Workshop summary

Hydropower flexibility

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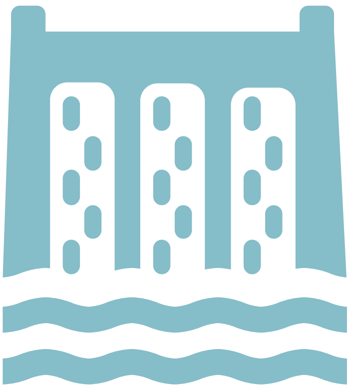
Workshop goal

Highlight opportunities and challenges related to flexibility from hydropower, and discuss the status and outlook on adapting hydropower for future flexibility needs

Topics

- What are the latest research findings related to flexibility from hydropower?
- What is the status and outlook for flexibility from hydropower?



Session 1

Flexibility services and market opportunities
Mari Haugen, SINTEF

Measures to quantify hydropower flexibility
Siri Mathisen, SINTEF

Hydropower investments for a flexible future—Uncertainty and prices
Birger Mo, SINTEF

Session 2

Panel discussion
Caroline Østlie, Statkraft
Toril Christensen, Eviny
Philip Mortensen, Oslo Kommune
Magne Fauli, Fornybar Norge

Breakout rooms, followed by a wrap-up

- *Technology adaptation and environmental impacts*
- *Business strategies*

Workshop Summary

In this fifth and last workshop of the series, we investigated supply-side flexibility, which is the network regulation service provided to the electric system operator by the generators. In Norway, where most of the generation capacity comes from hydropower plants, this technology dominated the debate. Hydropower plants, provided they have a reservoir with spare capacity, can store potential power in the form of water reserves that can be used to generate electricity at a specific time, in other words they are dispatchable power sources. Given the relative high speed that those power plants can be turned on or off, they are suited for most forms of frequency regulation, except for the fastest form, which is dominated by battery technology.

This contrasts with other parts of Europe, where flexibility is provided by fossil-fuel-powered plants that can stop and start production and store potential electricity in the form of fuel reserves. Those conventional power plants are responsible for a large share of emissions in the power sector, and alternative solutions are to be developed to achieve emissions reduction. The most inexpensive renewable generation technology being used today, wind and solar power plants, are less capable of increasing or decreasing production to adjust for the system's needs. Much to the contrary, as those technologies depend on natural resources for which the availability is uncertain, they are named variable renewable energy (VRE) generators.

Recently, the need for flexibility is increasing due to the participation of variable renewable energy, together with the decommissioning of nuclear power plants and the greater integration of electricity markets. In this workshop, we heard from researchers and market participants on what are the biggest challenges and latest findings related to flexibility from hydropower.

Even though hydropower plants with storage are not considered variable renewable energy sources, since they are dispatchable, operation of a hydropower reservoir depends on forecasting rain regimes, over a long-term period, and the management of a complex system of interdependence between multiple reservoirs and run-of-the-river plants in the same basin. This complexity has been increased recently by proposed or effective changes in markets and regulation, which directly impact revenue and future investment prospects. Research on forecasting methods for investment in new power plant developments is of the foremost importance at this moment.

Hydropower storage in Norway is not only strategic for the country, but relevant for the whole region. Having Europe's largest hydropower storage capacity, Norway is sometimes referred to as the battery of Europe. In this sense, electricity stored in Norwegian reservoirs can not only provide the for local system but holds even a greater value if exported to other markets in times of need. The feasibility of such connections, the social impacts both within and outside of Norway, and the relevance for the participants of the power sector have been discussed in the panel and breakout rooms. In a pure economic analysis, electricity export is an efficient solution for the overall wellness of the continent, but a sensitive issue in the current political scenario.

Finally, new technologies and market design were discussed, in broad terms, to address the most pressing needs. Taxation and regulation, mostly in the form of the current windfall profit tax, were analysed, pointing that they aggravate the already difficult task of forecasting investment profitability, and may lead to a lack of flexibility in the future, when we might need it most.

Workshop overview

Organised by: FME NTRANS + FME HydroCen
Number of participants: 26

Participants included researchers and partners of FME NTRANS and FME HydroCen. Researchers and partners from related research centres were invited and represented, including, PowerDig, FME ZEN and FME CINELDI.

In Session 1, three presentations gave an overview of the latest research findings related to flexibility from hydropower, including:

- How can flexibility services from hydropower be supplied in current power markets?
- How can the flexibility potential from a hydropower plant be characterized and quantified?
- How can different simulation models be used to evaluate profitability of future investments?

In Session 2, four panellists from different institutions presented their perspectives on opportunities and challenges with increased flexibility from hydropower. After the panellists shared their views, all participants were invited to join breakout rooms organised according to two thematic topics, namely:

Technology adaptation and environmental impacts	Business strategies

The discussion was facilitated in each breakout room by the leaders of UC7. Finally, the relevant topics were summarised in the wrap-up.

The presentations, discussions, and input during the workshop are presented in this report summary.

Session 1A

Flexibility services and market opportunities

Mari Haugen, SINTEF

Key takeaway—Flexibility is needed both to plan for variability and to react to unplanned or sudden variability, and there exists opportunities to sell both reserved capacity and activated energy on different time scales.

In the electricity markets, electric energy or capacity is traded in both physical and financial form. There is also trading of bilateral contracts between electricity producers and consumers directly. Markets help to maintain the balance between supply and demand in the electricity system. However, as balance is verified in real-time, while markets occur in advance, it can happen that the system is not in balance. When this happens, there is a need for flexibility services. The flexibility services are used to adjust production or consumption to bring the system back to balance across all timescales (seasons, days, hours, minutes, seconds).

Flexibility is needed both to *plan* for variability and to *react* to unplanned or sudden variability. The most important market for planned variability is the day-ahead market, where the complete schedule for the next day is traded. The intraday market can also be used to trade energy up to one hour before delivery, for example if a producer expects to deviate from the commitment in the day-ahead market. For unplanned or sudden variability, there exists several reserve markets: Tertiary reserves (mFRR), secondary reserves (aFRR), primary reserves (FCR), and fast frequency reserves (FFR). In the reserve markets, both capacity and energy are traded. Capacity trading ensures the availability of flexibility, while activation trading ensures that unplanned or sudden variability is balanced. When reserves are needed, the fastest responding reserves (FRR and FCR) are activated first, followed by the slower responding reserves (aFRR and mFRR) until the variability is balanced. Although hydropower is a good source for flexibility and can provide it in short time, the fastest reserves (FFR) need to respond within 2 seconds, and a pilot study by Statnett[1] found that hydropower is currently not suited to deliver the fastest reserves.

Q: *Who is participating in the reserve markets today and has there been changes?*
A: Previously, there was a mandatory delivery for power producers in FCR, which meant that the market had very high supply. Now, the producers need to qualify to participate in FCR, which will reduce the supply side. That will likely lead to increased prices in these markets, which could trigger new investments. The volumes are also growing because there are more unplanned or sudden variability in the electricity system today compared to previously.

Q: *How do the producers bid into the reserve markets?*
A: For tertiary reserves (mFRR), the participants can sell their reserved capacity to guarantee their participation in the activation market. This capacity market (RKOM[2]) is cleared for per winter season and before each week. To participate in the activation market (RKM[3]), the producers need to either (a) have sold their capacity in the capacity market or (b) bid in capacity for potential activation before 21:30 the day before. In the latter case (b), there is only payment if activation is needed.

[1] Statnett (2018). Fast Frequency Reserves 2018 - pilot for raske frekvensreserver
[2] Regulerkraftopsjonsmarkedet | Statnett
[3] Regulerkraftmarkedet | Statnett

Session 1B

Measures to quantify hydropower flexibility

Siri Mathisen, SINTEF

Key takeaway—Flexibility in hydropower systems can be quantified in terms of energy, power, and costs, and the flexibility available can be impacted by environmental constraints.

Flexibility can be defined as: "The ability to adjust production according to a price signal". Hydropower is a flexible power source as its operators can choose when to start or stop producing electricity. However, hydropower flexibility is constrained by environmental concerns and joint reservoir operation rules, that require producers to maintain certain storage levels. The requirement of a minimum reservoir level can impact hydropower income because it restricts the ability to produce. If the minimum reservoir level is considered during production planning, this leads to less potential income than if it is ignored.

New research investigates how the hydropower flexibility is impacted by the minimum reservoir level. This is done using the hydropower production planning tool ProdRisk[4] to produce two optimal hydropower schedules: with and without considering environmental constraints. These two cases are compared to understand how environmental constraints impact hydropower flexibility. The results show that there is less production during high price hours when environmental constraints are considered.

The change in hydropower flexibility in this study is quantified using the "flexibility factor", which is calculated as the average price paid to the hydropower producer divided by the average price over the same period. If the flexibility factor is 1, it means that the hydropower producer gets paid exactly the average price. If the flexibility factor is more than 1, the hydropower producer avoids low price hours and gets paid a higher price than the average price. Another way of quantifying the change in flexibility is to calculate how big an "equivalent battery" needs to be to exactly compensate for the change in income. It is then possible to estimate the "flexibility loss" as the potential income of the equivalent battery. All these ways of measuring change in flexibility are dependent on the prices and the price variations assumed.

In two case studies of Aura and Sokna hydropower systems, the change in hydropower flexibility has been calculated when limiting the minimum reservoir level of the biggest reservoir of each system to 85%. To compensate for the flexibility loss compared to no minimum reservoir level, the Aura system would need an equivalent battery which could store about one third its total storage capacity. In both case studies, the flexibility factor is decreased, which means that the hydropower producer gets a lower average price for the production when the minimum reservoir levels are considered. Future work includes exploring more environmental constraints and different price profiles.

***Q:** Did you already explore different environmental constraints?*

A: Yes. So far, we see that the severity of the environmental constraint has high impact on the change in flexibility. We also found some surprising effects, e.g., that the flexibility factor increased when introducing one environmental constraint.

[4] ProdRisk - SINTEF

Session 1C

Hydropower investments for a flexible future—Uncertainty of inflows and prices

Birger Mo, SINTEF

Key takeaway— Value of flexibility and storage are expected to increase. Norwegian hydropower production is a good option for flexibility provision, and relevant investments include more tunnel capacity.

More new renewables will increase the need for flexibility and storage in electricity markets, and there is a potential for hydropower producers to make valuable investments to provide more flexibility. To support such investment decisions, two types of tools are useful: (1) price forecasting and (2) revenue calculations. For price forecasting, the EMPS model[5] can be used to simulate market prices in a system with generator capacities pre-defined. When prices have been calculated, the next step is to calculate the income from having an optimized response to those prices. For hydropower producers, the ProdRisk model is a useful tool to support hydropower scheduling.

An example of such an investment analysis has been done for the Røldal-Suldal power plants (RSK-system). First, the prices were simulated for North Europe in 2030 resulting in prices for different historical weather years. When comparing the variability in the price forecasts compared to historical variability, the variability of the price forecasts is generally lower, especially with time resolutions up to weeks, months, and years. This is corrected for by scaling the prices for different time resolutions.

Second, several investment options were mapped, including building parallel tunnels to the existing power plants in the RSK-system. Then, the income from when each investment is implemented and calculated for the different prices. The consequences of forced outages in terms of timing and duration were also quantified. Depending on the details in the model used to calculate the hydropower schedule and the income, there could be some differences in the results.

***Q:** For the price forecasting, is it relevant to predict prices that are more reflecting the reserve markets (rather than day-ahead)?*

A: Yes, but I am not aware of any existing tools to make predictions on prices in the reserve markets in 2030 or 2040. Still today, the main income for the producer is from the day-ahead market, but we are working on developing models that can calculate prices in reserve markets.

***Q:** Volatilities that are obtained from the model are lower than the historical data?*

A: In this case yes. This is due to an increase in transmission to Europe in our case design, associated with deterministic thermal costs and CO_2 prices modelling. Those cause the forecasted volatility to drop.

[5] EMPS - multi area power-market simulator - SINTEF

Session 2A

Panel discussion

Caroline Østlie, Statkraft

Statkraft has 97% of its generation capacity in renewable assets, located in continental Europe and the Nordics, India, Nepal, and South America. The company's new strategy is to be the largest hydropower company in Europe, and a significant player in South America and India. As head of the strategic market analysis, we are responsible for the long-term power prices used in investment decisions. We think that there will be a large need for flexible providers going forward. 88% of the global carbon emissions are under net-zero plans. Electrification is the most cost-efficient way to decarbonise and there will be a large growth in electricity consumption globally. Wind and solar are the cheapest renewable technologies and are expected to increase in capacity worldwide, also covering the decommissioning of thermal plants. Flexible technologies will be valuable to balance the energy and power system in times with no sun and little wind. In wholesale markets, a higher price can be achieved by flexible units. With higher price volatilities, the share of the income from being flexible will increase over time. Other markets also exist, such as ancillary services and green markets. There are several competing technologies that can provide flexibility within a short time frame such as batteries, demand side management, and hydrogen electrolysis. One of the largest threats comes from regulations which can cause loss of flexibility. Long lead times for development and construction of hydropower, and no standardized technology are other challenges. Also, climate change can decrease hydropower production volume in the future.

Philip Mortensen, Oslo Kommune

The city of Oslo is working to mitigate climate change with ambitious goals of zero emissions towards 2030. The city represents the client side on the energy system, and the role of the climate agency is to develop policy initiatives and to understand the risks and opportunities related to the transition. In the future, there will be a need to much more supply and capacity. New solutions and consumption patterns, such as zero-emission construction and transportation, are being analysed. An early phase experience shows that, in a worst-case scenario, if all diesel-powered machinery in the city is electrified, this would represent an increase in the grid load of the city from 2.2 GW to 3.7 GW. In an optimised scenario with local sources of flexibility, there would be a need of 120 MW extra, and this also represent a challenge for the grid regarding the peak demand. Different solutions, with more flexible power productions, are explored to tackle the risk of not having enough capacity. The current needs in the city's perspective are modelling tools for the future risk, and how to develop and support structures to reduce it.

Toril Christensen, Eviny

Eviny Renewable is active in research centres NTRANS and HydroCen from a hydropower perspective. With intentions to invest in both onshore and offshore wind, the research focus increases. The main challenges identified in investments decisions are issues of investment calculations, which are not easily obtained with currently available models, especially when it comes to calculating the flexibility values. Also, concessions are being revised, which add uncertainty to calculations. Regulation and policy are important issues going forward, and the discussion of market design and whether it is to remain market-based is relevant. We recognize that there are great benefits in improving and making hydropower scheduling more efficient. In operation, more value will move to the balancing markets from the day-ahead market, changing the forecast of future profit. The technical requirements for generators to qualify for the different balancing markets have become stricter, so the company is looking at the portfolio of assets and especially those that require little cost to make them adequate for participating in the markets. Many other firms will have to do this time-intensive job. Some generators that were built for energy may be converted to become flexibility providers in line with market needs.

Magne Fauli, Fornybar Norge

As lead of the onshore team in "Renewable Norway", we represent land-based generation asset, such as hydropower, onshore wind, and solar. Renewable Norway is the name of the merger of Energy Norway and the Norwegian Wind Association. As Norway has 50% of the European reservoir capacity, this makes us an important supplier of flexibility to the Nordics and European markets. Increased power consumption represents an opportunity to invest in more generation and pumping capacity. The most important challenge now is Norway's position with respect to the largest markets for power consumption. Building cables to other countries is a financial and political challenge with crucial consequences. There are also environmental and acceptance issues that are taken very seriously. Voices in the governmental sphere, at the European level, prompt for changes in market designs fundamentally, which adds to other existing uncertainties that are hard to quantify into investment decisions. Short-term regulation changes and political risks are also difficult to forecast and can impact investment. Tax increase risk is also worth mentioning, as frequent and unfavourable changes are seen currently. A long-term risk of tax increase is stopping investments in flexible assets. Another effect of tax increase is that profit allocation for generators will no longer produce the best outcome for society.

Session 2B

Breakout rooms

Researchers and partners teamed up in smaller groups to discuss their perspectives on two thematic areas related to flexibility from hydropower.

Room #1: Technology adaptation and environmental impacts

Data collection and interpretation open new challenges. New data is coming from the low-voltage level of electricity distribution. Aggregation of this information to the regional level and integration of distributed flexible resources are among the problems faced by incumbent distribution companies.

New technology should be made to improve the ability to estimate the environmental impacts of new generation projects, such as reservoir level changes. For example, measuring temperature changes, and the effect on fishing activities. It may be difficult to include the value of biodiversity in the optimisation of the operation.

Taxation should also be improved, but in a way that favours stability and does not cause overnight changes. There are currently many sources of uncertainty, such as future price, environmental impacts, and political and regulatory.

Room #2: Business strategies

The current strategies are being made assuming that windfall profit tax is only present until 2024. This allows companies to make regular investment strategies, otherwise this could impact the future value of flexibility.

Bidding in different markets is a compelling strategy and might require dedicated teams to capture the best opportunities. A good strategy might require to plan for the day-ahead market first, and then optimise at each step. Not every generator is qualified for every market. Space resolution is different among markets, and this requires companies to recalculate frequently.

More investment in onshore wind power plants could be made if one assumes that the windfall profit tax is removed, but this faces issues of public acceptance. The market signals a need for those investments, and politician agree. Yet, this is focused on energy provision, rather than in flexibility.

The missing money problem also affects onshore wind power plant developments, as well as offshore plants. Another problem is profit calculation, which is affected by many uncertainties, making it hard to sell new projects to the board. The best projects are the ones that can be made in parallel with existing ones, as the cost of shutting down tends to overcome the benefit of retrofitting.

Solar energy does not have a prominent role in Norway in comparison to continental Europe, and by 2030 it should be present mostly as small rooftops installations. This also means that there should be no problem in integrating solar generation in the distribution grid. Offshore wind generation capacity is expected to grow towards 2030, but also affected by a different set of problems, involving uncertainty on the consumption and excessive generation (negative surplus) from 2027 onwards.

One good strategy to deal with peak capacity deficit is to increase hydropower generation. Yet, any forecast should consider the fact that the current high price level is not expected to be kept, and with lower prices, fewer installations are commercially viable. Flexibility can then become a more important source of revenue. But to have value, flexibility depends on price volatility, and a market design that allows for it. At the same time, market design should also provide reliable income for investments. Other indicators to be analysed are import and export capacity, which can measure electricity demand, and be used for forecasts.

On the consumer side, market platforms could provide trading opportunities for flexible assets. However, incumbents are slow to adapt new technologies. New mechanisms are being built specifically for consumers, which will face more price volatility in the future. Vehicle to grid poses interesting questions, as well as neighbourhood sharing of electricity.

Concluding remarks and future steps

The fifth workshop in User Case 7 brought the perspective of adapting hydropower investments and production planning to an increasing need for flexibility. Several existing power markets facilitate trading of supply-side flexibility from hydropower, both planned flexibility (day-ahead) and reactive flexibility (reserve markets). There are also several ways of characterizing and quantifying flexibility as indicators, which are useful to quantify the effects of environmental constraints on the flexibility potential.

Future steps include more research on forecasting methods and scheduling tools to support investment decisions towards making hydropower provide valuable flexibility. It is also relevant to explore alternative solutions to current tax regimes to promote investment in flexible technologies. Additionally, there is a need to explore the feasibility of electricity export from Norway to other markets and the social and political implications of such a move.

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