Which role may Norwegian hydropower play in 2050?

Scenarios for large-scale balancing and storage from Norwegian hydropower

We have developed four scenarios for using the flexibility and storage potential of the Norwegian hydropower system to balance generation and load in a European energy system with medium to high share of variable renewable energy sources in the year 2050 [1]. The scenarios set the scope for analyses of this potential with respect to the power system, environmental impacts in reservoirs, economic viability and social acceptance. The results will feed into the development of a roadmap for large-scale balancing from Norwegian hydropower.

Four scenarios

The scenarios differ from each other regarding mainly three aspects (**Figure 1**): 1) The degree of integration of Norway with the power markets and grid of Central Europe and the UK; 2) The expected volume of balancing provided by Norwegian hydropower to European power markets; 3) The type of balancing in terms of the time horizon, from seconds and minutes to days and weeks.

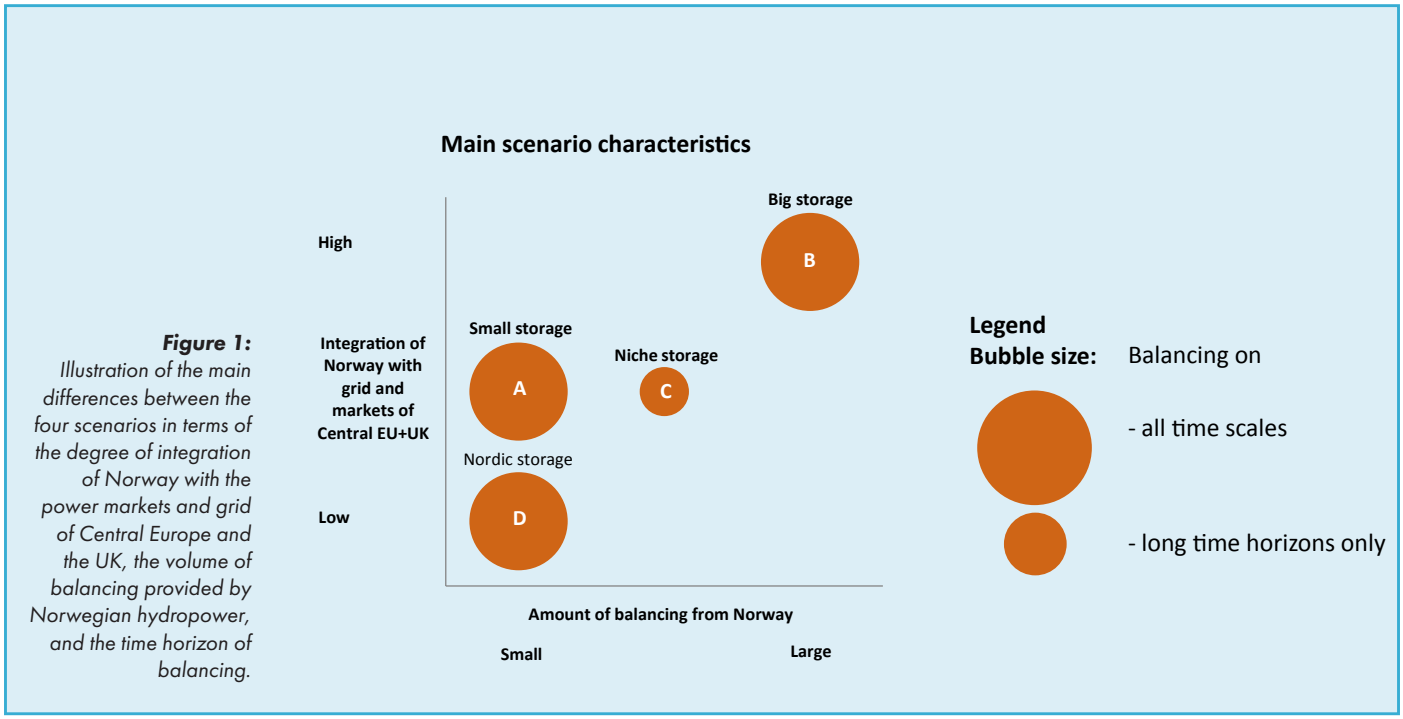

Figure 1: *Illustration of the main differences between the four scenarios in terms of the degree of integration of Norway with the power markets and grid of Central Europe and the UK, the volume of balancing provided by Norwegian hydropower, and the time horizon of balancing.*

Building the scenarios

We chose an approach for the scenario development that systematically categorises influencing factors, trends, options and uncertainties according to their importance, and combines these into scenarios [2].

We started the scenario building process **(Figure 2)** with defining the key research question: **Which role can balancing and energy storage from Norwegian hydropower play in the future European electricity market?**

To identify influencing factors and trends with respect to this question, and to select the most important ones, we organised a workshop with the project stakeholders. We defined the aspects that Norwegian decision makers cannot control as **uncertainties**, and the aspects that they can control as **options**. Different combinations of the uncertainties resulted in various **futures**, while different combinations of the options resulted in various **strategies.** Finally, we developed four scenarios by combining the futures and strategies, and selecting the most reasonable and targeted combinations. We called them *Small Storage*, *Big Storage*, *Niche Storage* and *Nordic Storage*.

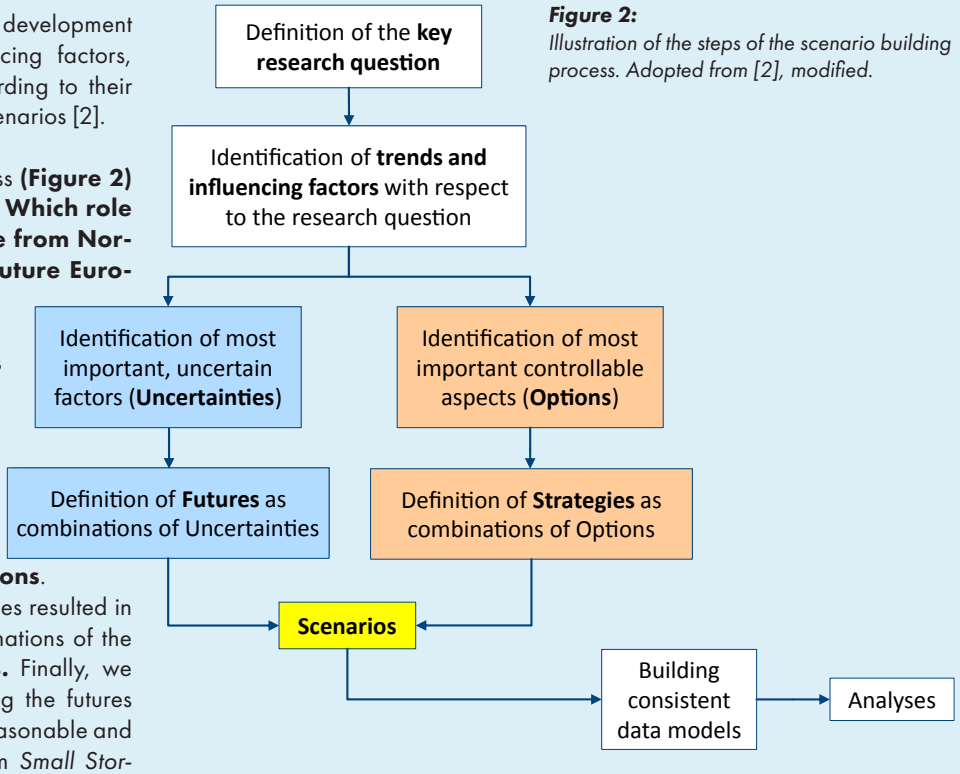

Figure 2: *Illustration of the steps of the scenario building process. Adopted from [2], modified.*

Table 1: *Uncertainties and options in scenario A – Small Storage.*

Small Storage	
Uncertainties in Future 1	***Medium Demand***
Technology	
VRES share in electricity generation	Medium
Expansion of European transmission grid	Moderate
Deployment of CCS	Yes
Market	
Competition from alternative flexible technologies	Low
EU regulatory framework and market integration	Fully integrated
Policy	
Ambitions of countries to connect with Norway	Moderate
Options in Strategy 2	***Moderate Expansion***
Expansion of Norwegian transmission grid	Moderate
New pumped hydro and upgrade of existing hydro	Moderate
Support of VRES development	Moderate
Ambitions of Norway to build interconnectors	Moderate

Scenario A – Small Storage

In *Small Storage* (**Table 1**), the degree of integration of Norway with grids and power markets of Central Europe and the UK is medium. Norway provides small volumes of balancing over various time horizons to the countries around the North Sea. In Central Europe and the UK, demand for balancing from Norwegian hydropower is at medium level. This arises from the use of carbon capture and storage, allowing for the same greenhouse gas emission reduction with less electricity generation from renewables. Consequently, the need for flexible generation is moderate, the European transmission grid and interconnectors with Norway are expanded moderately and no other new storage technologies than decentralised ones are deployed. This leads to a lack of units providing balancing at large scale, and low competition with Norwegian hydropower. This development goes along with moderate ambitions of Norway to build interconnectors. Norway's strategy is a moderate development of its hydropower system, transmission grid and renewables. The main goal is to secure national security of supply, balance Nordic variable renewable generation and use surplus energy mainly within the Nordic Countries.

Scenario B – Big Storage

In *Big Storage* (**Table 2**), Norwegian hydropower plays an important role in integrating variable renewable sources into the European power system by providing large volumes of balancing over various time horizons to the North Sea Countries through highly integrated grids and power markets. In Central Europe and the UK, there is a high demand for balancing. The high demand occurs as a consequence of a high share of variable renewable generation and low competition from alternative flexible technologies with Norwegian hydropower. No other new storage technologies than decentralised ones are deployed. The strong expansion of the European transmission grid and interconnectors with Norway, and full integration of power markets across Europe allow for large volumes of balancing from Norwegian hydropower. Norway pursues an active climate policy including the support of integrating renewables into the European energy system. The strategy aims at a strong development of the Norwegian hydropower system, transmission grid and renewables, and creates a climate for public acceptance of environmentally sound projects. All in all, Norway becomes a net exporter and provides various types of balancing to the North Sea Countries through a strong transmission grid and fully integrated power markets.

Table 2: *Uncertainties and options in scenario B – Big Storage.*

Big Storage	
Uncertainties in Future 3	***Various Flexibility***
Technology	
VRES share in electricity generation	High
Expansion of European transmission grid	Strong
Deployment of CCS	No
Market	
Competition from alternative flexible technologies	Low
EU regulatory framework and market integration	Fully integrated
Policy	
Ambitions of countries to connect with Norway	Strong
Options in Strategy 1	**Active Climate Policy**
Expansion of Norwegian transmission grid	Strong
New pumped hydro and upgrade of existing hydro	Strong
Support of VRES development	Strong
Ambitions of Norway to build interconnectors	Strong

Scenario C – Niche Storage

In *Niche Storage* (**Table 3**), the degree of integration is at medium level. The role of Norwegian hydropower is limited to balancing on long time horizons and medium volumes, while other countries cover their demand for balancing on short time horizons themselves. Central European countries and the UK demand balancing from Norwegian hydropower on long time horizons only, i.e. on a time scale of a day to several days and longer. This arises from the high competition in Europe from other flexible technologies. Both decentralised and centralised storage technologies are deployed and cover parts of the high balancing volume required to integrate a high share of variable renewable generation. In addition to pumped storage hydropower, at large scale and long time horizons hydrogen/power-to-gas and compressed air supply parts of the required high volume in Central Europe. This goes along with a moderate expansion of the European transmission grid and interconnectors with Norway. Power markets are integrated within Europe with respect to trade on long time horizons, but there is no common regulatory framework for the trade of services across Europe related to balancing on short time horizons. Norway's strategy is to exploit the potential of its hydropower system focusing on flexible generation and storage on long time horizons and balancing of variable renewable generation abroad. The expansion of the Norwegian transmission grid as well as the construction of new hydropower plants and interconnectors is supported. For environmental or economic reasons, domestic renewables are not developed in Norway beyond the existing plans until 2020.

Table 3: *Uncertainties and options in scenario C – Niche Storage.*

Niche Storage	
Uncertainties in Future 2	***Niche Market***
Technology	
VRES share in electricity generation	High
Expansion of European transmission grid	Moderate
Deployment of CCS	No
Market	
Competition from alternative flexible technologies	High
EU regulatory framework and market integration	Day-ahead only
Policy	
Ambitions of countries to connect with Norway	Moderate
Options in Strategy 3	***Value Creation***
Expansion of Norwegian transmission grid	Strong
New pumped hydro and upgrade of existing hydro	Strong
Support of VRES development	Limited
Ambitions of Norway to build interconnectors	Strong

Scenario D – Nordic Storage

Nordic Storage (**Table 4**) is a scenario with low integration between the Nordic Countries and the rest of Europe.Norway provides small volumes of balancing on various time horizons primarily to the Nordic Countries. The demand for balancing in Central Europe and the UK is high, but limited grid connections within Europe and to the Nordic Countries only allow for small volumes of balancing from Norway. The high demand occurs as a consequence of a high share of variable renewable generation and low competition from alternative flexible technologies. No other new storage technologies than decentralised ones are deployed. Hence, there is a strong lack of units providing flexibility and storage at large scale. However, the expansion of the European transmission grid is limited due to conflicts, public opposition or delays in grid projects. While the Central European countries and the UK have strong ambitions to build interconnectors with Norway, the Norwegian strategy is to focus on the development of the Nordic energy system. Electricity from renewables is primarily used domestically or within the Nordic Countries, i.e. there is no net export. Surplus energy is e.g. used to provide cheap electricity to energy-intensive industry. The national grid is strongly expanded in order to enable development and balancing of variable renewable sources. Norway's ambitions for building interconnectors to countries outside the Nordic Countries are weak. The expansion of the Norwegian hydropower system is limited. Capacities in existing hydropower plants are increased, but pumped storage is not expected to be constructed. Overall, the high share of variable renewable generation, limited transmission capacities and the lack of flexible generation and storage in Central Europe in combination with limited transmission capacity to the Nordic Countries cause situations of critical security of supply in Central Europe. The demand for balancing from Norwegian hydropower is high. However, Norway primarily provides balancing to the Nordic Countries, while exchange with other countries is restricted to balancing on long time horizons.

Table 4: *Uncertainties and options in scenario D – Nordic Storage.*

Nordic Storage	
Uncertainties in Future 4	***Critical Supply***
Technology	
VRES share in electricity generation	High
Expansion of European transmission grid	Limited
Deployment of CCS	No
Market	
Competition from alternative flexible technologies	Low
EU regulatory framework and market integration	Day-ahead only
Policy	
Ambitions of countries to connect with Norway	Strong
Options in Strategy 4	***Nordic Only***
Expansion of Norwegian transmission grid	Strong
New pumped hydro and upgrade of existing hydro	Limited
Support of VRES development	Strong
Ambitions of Norway to build interconnectors	Weak

Roadmap development

Based on these scenarios we will perform energy system and power market simulations. The results will feed into the development of a roadmap for large-scale balancing from Norwegian hydropower. This roadmap aims at showing possible pathways for increasing and utilising the flexibility and storage potential of the Norwegian hydropower system until the year 2050. We will address drivers and limitations as well as give recommendations to the industry and authorities regarding the regulatory framework, environmental impacts in reservoirs, public acceptance, business models and investment needs.

References

[1] J. F. Sauterleute, O. Wolfgang, and I. Graabak, "Scenarios for large-scale balancing and storage from Norwegian hydropower – Scenario building process and scenario description for the HydroBalance project," SINTEF Energy Research, Trondheim, Norway, Technical Report TR A7227, Feb. 2015.

[2] D. Huertas-Hernando and B. Bakken, "Modular Development Plan of the Pan-European Transmission System 2050 - Structuring of uncertainties, options and boundary conditions for the implementation of EHS," e-HIGHWAY 2050 Project, D 1.2, May 2013.

Facts about the HydroBalance project

The project addresses key questions regarding the increasing need for balancing variable electricity generation from renewable energy sources and providing flexibility by the use of Norwegian hydropower including deployment of pumped storage. These key questions are investigated in the research tasks of five work packages. The interdisciplinary project integrates perspectives on the topic according to CEDREN's vision: technology, nature and society:

WP 1 - Roadmap for balancing from Norwegian hydropower
WP 2 - Demand for balancing and storage
WP 3 - Modelling and analyses to develop business models
WP 4 - Environmental impacts of new operational regimes in reservoirs
WP 5 - Social acceptance and regulatory framework
Project period: October 2013 to September 2017
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CEDREN
SINTEF Energy Research
Postal address: P. O. Box 4761 Sluppen, NO-7465 Trondheim
Office address: Sem Sælands vei 11, NO-7034 Trondheim
Telephone: +47 73 59 72 00
www.cedren.no

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Contact CEDREN/HydroBalance
Atle Harby, Centre Manager atle.harby@sintef.no
Michael Belsnes, HydroBalance Project Leader michael.belsnes@sintef.no
Julian Sauterleute, HydroBalance scenario and roadmap development julian.sauterleute@sintef.no

Website: http://www.cedren.no/Projects/HydroBalance