The uncertainty is modeled using historical variation in inflow, temperature and wind and sun. The risk is given by high prices and associated costs to society.

Discussion of FanSi results

FanSi is a two -step simulator stochastically optimization problem, where the second step is represented by individual scenarios that are resolved determinist. Each scenario is basically equal to probability that corresponds to risk neutral optimization. Based on the results and compilation with the interconnection model, we consider that FanSi underestimate the consequences of the most extreme scenario. The explanation may be that the other step in the FanSi model is deterministic and that we have used weekly resolution in the scenariova, which reduces short -term variation in production and consumption during strategy calculation. This causes the water values to be too low, prices rise a little too late and you get a not insignificant average price increase during the spring knot period. Due to computational time, we have used scenario reduction to reduce the number of scenarios in the fan from 41 possible scenarios to 14 scenarios. This can also help the most extreme outcomes not represented well enough. The criterion used to choose scenarios is based on the sum of energy (inflow and wind) throughout the modeled system that does not necessarily give the weather years that give the most extreme consequences for Southern Norway. Weekly resolution in the scenariova faces means that you do not see effect problems in the same way and as early as you would do if you used fine time resolution in the scenarios. FanSi has p.t. Too little flexibility with regard to modeling of time resolution along the scenario fabric. Ideally, one will use the accumulated price section for

The power balance and week -level magazine balance in the scenarios. In our opinion, this will cause the best compromise between calculation time and necessary detail for a good result.

In a manual calibration of the interconnection model, implicit is also not included modelled risk considerations, one does not want to be lower than a given magazine level at a given time.

It is possible to introduce risk considerations in the FanSi model as well. We have already implemented functionality where you can emphasize extreme scenarios with a higher probability than the history indicates. This functionality is not used in the analysis conducted. It is also possible to include scenarios in the fan that are somewhat more extreme than those found in the statistics, such as including the year of time that is 10

% drier and wetter than that as observed. This will give a cautious disposal.

There are also theory and practical applications for modeling CAR (Conditional Value at RISK) in this type of planning models23. So far we have not considered whether CVAR methodology can be implemented in FanSi.

10.3 Consequences of cables

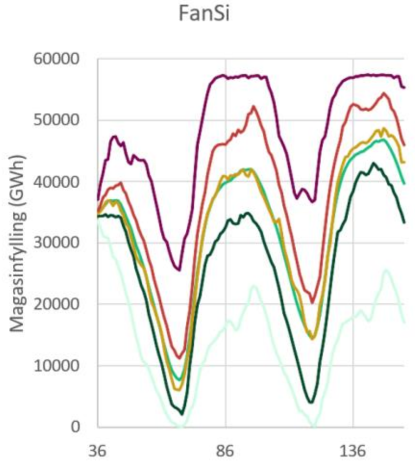
In the introduction, we mentioned that fans are particularly well suited to assess the consequences of various changes in the assumptions. In this chapter, we analyze with the help of FanSi the same case discussed in Chapter 6, that is, what is the consequence of the cables against the United Kingdom and Germany on the prices in the fall of 2021. We simulate the data set from week 36, 2021 with and without the aforementioned cables mentioned . In these simulations, it is assumed that the exogenous electricity prices and development capacities between price areas up to and including week 25, 2022 are known. These are the same assumptions used for the interconnection model The assessment in Chapter 6. The results of the price calculations are shown Table 4. We see FanSi results give a slightly larger consequence (as a percentage) than what was estimated from the manual calibration with the interconnection model.

Table 4. Results for price consequences of cables to the UK and Germany. Simulated prices (ear/kWh) in NO1 for different cases.

Type	Strategy	With cable	Without cables	Difference (%)
Uke36-52, 2021	**FanSi**	**103.4**	**84.0**	**23.1**
Week 36-52, 2021	a) EMPS, qualitative calibration	124.7	109.4	14.0
Week 36-52, 2021	b) EMPS, max socio - economic profits	124.9	99.0	26.1
All scenarios and weeks	**FanSi**	**81.0**	**60.4**	**34.1**
All scenarios and weeks	a) EMPS, qualitative calibration	88.2	71.2	23.8
All scenarios and weeks	b) EMPS, max socio -economic profits	88.4	83.9	5.4

Figure 29 compares the magazine disposal for Southern Norway from simulations with the interconnection model and fans for the case without cables. We see that although FanSi tap the magazines as much down as interconnections-

The first year model chooses fans to end up with a significantly higher magazine filling in the second year. It is reasonable that with less exchange capacity one must have a higher filling to achieve adequate security of supply. In the interconnection model, perhaps the calibration should have changed to get this well taken into account. The example shows one of the benefits of fans. The model optimizes the disposal of each case in space and time taken into account all restrictions without manual impact. In a series simulation with the interconnection model, automatic calibration could be used and thus also there avoided the manual influence.



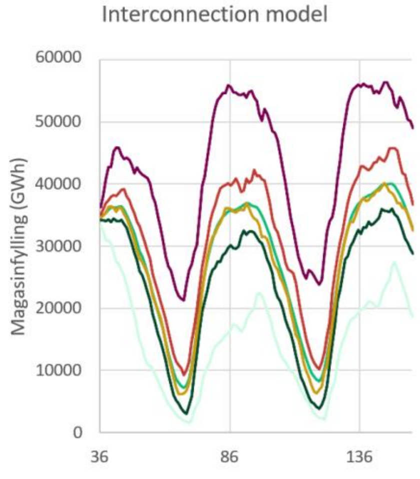


Figure 29: Comparison of simulated magazine filling in Southern Norway with fansi (left) and the interconnection model (right) for the case without cables against Germany and the UK. Percentiles (0%, 25%, 50%, 75%, 100%) and average.

Figure 30 compares fans with and without the two new cables between Norway and the UK. The figure shows very clearly that with the aforementioned cables available, the magazines are much more tapped down in the past year.

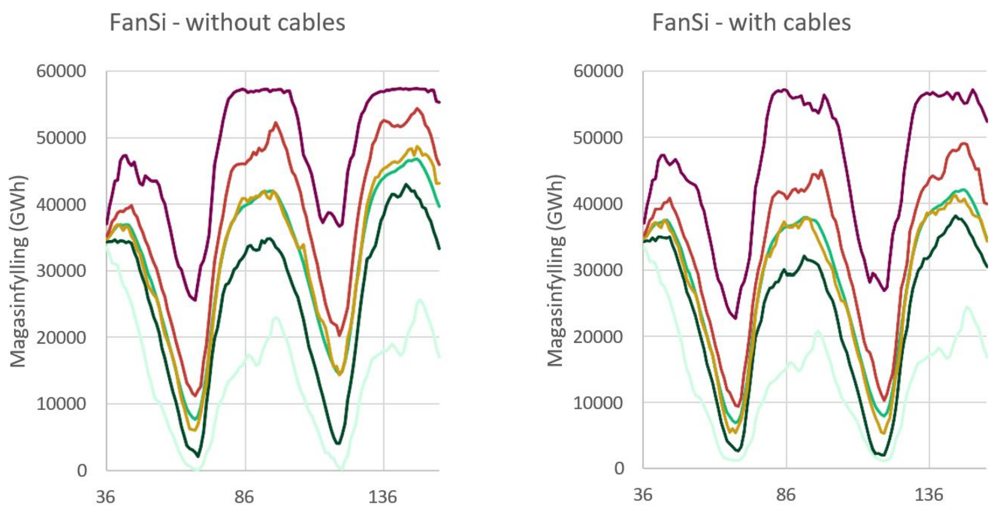


Figure 30: Comparison of simulated magazine filling in Southern Norway with the use of the fansi model for case without (left) and with cables (right) against the UK and Germany. Percentiles (0%, 25%, 50%, 75%, 100%) and average.

10.4 Individual magazine restrictions

The fansi model is used to check the consequences of individual hard magazine restrictions. These are the same restrictions described and analyzed using the interconnection model in Chapter 8.2. We have chosen to focus on individual hard restrictions because fansi p.t. Functionality has not implemented that allows modeling of magazine restrictions at aggregated level. Fansi may include soft magazine restrictions, which are most common in today's regulation, but because the interpretation of these restrictions in fansi is not quite similar to the more correct handling in the interconnection model, we have chosen to compare based on hard restrictions that have the same interpretation in the two models. Soft magazine restrictions, on the other hand, mean that tap restrictions depend on the volume of the magazine, this is a type of condition dependency that is difficult to include in optimization models and must therefore be handled in a simplified way.

The hard magazine restrictions are specified from week 1 to week 11 for each year during the planning period. During the restriction period, the minimum magazine filling is 25 % and the requirement is introduced for the 24 largest magazines in Southern Norway. In sum, the requirement corresponds to 8 TWh. Figure 31 shows simulated magazine filling for Southern Norway from the fansi model compared to similar results from the interconnection model (manual calibration). The fansi model has a simulated minimum filling in week 63 at 8.9 TWh and an absolute minimum of 1.6 TWh in week 69. Corresponding figures from the interconnection model are 9.5 TWh in week 63 and an absolute minimum of 3.0 TWh. Both models meet the specified requirement of 8.0 TWh in week 63.

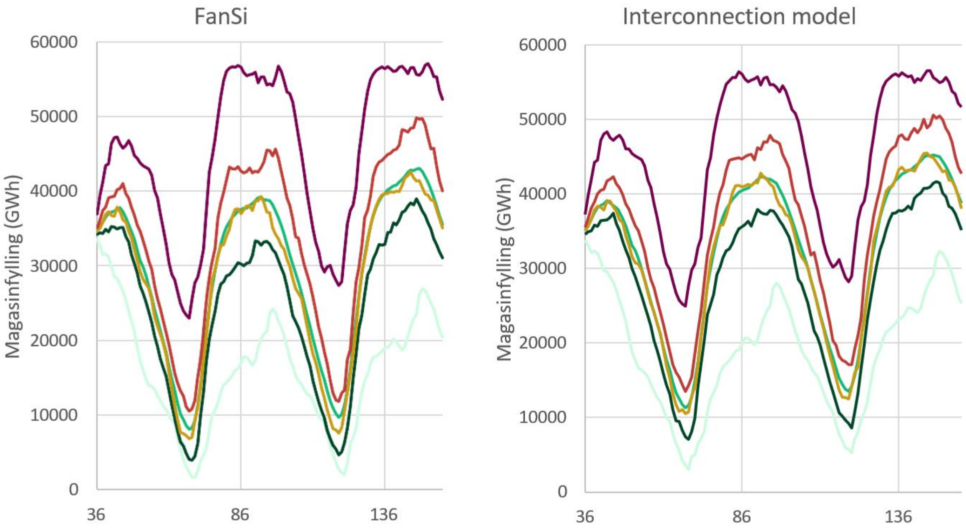


Figure 31: Comparison of simulated magazine filling in Southern Norway with FanSi (left) and the interconnection model (right) for the case with hard individual magazine restrictions. Percentiles (0%, 25%, 50%, 75%, 100%) and average

Figure 32 shows a comparison of simulated prices in Sub -area Ostland from the interconnection model and fans. We look the same as we have seen for other cases, FanSi provide an average of lower prices, but somewhat higher maximum price. This is especially clear for the first year of the planning period.

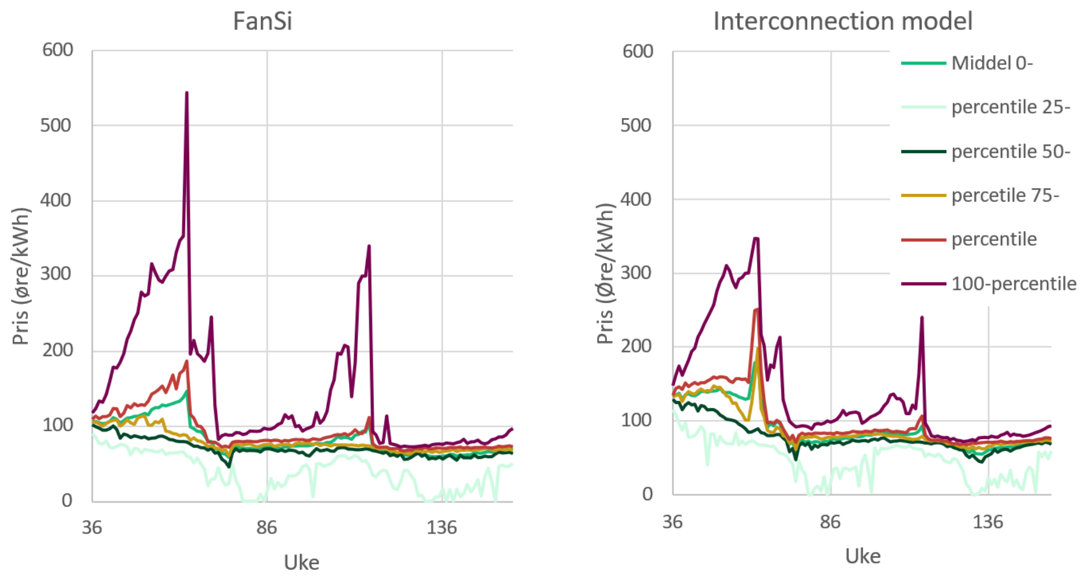


Figure 32: Comparison of simulated prices in Southern Norway with FanSi (left) and the interconnection model (right) for the case with hard individual magazine restrictions. Percentiles (0%, 25%, 50%, 75%, 100%) and average.

Figure 33 shows only the average simulated price for Sub -area Ostland. The simulated average price from FanSi is more gradually rising towards the restriction period, which indicates better planning ahead of the restriction period. This is an expected difference between the models because FanSi "looks forward" including the detailed hydropower description. The forward -looking feature of the interconnection model is linked to the aggregated hydropower description plus the logic of the tap distribution. The same difference between the models also applies in relation to planning operations in advance of audits of individual hydropower units. FanSi will to a greater extent redistribute, drain in advance of audits in such a way that the total cost of the system in the revisions is lost.

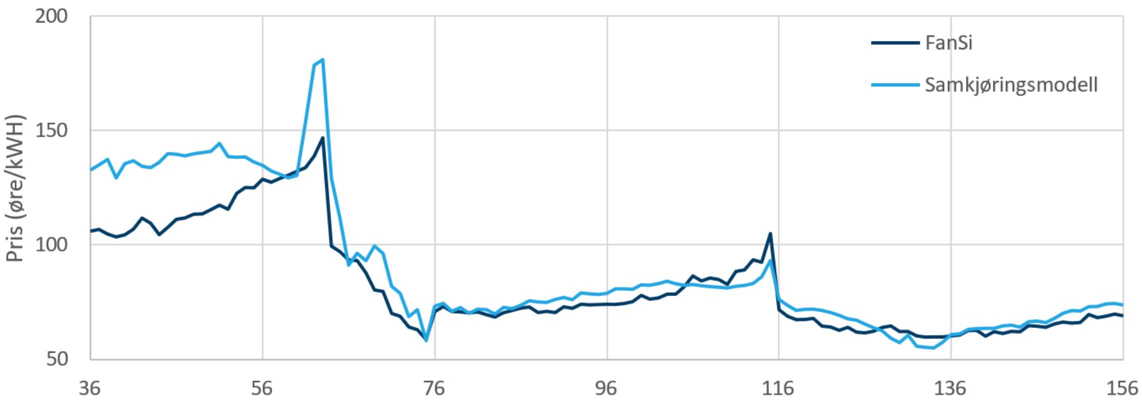


Figure 33: Simulated average prices for sub -area Ostland for the case with hard individual magazine restrictions.

10.5 Changed rationing price

FanSi has also been tested on the dataset with increased rationing price and changed price elasticity, the same case described in Chapter 9. Figure 34 shows a comparison of simulated magazine filling from fans for southern Norway for the two cases with different rationing prices. Somewhat surprisingly, the simulations do not show a clear change in the magazine disposal in the same way as the interconnection model, see Chapter 9.

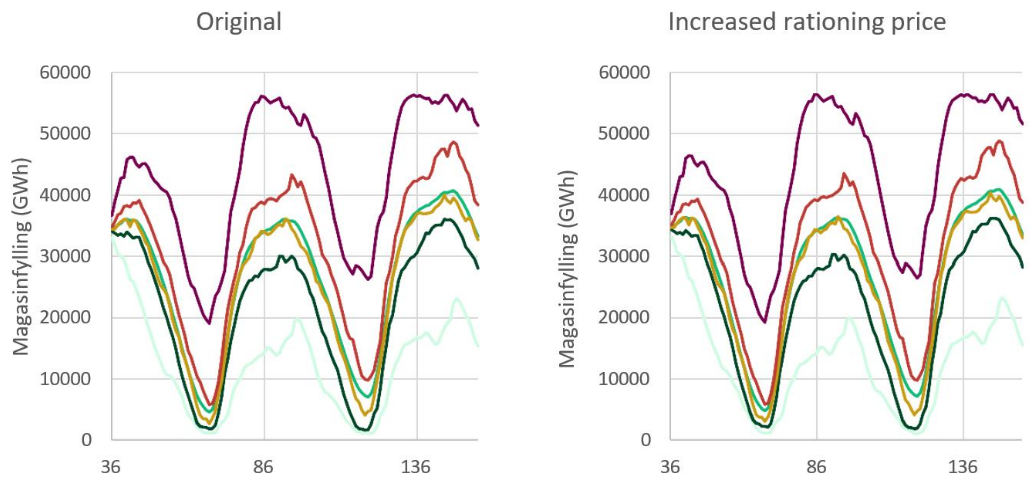


Figure 34: Simulated magazine filling with fans for original case (left) and case with increased (right) rationing price. Percentiles (0%, 25%, 50%, 75%, 100%) and average.

Figure 35 and Figure 36 show a comparison of simulated prices. We see that prices increase as the rationing price increases. This is as expected, but the profile of the price change indicates that you see the risk of energy button/rationing later than is the case in the interconnection model.

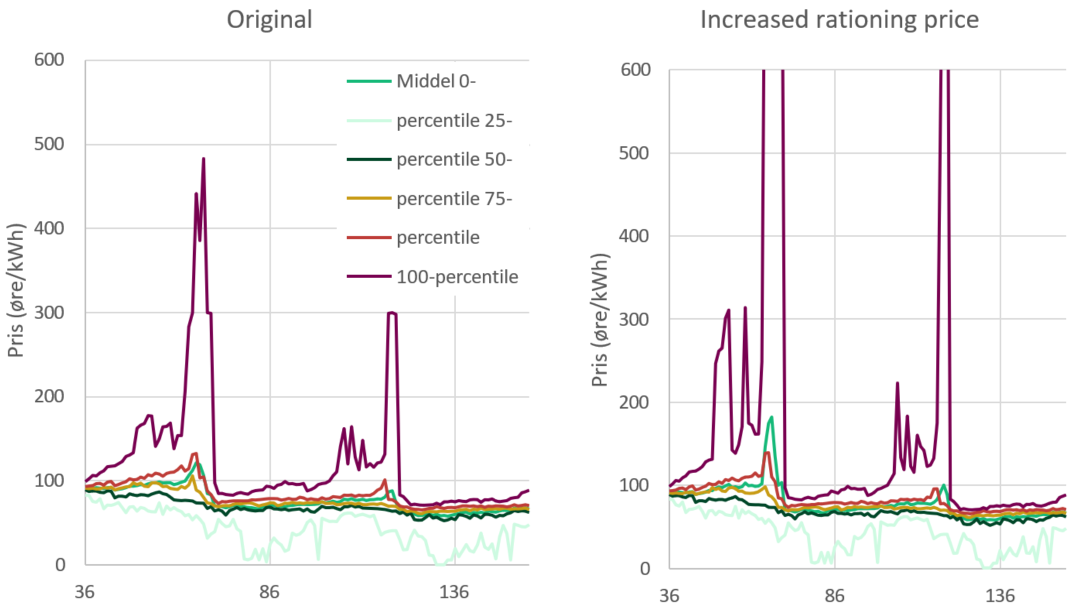


Figure 35: Simulated prices with organic case (left) and case with increased (right) rationing price. Percentiles (0%, 25%, 50%, 75%, 100%) and average.

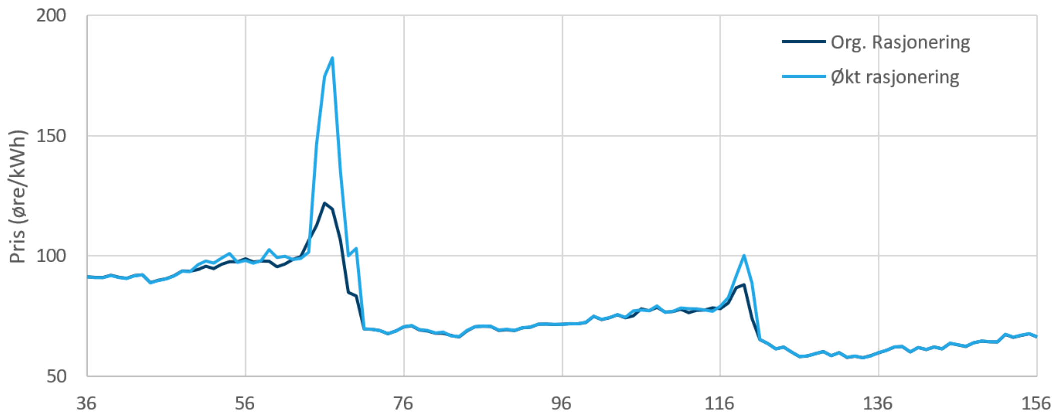


Figure 36: Simulated average prices for sub -area Ostland with fans for case with original and increased rationing price.

Prices in week 36 and until Christmas are almost unaffected by the increased rationing price and the changed price elasticity. This is probably related to the same as we discussed in Chapter 10.1. Before Christmas, none of the scenarios provide water values in the price area where prices have changed.

There may be several reasons for this:

- The scenario reduction can lead to the scenario that is most extreme and most important for the prices in Ostland is not represented. As mentioned earlier, scenario reduction is based on sum energy (inflow, wind and sun) throughout the system. A comparison of simulated prices from simulations with different numbers (14 scenario and all) scenarios in the scenario fabrics are shown in the Appendix C. The result shows that the prices are somewhat lower in the spring knot when running without scenario reduction, ie all scenarios are included.

- Time resolution. Weekly resolution has been used in the scenarios that smooth out the consumer variations within the week and hide any effect problems. The consequence of this may be too low water values in areas with low magazine filling. If fans were implemented with a greater flexibility to model varying time resolution in the scenarios, we could have avoided this.

FanSi is a simulator of two -step optimization problem which is a simplification of the real multi -stochastic decision problem. It is conceivable that this simplification is part of the explanation even though we believe that the first points are most important.

10.6 FanSi - status and further work

FanSi is a research protection market model developed for detailed operating analyzes of the future power system, a power system with a larger proportion of new renewable production balanced with different types of flexibility on production and consumption side. The model is used today in many research projects where the system is analyzed. The model has to a lesser extent been tested in analyzes of today's power system as we have done in this project.

We believe that FanSi (which includes the EMPSW) concept is the right tool for detailed analyzes of the future system. That is not to say that the model is fully researched, developed and tested. The industry should be more involved with testing on the current system so that the properties of the model are also more assessed in relation to the operation of the existing system than has been done so far.

Below is a list of issues that we believe should be continued based on the experiences we have with the use of the model, including the experiences of this project.

- Testing the model's properties on today's system in the industry. Such an activity requires follow -up from those who have developed the model and will contribute to robustization and improvements to known and unknown weaknesses. Testing should cover different types of analyzes and user needs.

- Possibility to include risk considerations in the strategy. Cvar, weighting of extreme scenarios, more extreme inflow, etc. Some of these measures need not increase the rain time. For example, more extreme scenarios can be included in the scenarios. This will make the disposal more robust without compromising the good properties of the model, or an increase in the rain time.

- The algorithm used to reduce the number of scenarios in the scenarios in FanSi is relatively simple and based PT. Only on sum annual energy for the entire system. More sophisticated reduction algorithms should be considered and tested. Implementation of such algorithms is relatively simple in the FanSi methodology.

- The model lacks functionality to use flexible time resolution along the scenariobanes. One must be able to use accumulated price sections in parts of the scenariobans and flexibility to be able to use different time resolution of magazine and power balances. This provides better utilization of available calculation time and facilitates more precision in the scenariency fee (the "water value calculation").

- Further work on reducing the calculation time. The aforementioned RAKKET project proposes several techniques to reduce rain time in the FanSi methodology. We note that the FanSi concept requires significantly more calculation time than the interconnection model, and so it will also be after the implementation of improvements proposed from the RAKKET project. This lies in the nature of the method, one tries to explicitly calculate details that in the interconnection model are simplified and adapted through model calibration.

- New methods for final valuation. FanSi uses water values from the interconnection model to set the value of the water at the end of the planning period to fans. One wants a relatively short planning horizon in FanSi due to the calculation time, but the shorter the planning horizon in the scenarios the greater importance, the end values from the interconnection model on the operation of the larger magazines get. A future goal must also be to base the final valuation on methods that use formal optimization to a greater extent, implemented in modern programming languages and packaging.

11 Conclusion

This report describes the analysis as well as results from the assignment "Assessment of the power situation 2021-22".

The following observations are made when assessing magazine disposal:

• In 2021, the fill rate was reduced from being above average before week 26 to below average and further down to the minimum fill rate in the statistics up to week 38. An important explanation for this reduction in relative fill rate may be that the inflow was much lower than average in the the period that happened. We have not analyzed this period in the assessment of magazine disposal.

• The fill rate then remained low out as much as 2021, despite the fact that the inflow was higher than normal and despite the fact that a typical should be more careful about using the magazine water when the fill rate is low. An important explanation for this is that European term prices increased throughout the autumn of 2021, while also expecting a "normalization" further in the future. It was therefore optimal to produce relatively much even if the magazine filling was already low.

• Calculations based on our models and the data sets from NVE, updated with the available data in the analysis times, however, indicate that the magazines were drained down somewhat more than what the special price trend would indicate.24

A sensitivity analysis with and without cables between Norway and Germany, and Norway and the UK show that simulated prices in Southern Norway in the autumn of 2021 are 15-25 øre/kWh higher with the two cables than without.

The extreme price trend in the fall of 2021 has not been observed before and is very far beyond the normal outcome room. We therefore expect increased focus on modeling uncertainty in underlying factors other than weather safety going forward.

Magazine restrictions can increase the system's robustness in relation to some types of uncertainties and events that are not taken into account during modeling. In some cases, they may also increase the system's robustness in relation to modeled events. An example of the last case with magazine restrictions, insecurity in inflow and reduced risk of rationing is shown in a previous report25.

The first case we have now exemplified in this report, focusing on the power situation 2021/22, by calculating the costs and utility of magazine restrictions for a case of cables. In a model like the interconnection model, we know what has been taken into account in the planning; That's what's modeled. We can thus quantify the cost and benefit of a measure given that an unplanned event occurs. In the example of minimum restrictions at one -magazine level in each sub -area, we quantified the cost of NOK 312 million for the planning period, while the benefit given the special outcome of all cables arises is calculated at NOK 314 million. In reality, you do not know what is included in the players' planning. It is also difficult to put probability on all sorts of events. Therefore, we cannot conclude what is the real cost and overall utility of magazine restrictions.

A market model can be used to compare observed magazine disposal with simulated disposal such as in part 1 of the report and thus uncover if the market works as intended.

This assumes that the market model is set up with the best possible market data. What is the cause of a possible discrepancy between model and reality cannot be directly derived, but one can investigate the importance of various factors such as the importance of rationing price.

The analyzes indicate that magazine restrictions at the aggregated level, which give the actors the flexibility to distribute the requirement freely to available magazines, gives the best result, ie the desired hedge with the minimum cost. The actors' operating planning tools, which are more detailed than the interconnection model, are p.t. Not adapted planning with sum requirements for magazine filling. SINTEF has assessed the consequences of various magazine restrictions, but not decided whether they should be introduced.

The actors' estimates at the rationing price are important for what is calculated optimal magazine disposal. Recent high prices have probably meant that the players have increased this estimate. This will provide a somewhat cautious magazine disposal. In our example, simulated minimum filling in Southern Norway increases by 2.8 TWh when the rationing price is three times higher than originally thought.

In the latter part of the report, we have tested and compared results from the interconnection model with similar results from a Prototype market model called FanSi.

The comparison shows the following:

- FanSi taps the magazines in southern Norway more down the first year than what the interconnection model did. The model also provides significantly lower prices on average.

- FanSi plans better in relation to individual hard magazine restrictions than what the interconnection model does.

- FanSi and the interconnection model provide roughly the same price effect of the cables of the UK and Germany.

Appendix A: Versions of the Datasets (A, B, and C)

We have added three different versions of the datasets, which are now called respectively. A, B and C. In the following, we describe each of these versions, as well as how they have been used. See also Table A.1.

The data sets we received from NVE, including SINTEF's update of the weather statistics, are the "A" version of the datasets. When we mention a dataset we also write which week the dataset was made for, cf. the 3 datasets we received from NVE. Therefore, the Case36-2021 -A dataset means that we have used the data set for week 36/2021, and that the A -version of the dataset has been used. The dataset shall represent the decision basis for magazine disposal with the information known at that time (ie in week 36 in this example).

In the A version of the data sets, there is a description of expectations of exogenous prices (including power prices in Germany, the United Kingdom, and the Netherlands) and available exchange capacity in the future. In the "B" version of the data sets, we have replaced this with observed values for exogenous prices and the exchange capacities used at Nordpool at the time of clearance. An optimization with the B version of the dataset therefore calculates an optimal magazine disposal with perfect foresight on European prices and transmission capabilities.

However, the motivation for establishing the B dataset was not to optimize with perfect foresight, but to investigate how the optimal disposal of the magazines becomes when the strategy (ie the water values) is calculated based on the information the actors had available for different weeks (ie strategy calculated from the A versions), while the realization of European prices and exchange capacities is set to what actually happened (ie according to the description in the B version). This is what is done in the "C" version of the data sets. Here is the strategy from the A version, while the simulation is done according to. The B version.

Tabell A.1 Description of Dataset Versions

Versjon	Description
A	Dataset with updated weather statistics (inflow, wind and sun series) until 2021. Strategy calculation and simulation run for datasets.
B	Dataset as version A, but with observed exogenous prices and exchange capacity for week 36/2021 - 15/2022. Strategy calculation and simulation run for datasets.
C	Dataset as version B, but with strategy (water values) from version A. Simulation run for datasets.

Appendix B: Key figures from the simulations with the interconnection model and fansi
Sub -areas 1-8 represent the sub -areas in Southern Norway.
The sub -areas 9-15 represent Central Norway and Northern Norway in order south to the north. The sub -areas 16-19 represent Sweden in order north to south, 20 Finland, 21-22 Denmark. Sub -areas 22-30 exogenous price areas

Table...

Appendix C: Fansi Simulation with different number of scenarios in the scenariova

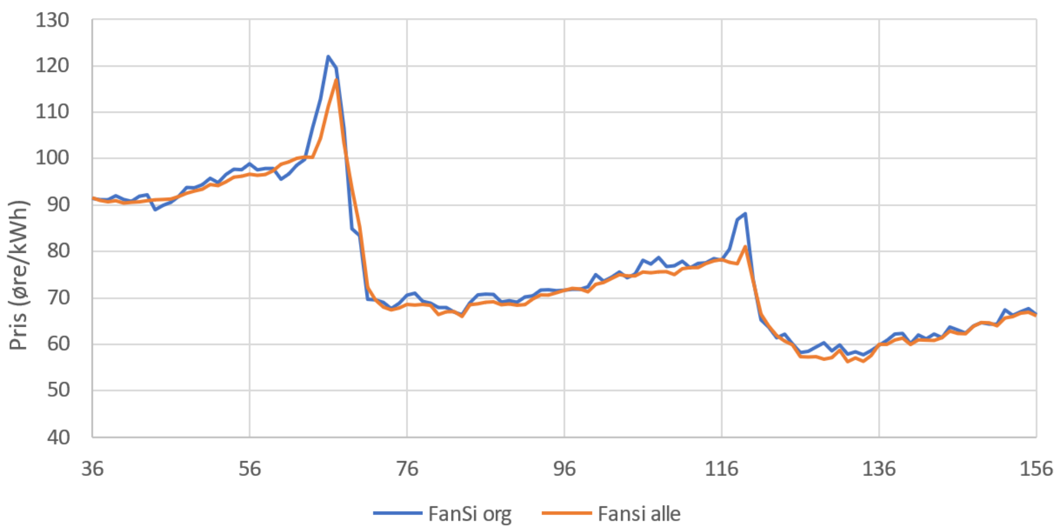


Figure A3.1: Simulated average prices for Sub -area Ostland by 14 (- orgent) and 41 (- all) scenarios in the scenarios of the Basis Case from week 36.

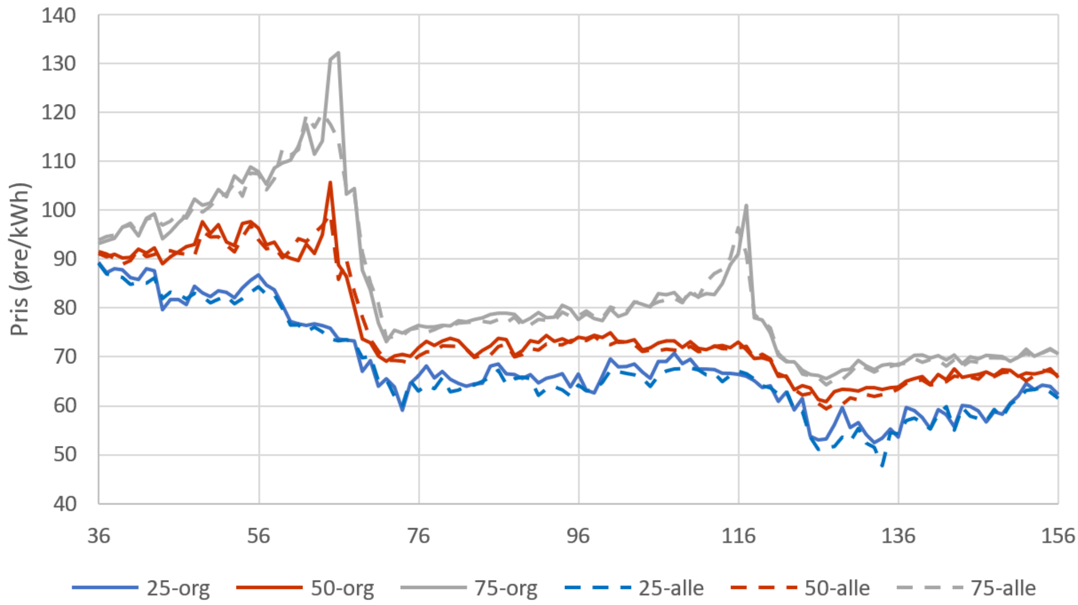


Figure A3.2: Simulated percentiles (25, 50 and 75) for price in sub -area Ostland with 14 (- orgent) and 41 (- all) scenarios in the scenarioship for Basis Case from week 36.