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Report

Scenarios for large-scale balancing and storage from Norwegian hydropower

Scenario building process and scenario description for the HydroBalance project

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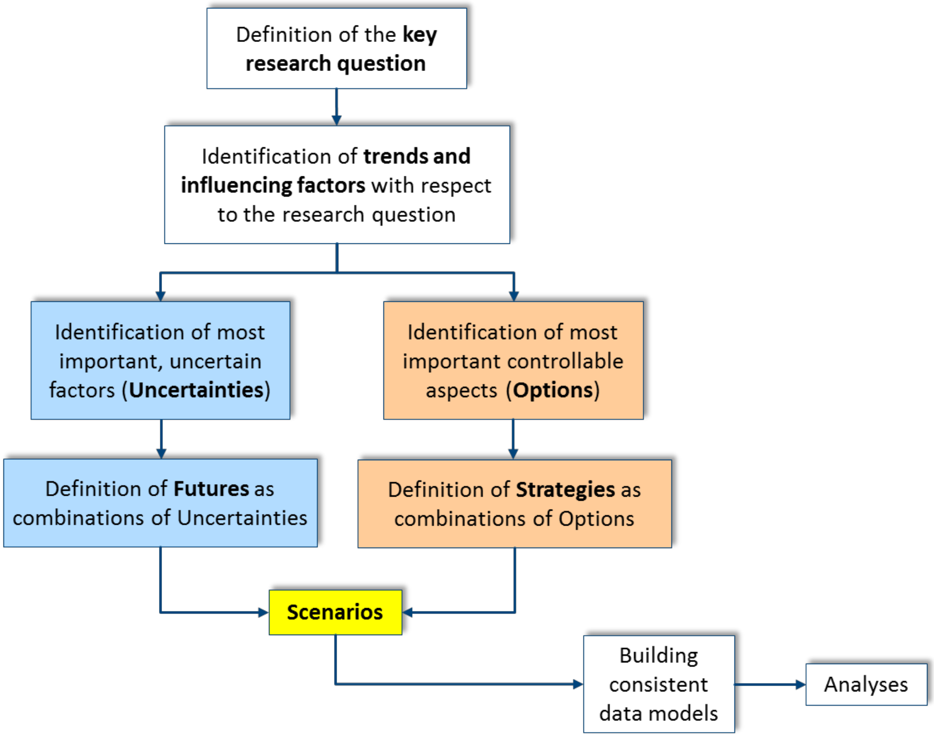

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ABSTRACT
Building scenarios for the utilisation of the hydro storage and pumped storage potential in Norway and for the provision of balancing and storage to the European electricity market was the first major step in the HydroBalance Project. The scenarios define the scope, boundary conditions and framework for the analyses to be carried out in other work packages, and build the basis for the development of the roadmap for large-scale balancing and storage from Norwegian hydropower. We developed four scenarios for the potential future roles of Norwegian hydropower by the year 2050. The scenarios primarily differ from each other in i) the degree of integration of Norway with the power markets and grid of Central Europe and the UK, ii) the volume of balancing provided by Norwegian hydropower, and iii) the type of balancing in terms of time horizons, from seconds and minutes to days and weeks. Scenario A – Small Storage includes medium integration, small volume and balancing over all time horizons; scenario B – Big Storage high integration, large volume and all time horizons; scenario C – Niche Storage medium integration, medium volume and long time horizons only; and scenario D – Nordic Storage low integration, small volume and all time horizons.

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APPENDICES

SINTEF

1 Background

In this report, the process of building scenarios for the HydroBalance project is documented, including the description of a workshop, consideration of relevant scenarios from other studies, and how the scenarios were built based on the workshop results. The scenarios will define the basis for analyses, case studies and simulations in other work packages as well as for developing a roadmap for large-scale balancing and storage from Norwegian hydropower.

The primary objective of the CEDREN project *HydroBalance – Large-scale balancing and energy storage from Norwegian hydropower* is to address key challenges to the use of Norwegian hydropower for large-scale balancing and storage related to technology, economy, environment and society. The project will draw pictures of the future for the use of hydropower flexibility towards 2050, assess alternative solutions for covering the need for balancing generation and load, analyse different markets and business models, investigate environmental consequences in reservoirs, and evaluate needs for the regulatory framework and public acceptance.

The HydroBalance project will develop a roadmap for the deployment of large-scale balancing and storage in Norway. The roadmap will show potential developments of using the flexibility and storage potential of the Norwegian hydropower system in order to balance generation and load, and provide related services to the European electricity market in the future. It aims at pointing out steps in the process of increasing the flexibility of the Norwegian hydropower system, drawing time lines for such use of hydropower until the year 2050, and addressing drivers and limitations regarding the political framework, environmental requirements, public acceptance, business models and investment needs.

HydroBalance includes building scenarios for the utilisation of the hydro storage and pumped storage potential in Norway to provide balancing and storage to the European electricity market. The main purpose of the scenarios is to define the scope, boundary conditions and framework for the analyses carried out in the other work packages. Building the scenarios is an essential step in the roadmap development, since they provide the basis for these analyses. Throughout the project the analysis results will feed back into the roadmap.

2 Scenario building approach

In this chapter we describe the scenario building process we applied during the development of the HydroBalance scenarios. This approach originates from the e-HIGHWAY 2050 project and is described more detailed in [1].

The scenario building process starts with defining the key research question, i.e. the perspective from which the scenarios ought to be developed (Figure 1). The key research question is developed also considering the main target group for the scenario analysis results (stakeholders). Then, the most important influencing factors, trends and uncertainties with respect to the key research question are identified and collated. A helpful way of structuring the influencing factors is to think along two scales ranging from certain to uncertain and important to unimportant, respectively. In this manner, the influencing factors are categorised into four groups (Figure 2). The certain and important factors should be present in all scenarios. They may be referred to as *Trends* or *Megatrends*. The unimportant and certain factors are less important for the scenarios, but should be kept in mind in case that they become important, while the unimportant but uncertain factors should be considered in the scenarios if possible. The category with the greatest significance for the scenarios includes the important and uncertain factors (*Uncertainties*). After having identified the *Uncertainties* they are grouped and sorted after importance. The most important *Uncertainties* will be the main drivers for the scenarios.

In the next steps, the *Trends* and *Uncertainties* are structured into scenarios (blue and orange boxes in Figure 1).The scenarios are built as combinations of *Uncertainties* (which cannot be controlled by decision makers) and *Options* (which can be decided on by decision makers). On the one hand, combinations of various *Uncertainties* result in the description of different *Futures*; on the other hand, combinations of various *Options* lead to different *Strategies*. Subsequently, the scenarios are built by selecting reasonable and targeted combinations of the *Futures* and *Strategies*.

After having defined the scenarios, data models have to be established in compliance with the story lines of the scenarios. The data models are the basis for the scenario analyses; they provide the input to modelling tools with which the scenario analyses are performed.

We involved stakeholders in the process of defining *Futures* through a workshop (cf. Chapter 4). As it turned out that the workshop results also included *Options* besides *Uncertainties*, we included these in building the *Strategies* (cf. Chapter 5.3). Furthermore, we used scenarios from other projects as benchmark when building the HydroBalance scenarios (cf. Chapter 7). After having selected four scenarios (cf. Chapter 5.4 and 6), they were reviewed by the stakeholders.

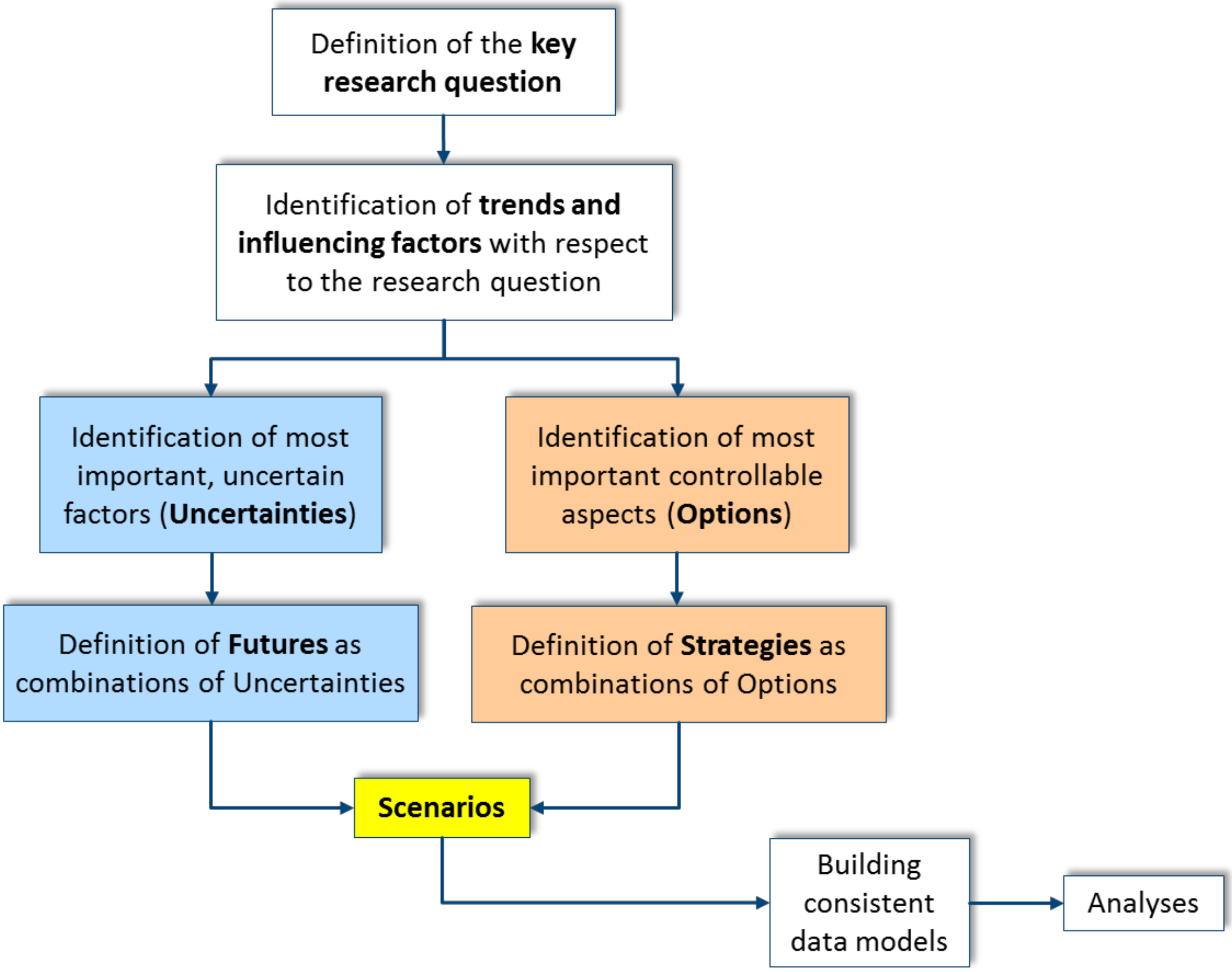

Figure 1: Schematic illustration of the steps in the scenario building process in HydroBalance. After [1].

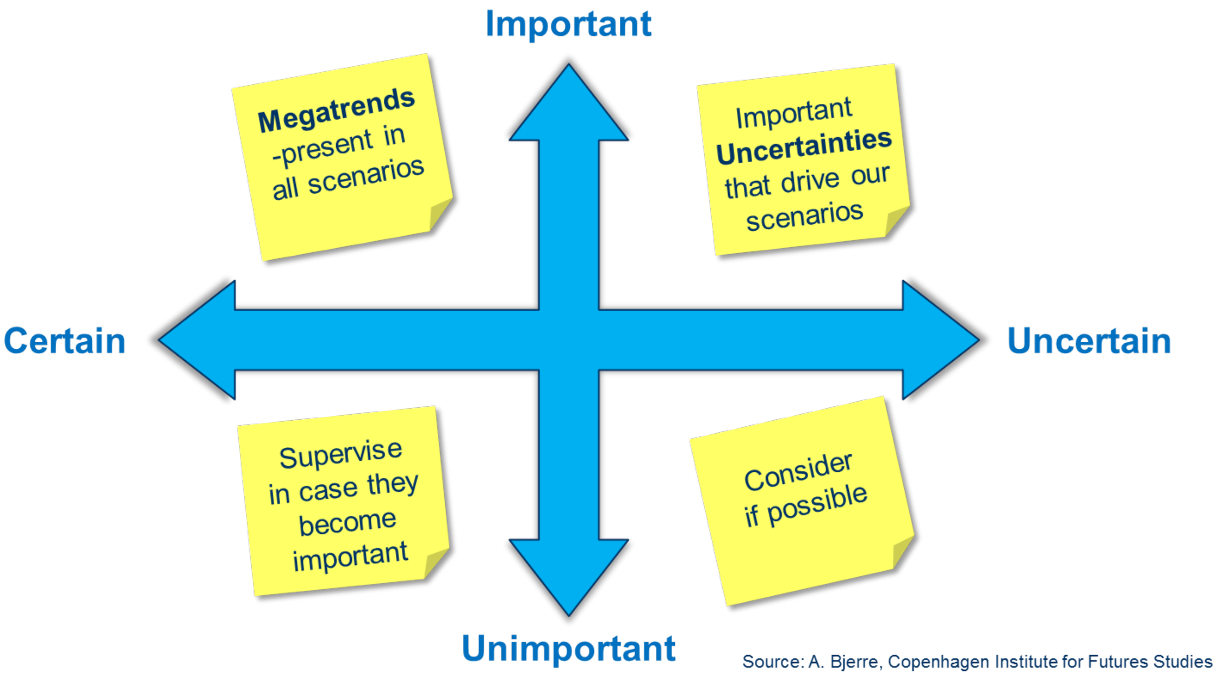

Figure 2: Categorisation of influencing factors into four categories along two scales ranging from certain to uncertain and unimportant to important. The important and uncertain factors (important uncertainties) are the main drivers for scenarios. Source: [2].

3 Premises for the HydroBalance scenarios

3.1 Key research question

The scenarios are to be developed in relation to the following focus, formulated as a question:

> **Which role can balancing and energy storage from Norwegian hydropower play in the future European electricity market?**

Selection of important uncertainties, main drivers for the scenarios and ranking of drivers are to be made from this perspective.

3.2 Stakeholders

The roadmap, one of the main results of the HydroBalance project, and hence the scenarios providing the basis for it, will address a group of stakeholders covering all work package topics: Power producers, energy companies, transmission system operators, politicians, decision makers, authorities and NGOs.

3.3 Time horizon

HydroBalance will build scenarios for the year 2050. Relevant steps on the time line towards 2050 are 2030 and 2040. The year 2020 is not considered as it is near to the present in this context.

3.4 Geographical extent

The focus of HydroBalance is on the potential of the Norwegian hydropower system for flexibility from hydro storage and pumped storage. The target customers and demand for balancing services are located in the countries around the North Sea. Therefore, the geographical focus area comprises Norway, Sweden, Denmark, Finland, Germany, Benelux, and the United Kingdom. However, these countries' energy systems cannot be considered isolated from the rest of the European energy system. Hence, other European countries will be considered, but on a less detailed level, e.g. through higher aggregation for representation in models.

3.5 Policies and consistency with other scenarios

The HydroBalance scenarios should be checked on compliance with relevant scenarios from other studies. At general level, e.g. regarding economics and demography, they ought to comply with global or European scenarios for the year 2050. Regarding integration of the European power markets and extension of transmission grids to a pan-European power system, the HydroBalance scenarios should be plausible with respect to EU policies and trends.

3.6 Norwegian hydropower system

HydroBalance will consider the potential for use of hydro storage and pumped storage in the Norwegian hydropower system which can be exploited by using existing reservoirs only. This may include upgrading existing hydropower stations as well as constructing new ones by connecting existing reservoirs with new tunnels and installing new turbines or pump turbines. Only power stations with outlets into reservoirs or fjords will be considered for exploiting the potential for balancing on large scale.

4 Scenario workshop

4.1 Workshop process

The goal of the workshop (cf. Appendix A3) was to achieve active participation of the stakeholder group in the scenario building process and to get valuable input for building the scenarios. Two group work tasks were designed (cf. Appendix A4). In the scenario building process, they were part of the definition of possible futures, see blue boxes in Figure 1, Chapter 2. The first task was to select the most important uncertainties; the second one to describe the futures. Three groups worked in parallel on the same tasks, and each of them presented their results in plenum afterwards. The same groups continued with working on the second task, based on the results of all groups from the first task.

4.1.1 Introductory session

After a brief introduction to the background, contents and objectives of the HydroBalance project, perspectives from other countries than Norway that are relevant for the development of the HydroBalance scenarios were presented in the first workshop session (cf. Appendix A3).

4.1.2 Group work tasks

The group work consisted of two tasks. The first task concerned the categorisation and ranking of influencing factors along two scales ranging from certain to uncertain and important to unimportant (cf. Figure 2, Chapter 2). The suggested categorisation of influencing factors, which the groups used as a starting point for their discussions, is given in Figure 3. The second task dealt with the selection of the main drivers for the scenarios, the most important uncertainties, and the definition of futures as combination of the most important uncertainties (cf. Chapter 2):

Task I

Discuss the uncertainty and importance of the given factors (Figure 3) in relation to the key research question.

Which changes would you make, and why? Are there any factors missing that you would consider?

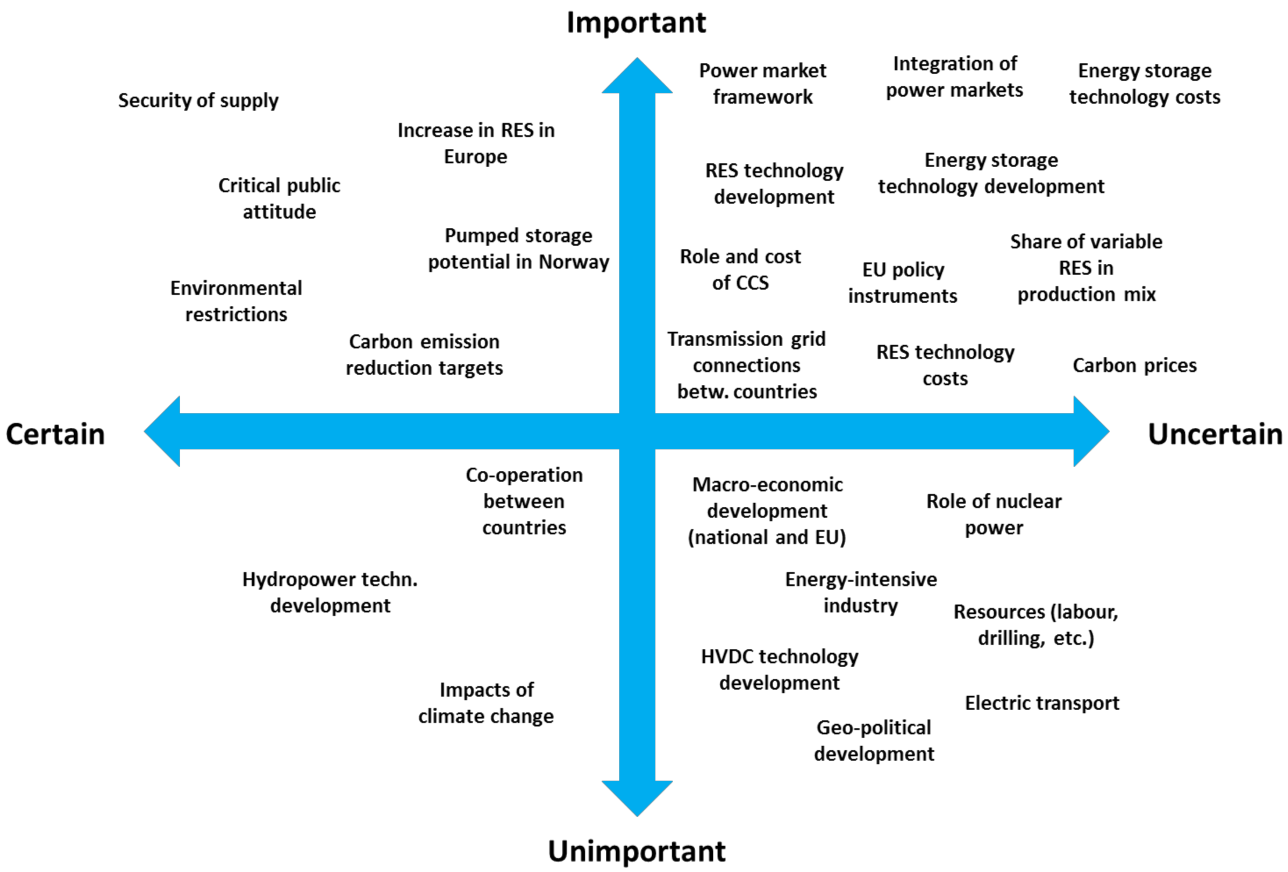

Figure 3: Categorisation of influencing factors in relation to the key research question as it was suggested to the groups as starting point for discussion in Task I.

Task II

a) Based on the results from group work I, identify the two or three most important, uncertain drivers. Combining the main drivers will result in possible futures.
b) How do the main drivers affect the HydroBalance project? Describe the possible futures resulting from combinations of the main drivers qualitatively (in words).

4.2 Group work results

4.2.1 Task I

Figure 4, Figure 5 and Figure 6 show how the groups categorised the influencing factors regarding their (un)importance and (un)certainty.

Group 1

The share and types of renewable energy sources (RES) was considered to be among the most important uncertainties and taken as a starting point. Other important uncertainties that were mentioned were the costs and availability of alternative technologies providing flexibility, including storage, at a centralised level. This was assumed to be less important at distributed level. The power market framework and how various markets are organised (integration of balancing markets, intra-day markets, balancing responsibility, etc.) as well as costs and capacities of interconnectors were seen as important and uncertain. RES policy instruments and carbon emission reduction targets were considered as unimportant.

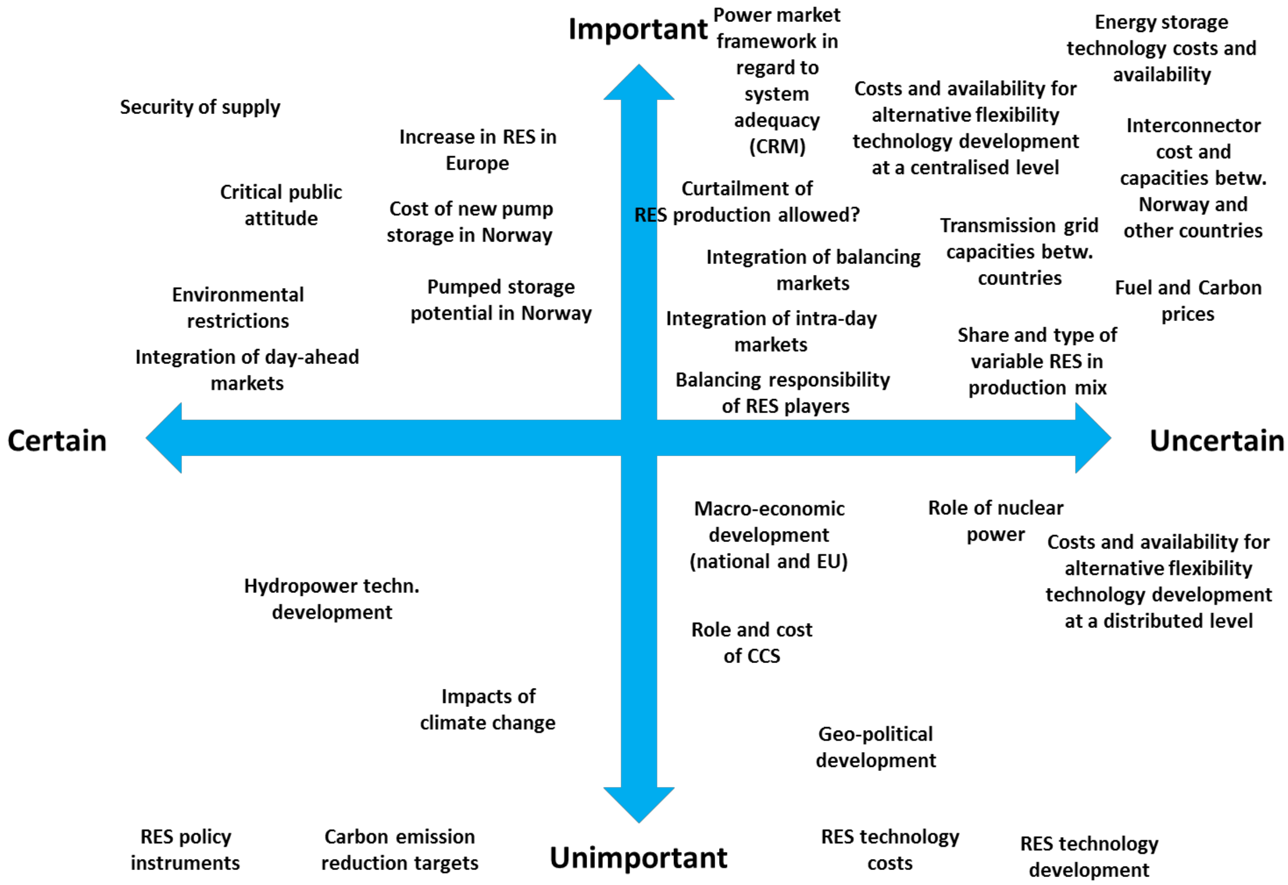

Figure 4: Result of Task I, Group 1.

Group 2

Policy was considered both important and uncertain. The group differentiated between national and international level: On the one hand, the Norwegian policy for the integration with the European power system, on the other hand policy instruments at EU level. Energy storage technology costs were assumed to decrease and be important, but the level to which the costs decline was considered uncertain. Transmission grid capacity expansions between countries in Europe were seen as important uncertainty because on the one hand, interconnectors with Norway are needed, and on the other hand more interconnectors between other countries reduce the demand for flexibility from Norway. Carbon prices and costs and flexibility of carbon capture and storage technology (CCS) as well as demand side management were other elements considered as important and uncertain. Increased energy efficiency and the power market framework were assumed to be relatively certain. The local versus global sides of environmental impacts were pointed out, i.e. local natural resources versus climate mitigation, but considered as rather certain and unimportant.

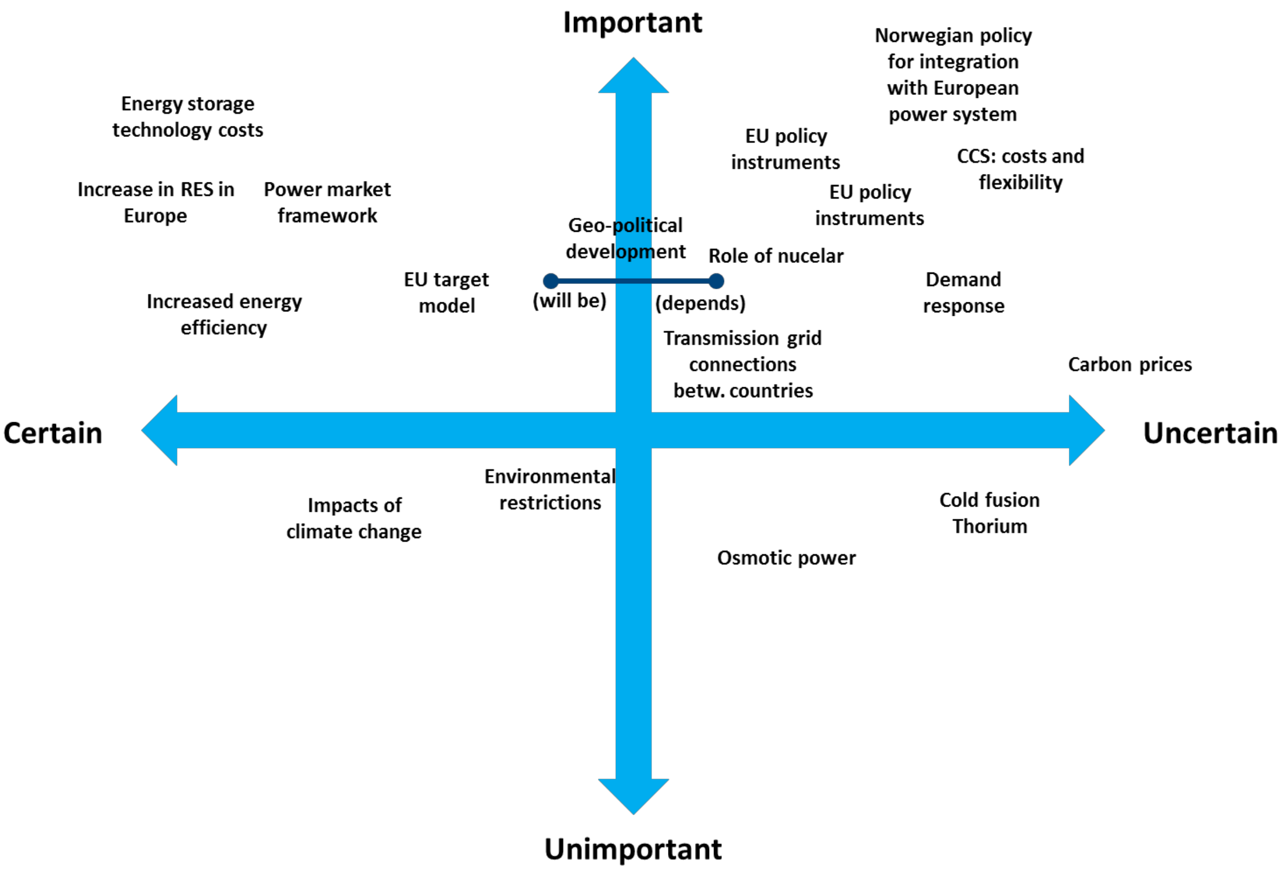

Figure 5: Result of Task I, Group 2.

Group 3

Integration of multiple power markets, the share of variable renewable energy sources (VRES), policy on EU level, transmission grid connections and demand side management were considered as important and uncertain. National and European economic development was also regarded as rather important but uncertain because of the impact on resources available for investments. The group placed geo-political development among the most important and uncertain factors, because it impacts security of supply and national self-sufficiency. Security of supply is an important issues and influences to what degree other countries are willing to make themselves dependent on energy delivered by other countries, e.g. other countries being dependent on flexibility from Norway. Development of energy storage technologies and costs were considered as uncertain but rather unimportant because large-scale storage over long time periods was assumed to not have any other competitive alternatives than hydro and pumped storage. A critical attitude of the public was regarded as certain and important. Environmental impacts were considered certain and important as well, where the local vs. global aspect was emphasised.

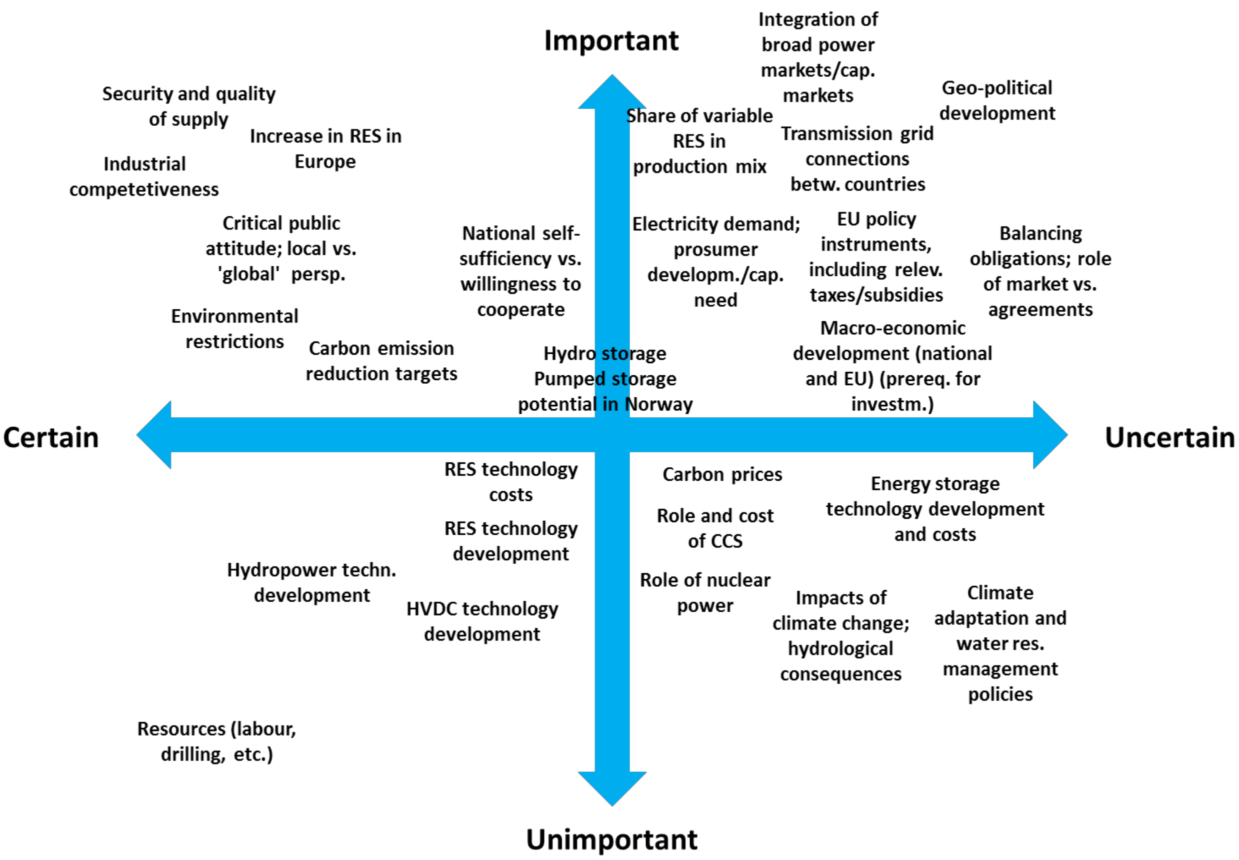

Figure 6: Result of Task I, Group 3.

4.2.2 Summary of Task I

All groups made substantial changes to the suggested categorisation of the influencing factors (Figure 3). Similarities in the results of Task I were:

1. Increase in RES in Europe, security of supply and a critical public attitude were regarded as certain and important.
2. Transmission grid connections between countries and either the power market framework and integration of markets, or policies determining the markets were considered as uncertain and important.

4.2.3 Task II

Group 1

Most important uncertainties:

1. Share of VRES in energy mix
2. Costs and availability of alternative technologies for flexibility at centralised level

These main drivers were chosen based on the following assumptions:

- Increase in VRES in Europe, while the share is uncertain

- Power market framework on EU level is established, markets are integrated
- Market for balancing is established at EU level
- Interconnectors Norway - Europe are constructed, European transmission grid is strengthened

Possible futures (Figure 7):

1. *Limited Possibilities*: A medium share of VRES and high competition from alternative flexible technologies result in limited possibilities for balancing from Norwegian hydropower, because the demand for flexibility is mostly covered by other flexible technologies than Norwegian hydropower in the European market. Hence, a small volume/capacity of the Norwegian hydropower system is utilised and provided to the European market.
2. *Good Possibilities*: A medium share of VRES and low competition from alternative flexible technologies lead to good possibilities for balancing from Norwegian hydropower. Moderate volume/capacity is utilised and provided to the European market.
3. *Niche Market*: A high VRES share in combination with high competition from alternative flexible technologies gives a large demand for flexibility from Norwegian hydropower. However, as flexibility from Norwegian hydropower is in competition with other technologies in the European market, Norwegian hydropower mainly provides certain types of (e.g. long-term) balancing to the European market.
4. *Very Good Possibilities*: A high VRES share combined with low competition from alternative flexible technologies results in very good possibilities for Norwegian hydropower. Since the central European power system cannot cover its demand for flexibility, the Norwegian hydropower system is utilised for providing various types of balancing.

The resulting futures may vary somewhat (sensitivity) depending on the balancing capacity of the Norwegian hydropower system, the types of VRES and fuel and carbon prices.

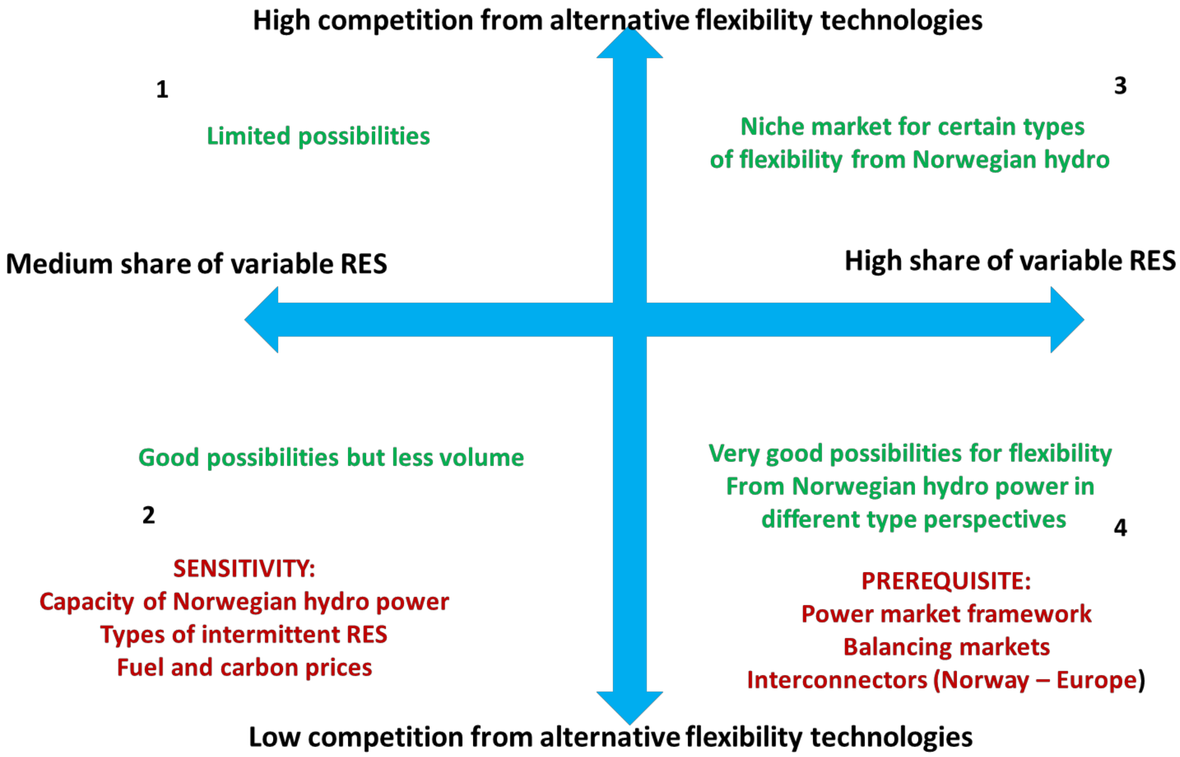

Figure 7: Four futures resulting from medium/high VRES share combined with high/low competition between Norwegian hydropower and alternative technologies for providing flexibility; increasing demand for balancing from Norwegian hydropower from future 1 to 4.

Group 2

Most important uncertainties:

1. EU and national state policy, particularly on transmission grid and markets
2. Norwegian policy for integration with European power system (positive public attitude, active involvement of authorities, transmission grid)
3. Technology development: level of energy storage technology costs, costs and flexibility of generation units with CCS, demand side management (DSM)

Possible futures (Figure 8):

1. *Fully Integrated*: EU policy creates integrated power markets in the EU, access of the central/western European market to Norwegian hydropower and a strong European transmission grid. The Norwegian government focusses on the topic and makes a policy that leads to good interconnection with the central/western European power grid as well as public acceptance for building necessary infrastructure (generation and transmission) and market effects (e.g. electricity prices). The EU achieves its emission and RES targets; carbon price is high.
   a) *Fully Integrated* combined with availability and competitiveness of alternative flexible technologies with Norwegian hydropower, such as energy storage, CCS and DSM; moderate to high demand for balancing from Norwegian hydropower.
   b) *Fully Integrated*, but available alternative flexible technologies are not competitive with Norwegian hydropower. This gives the highest demand for balancing from Norwegian hydropower.

2. *Nationalism*: EU policy leads to national power markets, and the access of the central/western European markets to Norwegian hydropower is on about the level as today.
   a) In Norway, there is no focus on the topic, so that the interconnections to the European markets are not strengthened. Alternative flexible technologies are competitive with Norwegian hydropower. This results in that the EU can achieve its emission and RES targets; carbon price is high. No demand for balancing from Norwegian hydropower.
   b) In Norway, focus on policy leads to new connections to central/western European power markets based on bilateral agreements with EU member states. The need for them arises from alternative flexible technologies not being competitive with Norwegian hydropower. However, as a result the EU cannot achieve its emission and RES targets; carbon price is low. Low to moderate demand for balancing from Norwegian hydropower.
1. *Non-Interested Norway*: EU policy creates integrated power markets in the EU, access of the central/western European market to Norwegian hydropower and a strengthened European transmission grid. However, Norwegian policy leads to no further connections to the European markets and limited public acceptance for building infrastructure and market effects (e.g. impact on electricity prices).
   a) Availability and competitiveness of alternative flexible technologies ensures that the EU achieves its emission and RES targets; carbon price is high. No demand for balancing from Norwegian hydropower.
   b) Available alternative flexible technologies are not competitive with Norwegian hydropower; hence, the EU has to take high costs to achieve its emission and RES targets. No to low demand for balancing from Norwegian hydropower.

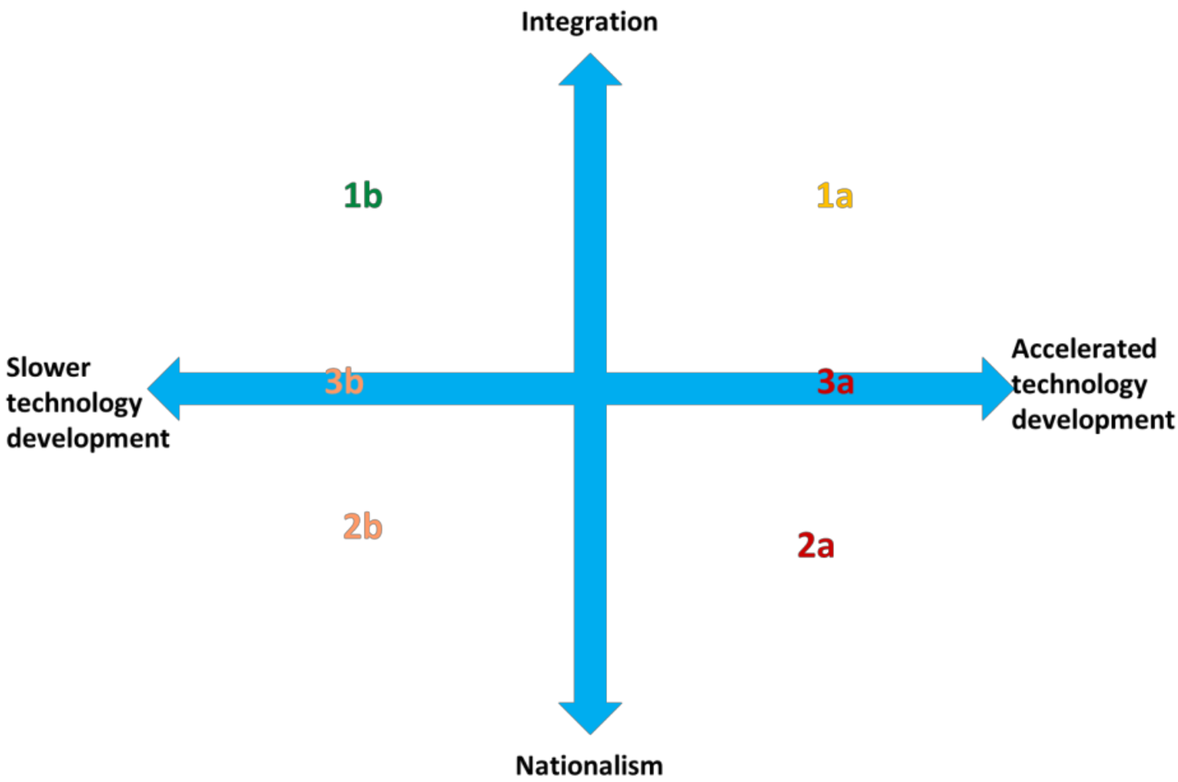

Figure 8: Six futures as a result of combining EU-wide integrative policy versus nationalistic policy and low versus fast technology development (competitiveness of alternative technologies providing flexibility). The resulting level of balancing provided by Norwegian hydropower is indicated by colours: none (red), low (light red), moderate (yellow), high (green).

Group 3

Most important uncertainties:

1. Power market framework for short-, medium- and long-term balancing
2. Regulatory regime and business models for interconnectors
3. Demand for flexibility from Norwegian hydropower

The group regarded it as important to differentiate the market framework for the power market and the interconnectors. The main drivers were selected assuming that flexibility from Norwegian hydropower is competitive with other technologies and economically viable, at least regarding specific types of flexibility (i.e. long-term balancing). Hence, a balancing demand is given, at least at a moderate level. Transmission grid expansion and construction of interconnectors were not regarded as main drivers because this was assumed to be a step-wise, parallel development triggered by other elements like market framework. Furthermore, the framework for the balancing market and the regulatory regime and business models for interconnectors were assumed to result from corresponding policy on both EU and Norwegian level. Strong increase in VRES in Europe was assumed given.

Possible futures (Figure 9):

1. *Critical Security of Supply*: Moderate to large demand for flexibility, depending on the VRES share, in unfavourable market/business model conditions for both the balancing market and interconnectors; this results in situations with critical security of supply.
2. *Continental Solution*: The combination of favourable framework for the balancing market with unfavourable regulatory framework and business models for interconnectors leads to a situation where Norway provides some balancing to the European market. Most of the demand for flexibility in Europe is covered by other flexible technologies.
3. *Bilateral Agreements*: Regulatory conditions for interconnectors are favourable, but an unfavourable balancing market framework induces bilateral agreements between Norway and neighbour countries. This only allows for provision of a small volume of balancing from Norway.
4. *Small Hydro Battery*: Both balancing market framework and regulatory framework /business models for interconnectors are favourable. However, moderate demand for flexibility form central/western Europe, e.g. due to competition from alternative flexible technologies, limits investments into infrastructure and the volume of balancing provided by Norway.
5. *Big Hydro Battery*: Both balancing market framework and regulatory framework /business models for interconnectors are favourable. Large demand for flexibility from central/western Europe results in large investments in both grid expansion and interconnectors. Norway delivers a large volume of balancing.

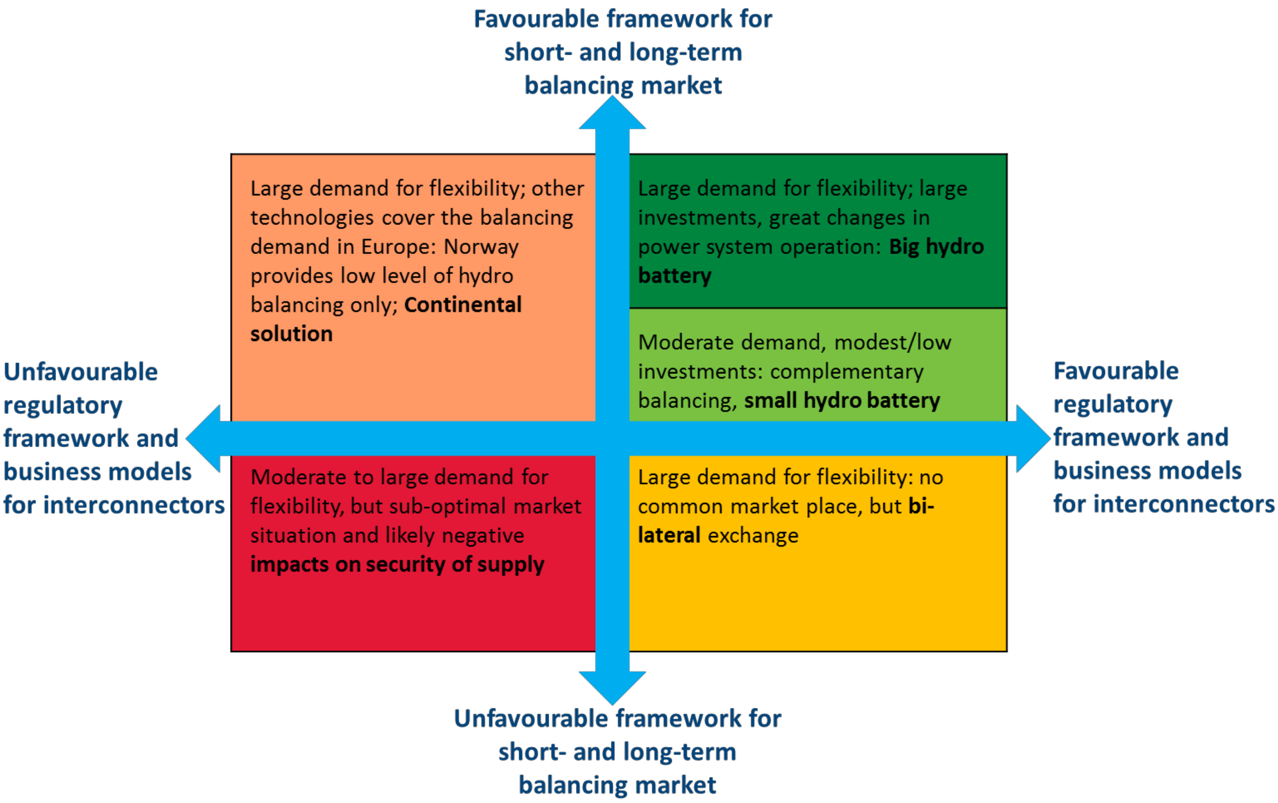

Figure 9: Futures as combination of (un)favourable balancing market framework and (un)favourable regulatory framework and business models for interconnectors. The resulting volume of balancing provided by Norwegian hydropower is indicated by colours: none (red), low (light red), moderate (yellow), high (light green), very high (dark green).

4.3 Conclusions from the workshop results

In all groups the following factors were among the most important uncertainties, driving the possible futures:

- Market framework and business models, integration of markets across Europe
- Level of competition between flexible technologies on European market
- Share of VRES in Europe
- Demand for flexibility from Norwegian hydropower
- EU and national policy

In general, it was pointed out that for some factors, it is important to differentiate between geographical perspectives/levels. On the one hand, there is the EU level with EU policies, on the other hand, there is the national state level with national policies, and Norwegian policy in particular.

Throughout the group work it became clear that the selection and ranking of the main drivers depend on the perspective on the energy system, and which elements are considered as given for other developments. Examples are:

- The increase in the share of VRES in the European energy system can be considered as given, because the share has been rising throughout the last years, and there are policies in place that support this development, at least until 2030. However, it is uncertain how large exactly the share will be.
- The market framework and business models determine the economic viability of flexibility provided by Norwegian hydropower. They are likely to be a consequence of policy, both on EU and national level.
- The demand for balancing from Norwegian hydropower is a basic requirement for making a business case, and is related to the share of VRES in the European energy system as well as how strong alternative flexible technologies will compete on balancing provided by Norwegian hydropower.

5 Building and selecting the scenarios

5.1 Structuring the workshop results

The futures resulting from the workshop were further considered based on the following criteria (Table 1):

1. Compliance with defined premises?
2. Relevance for the objectives of the project?
3. Lack of differentiation between options and uncertainties?

At the time of the workshop the differentiation between options and uncertainties had not clearly been defined and communicated to the participants of the group work. As a result, the groups did not strictly differentiate options and uncertainties when building their futures. Options are factors that decision makers can choose, i.e. have control on. Which factors a decision maker has control on depends on the perspective from which the scenarios are built. Consequently, the options have to be defined in accordance with the research question. Since the Norwegian hydropower system and its potential future roles are subject of HydroBalance, we here defined **options** as **factors which Norwegian decision makers can decide on**. Hence, options in HydroBalance do only refer to choices which Norwegian policymakers control, while EU and national state policies are considered as uncontrollable, i.e. as uncertainties. Some of the futures resulting from the workshop included factors that decision makers in Norway can have control on, e.g. Norwegian policy on national transmission grid expansion. These futures were not considered further, but the options they included were considered when defining the strategies. Table 1 shows the reasoning behind the inclusion or omission of the futures resulting from the workshop for further building the HydroBalance scenarios. Six futures were selected, but some of them were similar. Therefore, future 1a and 1b of Group 2 were combined with future 3 and 4 of Group 1, respectively. Hence, we included four futures when building the HydroBalance scenarios.

Table 1: Structuring and further consideration of the futures resulting from the workshop. Futures selected for further consideration are highlighted.

Future	Further considered?	Reason
Group 1		
1 - *Limited Possibilities*	No	Not interesting/relevant (limited volume of balancing from Norway)
2 - *Good Possibilities*	**Yes**	Interesting/relevant (moderate demand, but various types of flexibility)
3 - *Niche Market*	**Yes**	Interesting/relevant (lower level of demand, but high demand for flexibility on long time horizons)
4 - *Very Good Possibilities*	**Yes**	Interesting/relevant (high demand for various types of flexibility)
Group 2		
1a - *Fully Integrated* and competition	**Yes**	Interesting/relevant, complies with future 3 of Group 1 (*Niche Market*)
1b - *Fully Integrated* and no competition	**Yes**	Interesting/relevant, complies with future 4 of Group 1 (*Very Good Possibilities*)

Future	Further considered?	Reason
2a - *Nationalism* without ambitions from Norway	No	Entails an option (Norwegian policy on interconnectors and hydropower development) + not interesting/relevant (no balancing from Norway)
2b - *Nationalism* with ambitions from Norway	(Yes)	Interesting/relevant, but entails an option (Norwegian policy on interconnectors, bilateral agreements), considered through strategy 2 (*Moderate Expansion*, cf. Chapter 5.3.2)
3a - *Non-Interested Norway* and competitiveness	No	Entails an option (Norwegian policy on interconnectors and hydropower development) + not interesting/relevant (no balancing from Norway)
3b - *Non-Interested Norway* and no competitiveness	(Yes)	Entails an option (Norwegian policy on interconnectors and hydropower development) + interesting in terms of system stability and reliability, considered through strategy 4 (*Nordic Only*, cf. Chapter 5.3.4)
Group 3		
1 - *Critical Security of Supply*	**Yes**	Interesting in terms of system stability and reliability, even though limited volume of balancing from Norway
2 - *Continental Solution*	No	Not interesting/relevant (no balancing from Norway)
3 - *Bilateral Agreements*	(Yes)	Interesting, but entails an option (Norwegian policy on interconnectors and market framework, bilateral agreements); outcome similar to future 2b of Group 2 (*Nationalism with ambitions*)
4 - *Small Hydro Battery*	(Yes)	Interesting, but entails an option (Norwegian policy on investment volume); outcome is similar to future 2 of Group 1 (*Good Possibilities*)
5 - *Big Hydro Battery*	(Yes)	Interesting, but entails an option (Norwegian policy on investment volume); outcome is similar to future 4 of Group 1 (*Very Good Possibilities*)

5.2 Building the futures

With the group work on the selection of the most important uncertainties as a starting point, the uncertainties which the futures were further built on are listed and briefly described in Table 2. This step corresponds to the blue boxes in Figure 1. The uncertainties under “Assumptions” were assumed to be constant over all futures, i.e. to have the same values. The built futures are qualitatively described in the following chapters (5.2.1 to 5.2.4). Table 3 summarises their characteristics.

Table 2: Uncertainties considered for building the futures and brief description of these.

Uncertainty	**Comment**
Technology	
Share of VRES in electricity generation	Share of renewable energy sources in total annual electricity generation (TWh/year), which have a variable nature, i.e. fluctuate depending on weather conditions.
Expansion of European transmission grid	To which degree the transmission grid in European countries is expanded in relation to the grid today; measure for transfer capacities between countries.
Deployment of CCS	Availability and deployment of CCS; CCS may be available and deployed in generation units where economically viable.
Market	
Competition from alternative flexible technologies	Availability and costs of technologies, which provide flexibility or storage, and to which degree these are in competition with Norwegian hydropower: flexible generation units (e.g. gas power plants); storage technologies (e.g. batteries, fly wheels, power-to-gas, compressed air, thermal storage, etc.) and possibilities for DSM (electric vehicles, industrial processes, etc.).
EU regulatory framework and market integration	European Union's regulations of the European power markets: integration of different power markets (day-ahead, intra-day, balancing market) across Europe; at least at a level as today.
Policy	
Ambitions of countries to connect with Norway	Policy of the countries around the North Sea and the EU concerning the expansion of transmission grid capacities between Norway and the North Sea Countries.
Assumptions – constant Uncertainty	
GHG emission reduction in Europe	Reduction in total greenhouse gas emissions of at least 80 % compared to emissions in the year 1990.
Electricity consumption	Total amount of electricity used in an area (TWh/year); assumed to increase in future, primarily due to electrification of the transport and heating sector.
Maturity of RES technology	Technological maturity of technologies which generate electricity from renewable sources; technologies become economically more viable according to their learning curves.
Maturity of DSM technology	Technological maturity of technologies which may smooth the load.
Maturity of decentralised storage technologies	Technological maturity of energy storage technologies at distribution grid and end user level.

Further annotations:

- Greenhouse gas (GHG) emission reduction of at least 80 % compared to 1990 levels was chosen for all scenarios because this is the primary policy target that triggers RES development. Integration of VRES into the energy system, primarily wind power and PV, is the major driver for the need of more flexible generation and storage, and creates interesting cases for potential future roles of Norwegian hydropower. This choice is still appropriate after the EU leaders agreed on new energy and climate goals for 2030, including at least 40 % reduction in GHG emissions compared to 1990 [3].

- Storage technologies at distribution grid and end user level (decentralised storage) are assumed to be available and deployed in all futures, but may be used in different ways: passive versus active, e.g. batteries with PV installations or electric cars for smoothing the load from households versus participation in day-ahead market acting as storage and enabling integration of VRES. While in the futures with high competition with Norwegian hydropower the former is assumed, the latter is assumed in the futures with low competition.
- Other storage technologies at transmission grid level (centralised storage) than pumped storage hydropower are assumed to be utilised only in the futures with high competition with flexibility from Norwegian hydropower. This implies that large-scale storage, such as compressed air energy storage (CAES), power-to-gas or hydrogen, i.e. storage with time horizons of one day, days or weeks, is deployed in these futures. However, it is assumed that Norwegian hydropower will still have an economic advantage over these technologies according to the merit order. Pumped storage hydropower in other European countries is present in all scenarios and competes with Norwegian hydropower.
- DSM is available, but assumed to be used in different ways: While in the futures with low competition with flexibility from Norwegian hydropower DSM is assumed in large-scale industrial processes only, wide-spread application of DSM in households is assumed in the futures with high competition.

5.2.1 Future 1 – *Medium Demand*

The share of RES in electricity generation is at medium level. CCS is deployed in fossil generation units when it is economically viable, dependent on the carbon price and generation technology (gas, coal). The same GHG emission reduction targets can be achieved with less renewable electricity generation. This implies less VRES such as wind power and photovoltaic, and moderate expansion of the European transmission grid, as well as moderate ambitions of countries around the North Sea area to build interconnectors with Norway. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. There is a lack of units providing flexibility and storage, and the European transmission grid's ability to balance the generation from VRES is limited. Hence, the competition with Norwegian hydropower as a provider of balancing is low, and there is still interest of countries around the North Sea in strengthening and expanding grid connections to Norway. EU policy leads to a regulatory framework that fully integrates markets across Europe, i.e. European-wide power markets for trade on both long time horizons (day-ahead) and short time horizons (intra-day, intra-hour, balancing market) are established. These conditions lead to medium demand for balancing from Norwegian hydropower.

5.2.2 Future 2 – *Niche Market*

CCS technology is not available. This leads to high penetration of RES in the European electricity sector. European countries strive to achieve their GHG emission reduction targets. Most of the electricity is generated by VRES leading to a high demand for flexible generation and storage. However, the European transmission grid is strengthened only moderately. Both decentralised and centralised storage technologies are deployed and cover parts of the required balancing in Europe. Consequently, the competition with balancing from Norwegian hydropower is high and the ambitions of the North Sea Countries to build interconnectors with Norway are moderate. Power markets are integrated within Europe with respect to trade on long time horizons (day-ahead), but there is no common framework for the trade of services across Europe related to flexible generation and storage on short time horizons (intra-day, intra-hour, balancing market). These conditions lead to Norway being a provider of balancing on long time horizons only (day, days and longer) with participation in the day-ahead market. Other European countries cover their need for balancing on short time horizons themselves.

5.2.3 Future 3 – *Various Flexibility Types*

CCS technology is not available. This leads to high penetration of RES in the European electricity sector. Most of the electricity is generated by VRES leading to a high demand for flexible generation and storage. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. There is a lack of units providing flexibility and storage. The European transmission grid is expanded strongly, and ambitions of the North Sea Countries to expand interconnections with Norway are strong. EU policy for the regulatory framework of power markets results in fully integrated European power markets including trade on various time horizons. The lack of alternative flexible technologies and the low competition with Norwegian hydropower create a large demand for balancing from Norwegian hydropower across all time scales. Norway provides various types of balancing to the North Sea Countries through a strong transmission grid and integrated power markets.

5.2.4 Future 4 – *Critical Supply*

CCS technology is not available. This leads to high penetration of RES in the European electricity sector. Most of the electricity is generated by VRES leading to a high demand for flexible generation and storage. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. Hence, there is a strong lack of units providing flexibility and storage, and the competition with balancing from Norwegian hydropower is low. However, the expansion of the European transmission grid is limited due to conflicts, public opposition or delays in transmission line projects. Ambitions of the North Sea Countries to expand interconnections with Norway are strong because these countries have a large demand for flexible generation and storage which they cannot cover themselves. The EU establishes a common market framework for trade on long time horizons across Europe, but there is no common framework for trade of services across Europe related to flexibility and storage on short time horizons. The combination of high generation from VRES, limited grid transmission capacities and a lack of flexible generation and storage causes situations of critical security of supply in the Central European electricity system. The demand for balancing from Norwegian hydropower is high.

Table 3: Characteristics of the four HydroBalance futures. Cells marked green indicate that this factor supports a large volume of flexibility and storage from Norwegian hydropower, while red indicates a medium or small volume.

Uncertainty	Possible values*	Future 1	Future 2	Future 3	Future 4
		Medium Demand	***Niche Market***	***Various Flexibility***	***Critical Supply***
Technology					
VRES share in electricity generation	High/Medium	Medium	High	High	High
Expansion of European transmission grid	Strong/Moderate/Limited	Moderate	Moderate	Strong	Limited
Deployment of CCS	Yes/No	Yes	No	No	No
Market					
Competition from alternative flexible technologies	High/Low	Low	High	Low	Low
EU regulatory framework and market integration	Fully integrated/Day-ahead only	Fully integrated	Day-ahead only	Fully integrated	Day-ahead only
Policy					
Ambitions of countries to connect with Norway	Strong/Moderate	Moderate	Moderate	Strong	Strong
Assumptions - constant *Uncertainty*					
GHG emission reductions in Europe	High	High	High	High	High
Electricity consumption	Increase	Increase	Increase	Increase	Increase
Maturity of RES technology	Mature	Mature	Mature	Mature	Mature
Maturity of DSM technology	Mature	Mature	Mature	Mature	Mature
Maturity of decentralised storage technologies	Mature	Mature	Mature	Mature	Mature

* Values like “strong”, “moderate” or “limited” always refer to today's situation. For instance, limited expansion of the European transmission grid means that more transmission capacity between countries is available than today, even though the development is limited.

5.3 Building the strategies

In the process of building the strategies (cf. orange boxes in Figure 1) a number of options was selected. Since the Norwegian hydropower system and its potential future roles is the focus of HydroBalance, we here defined options as factors which Norwegian decision makers can decide on. Hence, options in HydroBalance only refer to choices which Norwegian policy controls, while EU and national state policies are considered as uncertainties. The selected options are described in Table 4. In this selection, the options in the futures resulting from the workshop were included, if possible. For instance, the Norwegian policy on interconnectors was included as an option in the strategies, and the idea of possible bilateral agreements (cf. Table 1) was included in *Strategy 2 – Moderate Expansion* (cf. 5.3.2). The defined strategies are qualitatively described in the following chapters (5.3.1 to 5.3.4). Table 5 summarises their characteristics.

Table 4: Options considered in the strategies.

Option	Comment
Expansion of Norwegian transmission grid	Expansion of the national transmission grid in Norway.
New PSPP and upgrade of existing HSPP	Construction of new PSPP and upgrade of existing HSPP in Norway.
Support of VRES development	Support of the development of variable renewable energy sources in Norway, primarily wind power and small hydro.
Ambitions of Norway to build interconnectors	Policy of Norway concerning the expansion of transmission grid capacities between Norway and the North Sea Countries, construction of interconnectors.

5.3.1 Strategy 1 – *Active Climate Policy*

Norway has high ambitions to reach its emission targets and to contribute to climate mitigation. The development of RES is supported using active policy and communication to create a climate of public acceptance for environmentally sound projects. Expansion of the Norwegian hydropower system through construction of both new HSPP and PSPP is considered a positive contribution because it offers flexibility and storage to Europe, and enables development of RES at large scale in other European countries. For this purpose, and to enable balancing of domestic VRES, the Norwegian policy aims at strong expansion of the national transmission grid. Likewise, ambitions for building interconnectors with North Sea Countries are high.

5.3.2 Strategy 2 – *Moderate Expansion*

Norway's policy is to support transmission grid expansion, construction of new hydropower facilities as well as development of RES in a moderate way. The goal is to secure national security of supply in the electricity sector, balance Nordic VRES and use surplus energy mainly within the Nordic countries. Norway's ambitions for building interconnectors are moderate, i.e. the construction of some interconnectors is supported. These may be bilateral projects where an agreement between Norway and another country secures economic viability of the energy imports/exports.

5.3.3 Strategy 3 – *Value Creation*

Norway strategically exploits the potential of its hydropower system for providing flexibility and storage to Europe. The expansion of the Norwegian transmission grid as well as the construction of interconnectors is strongly supported, while the support of the development of RES in Norway is limited. For environmental or economic reasons, domestic VRES are not developed beyond the existing plans until 2020. The hydropower potential is used to balance VRES abroad.

5.3.4 Strategy 4 – *Nordic Only*

Norway develops its energy system in collaboration with the other Nordic Countries. Development of RES and phase-out of both nuclear and fossil generation is central in the Nordic countries' policy. The national transmission grids are strengthened in order to enable development and balancing of VRES. Ambitions for building interconnectors with countries outside the Nordic Countries are weak, while connections to Nordic Countries are supported. Consequently, capacities in hydro storage plants are increased in order to provide more flexible generation for balancing VRES, but the construction of pumped storage plants is not expected. Furthermore, Norwegian policy actively supports the use of surplus electricity domestically or within the Nordic Countries, e.g. by attracting energy-intensive industry.

Table 5: Characteristics of the four HydroBalance strategies.

Option	Possible values	Strategy 1	Strategy 2	Strategy 3	Strategy 4
		Active Climate Policy	***Moderate Expansion***	***Value Creation***	***Nordic Only***
Expansion of Norwegian transmission grid	Strong/Moderate	Strong	Moderate	Strong	Strong
New PSPP and upgrade of existing HSPP	Strong/Moderate/Limited	Strong	Moderate	Strong	Limited
Support of VRES development	Strong/Moderate/Limited	Strong	Moderate	Limited	Strong
Ambitions of Norway to build interconnectors	Strong/Moderate/Weak	Strong	Moderate	Strong	Weak

5.4 Building the scenarios

The combination of the futures and strategies resulted in 16 scenarios (Table 6). These are briefly described in Table 7. Out of the 16 scenarios, 4 were selected. The main criterion for the selection was whether the scenarios are expected to represent relevant and interesting cases for analyses in the project. Another goal was to achieve differences between the scenarios in terms of volumes and types of flexibility to be provided by Norwegian hydropower, so that the scenario analyses would result in different but relevant pictures of the future. In the case that several scenarios resulted in similar outcome, they were selected with the aim to use different futures and strategies. For instance, scenario 1, 2, 3 and 10 resulted in similar volumes and types of flexibility, but scenario 2 was chosen because it was the only scenario strategy 2 – *Moderate Expansion* and future 1 – *Medium Demand* were interesting to use with. The four HydroBalance scenarios are described qualitatively in Chapter 6.

Table 6: Combination of futures and strategies into scenarios. Bold numbers indicate relevant scenarios, grey numbers irrelevant scenarios, grey shading grouping of scenarios with similar outcome (1, 2, 3 and 10; 5 and 7; 9 and 11), and borders the four selected scenarios.

	Strategies	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Futures		***Active Climate Policy***	***Moderate Expansion***	***Value Creation***	***Nordic Only***
Future 1	***Medium Demand***	**1**	**2 = A**	**3**	4
Future 2	***Niche Market***	**5**	6	**7 = C**	8
Future 3	***Various Flexibility***	**9 = B**	**10**	**11**	12
Future 4	***Critical Supply***	13	14	15	**16 = D**

Table 7: Short description of each scenario resulting from combining the futures with the strategies, including the resulting volumes of flexibility and storage, and the time horizon of balancing provided by Norwegian hydropower in each case. The four scenarios in bold were selected based on these characteristics.

Scenario number	Characteristics	Volume and type of balancing
1	Ambitions in Norway higher than in EU, but moderate flexibility and storage demand leads to medium volume of balancing over various time scales delivered by Norway.	Medium, all time scales
2 = A	**Ambitions are at moderate level both in Norway and EU; leads to a small volume of balancing over various time scales.**	**Small, all time scales**
3	Ambitions in Norway higher than in EU, but moderate flexibility and storage demand leads to medium volume of balancing over various time scales delivered by Norway	Medium, all time scales
4	Weak ambitions of Norway (focus on balancing its own/Nordic VRES) in combination with moderate ambitions by EU to build interconnectors; hence, no substantial exchange, level about as expected in 2020.	No substantial volume
5	High ambitions in Norway, but moderate interest of countries to connect to Norway due to alternative solutions for balancing on short time horizons; leads to medium volume of balancing on long time horizons only, based on common day-ahead market.	Medium, long time horizons only
6	High competition with Norwegian hydropower in combination with moderate ambitions from Norway and EU lead to small to medium volume of balancing on long time horizons.	Small to medium, long time horizons only

Scenario number	Characteristics	Volume and type of balancing
7 = C	**High competition with Norwegian hydropower in combination with strong focus in Norway to provide balancing leads to medium volume of balancing on long time horizons.**	**Medium, long time horizons only**
8	Weak ambitions of Norway in combination with high demand for balancing on long time horizons by EU lead to no substantial volume of balancing from Norway to EU, but small volume to other Nordic Countries.	No substantial to small, long time horizons only
9 = B	**EU's and Norway's development are complementary; this leads to high demand and large volume of balancing from Norway over various time scales.**	**Large, all time scales**
10	Demand from EU is high and conditions are very good, but Norway's moderate ambitions lead to medium volume of various types of balancing.	Medium, all time scales
11	Demand from EU is high and conditions are very good; in combination with Norway's focus on providing flexibility and storage this leads to a large volume of various types of balancing.	Large, all time scales
12	Weak ambitions of Norway/Nordic focus in combination with high demand for flexibility and storage by EU lead to a small volume of balancing (limited by interconnectors).	Small, all time scales
13	Specific countries and Norway support interconnectors. EU transmission grid is not sufficiently expanded. This leads to critical supply situations within EU. Norway can provide flexibility and storage on long time horizons.	Medium, long time horizons only
14	EU demands flexibility and storage due to critical supply situations, but Norway supports interconnectors only to moderate extent; small volume of balancing.	Small, long time horizons only
15	EU demands flexibility and storage due to critical supply situations, and Norway works actively for interconnections. This leads to a small to medium volume of balancing from Norway (limited by EU grid and interconnectors).	Small to medium, long time horizons only
16 = D	**Weak ambitions of Norway/Nordic focus (no support for interconnectors), critical supply situations in EU. Hence, Norway uses its flexibility and storage mostly within the Nordic countries, while exchange with other countries is about as expected in 2020.**	**Small, long time horizons only**

6 Description of the selected scenarios

In this chapter, the four selected scenarios for the HydroBalance are described in detail. First, they are described one by one in Chapter 6.1 to Chapter 6.4. Then their main characteristics are summarised and compared in Chapter 6.5 (see also Appendix A5).

6.1 Scenario A – *Small Storage*

Both Norway and other European countries have moderate ambitions for using Norway's hydropower resources in order to balance electricity generation from VRES. The moderate demand for flexible generation and storage from Norwegian hydropower in European countries is a consequence of the medium RES share in electricity generation in combination with a lack of large-scale storage and moderate transmission grid expansion. Deployment of CCS in fossil generation units gives lower investments in RES. Even though the share of RES in electricity generation is at medium level, the same GHG emission reductions are achieved. Less RES deployment results in moderate expansion of the European transmission grid. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. In combination with limited capacities in the European transmission grid this results in a lack of flexibility and storage at large scale, and hence low competition with Norwegian hydropower as a provider of balancing. EU policy leads to a regulatory framework that fully integrates markets across Europe, i.e. a European-wide power market for trade on both long and short time horizons is established, providing good conditions for trading products related to balancing across national borders. In line with the moderate ambitions of European countries to strengthen grid connections with Norway, Norway's policy supports a moderate expansion of its transmission grid as well as hydropower system and VRES generation (wind power, small hydropower, photovoltaic). Securing national security of supply, balancing Nordic VRES and using surplus energy mostly within the Nordic Countries is prioritised. However, some interconnectors are supported. These connections may be part of the European transmission grid expansion or bilateral projects, where an agreement between Norway and another country secures economic viability of the energy and service exchanges. Consequently, Norwegian hydropower provides small volumes of balancing to the North Sea Countries over all time scales.

6.2 Scenario B – *Big Storage*

Both Norway and European countries have strong ambitions for using Norway's hydropower resources in order to balance electricity generation from VRES. In the European countries the high demand for flexible generation and storage from Norwegian hydropower is a consequence of the high RES share in electricity generation in combination with a lack of large-scale storage. Since CCS technology is not available the penetration of RES in the electricity sector is high. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. Hence, there is a strong lack of units providing flexibility and storage at large scale, and the competition with Norwegian hydropower as a provider of balancing is low. The strong expansion of the European transmission grid and integration of markets across Europe for trade on both long and short time horizons create good conditions for trading products related to flexibility and storage across national borders. Norway's policy is an active climate policy, focusing on GHG emission reductions and climate mitigation. Norway is expected to develop RES and to contribute to the integration of VRES into the European energy system by providing balancing on large scale. The Norwegian hydropower system is strongly expanded with new hydro storage and pumped storage power plants using existing reservoirs. The national transmission grid is expanded including interconnectors with the North Sea Countries. Active policy and communication create a climate of public acceptance for environmentally sound projects. Norway provides various types of balancing to countries around the North Sea through a strong transmission grid and integrated power markets. Consequently, Norwegian hydropower provides large volumes of balancing to the North Sea Countries over all time scales.

6.3 Scenario C – *Niche Storage*

While European countries have moderate ambitions for using Norway's hydropower resources in order to balance electricity generation from VRES, Norway has strong ambitions and focuses on strategically using its hydropower resources to provide services which are demanded on the European power market. In European countries the high demand for specific types of flexible generation and storage from Norwegian hydropower is a consequence of the high RES share in electricity generation in combination with the availability of energy storage technologies. Since CCS technology is not available the penetration of RES in the electricity sector is high. Both decentralised and centralised energy storage technologies are deployed. Hence, the competition with Norwegian hydropower as a provider of flexible generation and storage is high. Parts of the required high volume of balancing in Europe are supplied by other technologies, on large scale and long time horizons by hydrogen/power to gas, in particular. This leads to moderate ambitions of the North Sea Countries for building interconnectors with Norway and moderate expansion of the European transmission grid. 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 flexible generation and storage on short time horizons. Norway exploits the potential of its hydropower system focusing on balancing on long time horizons, since the demand for this type of balancing in the European power market is high. The expansion of the Norwegian transmission grid as well as the construction of new hydropower plants and interconnectors is strongly supported. However, the deployment of VRES in Norway is limited due to environmental or economic reasons. The additional hydropower potential is used to balance VRES abroad. Consequently, Norwegian hydropower provides medium volumes of balancing to the North Sea Countries, but only on long time horizons (participation in the day-ahead market).

6.4 Scenario D – *Nordic Storage*

While European countries have strong ambitions for using Norway's hydropower resources in order to balance electricity generation from VRES, Norway has weak ambitions and focuses on using its hydropower system to provide services to the Nordic Countries. Since CCS technology is not available the penetration of RES in the electricity sector is high. Decentralised storage technologies are used, while other centralised storage technologies than pumped storage hydropower are not deployed. Hence, there is a strong lack of technologies providing flexibility and storage at large scale, and the competition with Norwegian hydropower as a provider of balancing is low. The expansion of the European transmission grid is limited because of conflicts, public opposition or delays in transmission line projects. The lack of transmission capacity increases the need for flexible generation and storage. Therefore, the ambitions of countries around the North Sea to strengthen grid connections with Norway are strong. 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 flexible generation and storage on short time horizons. However, Norway pursues a policy that supports the development of a common Nordic energy system. Electricity from RES is mainly used domestically or within the Nordic Countries, respectively, i.e. there is no net export. Value creation is supported, e.g. by using surplus energy for providing cheap electricity to energy-intensive industry. Instead of exporting renewable electricity, Norway becomes an exporter of products manufactured based on renewable energy. The national transmission grid is strongly expanded in order to enable development and balancing of VRES. Both fossil and nuclear generation in the Nordic power system are phased out. Ambitions for building interconnectors to countries outside the Nordic Countries are weak, while connections to other Nordic Countries are supported. The expansion of the Norwegian hydropower system is limited, i.e. capacities in existing hydro storage plants are increased in order to provide more flexible production for balancing VRES, but pumped storage plants are not expected to be constructed. All in all, the combination of a high VRES share, limited grid transmission capacity, a lack of flexible generation and storage in Central Europe and too little transmission capacity between the Nordic Countries and other European countries causes 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 European countries is restricted to balancing on long time horizons with transmission capacities as they are foreseen for the year 2020.

6.5 Main scenario characteristics

The four scenarios differ from each other in basically three aspects: i) the degree of integration of Norway with the power markets and grid of Central Europe and the UK, ii) the expected volume of balancing provided by Norwegian hydropower, and iii) the type of balancing in terms of time horizons, from seconds and minutes to days and weeks. The differences between the scenarios regarding these three aspects are illustrated by Figure 10. In order to enable to grasp at a glance most of the information lying in the scenarios and to facilitate comparison between them, Figure 11 displays the values of all uncertainties as well as options in the four scenarios by the use of radar diagrams. Values towards the outside of the circles indicate conditions which are in favour for large volumes of balancing from Norwegian hydropower[1]. The radar diagrams visualise the conditions in each of the scenarios. While in the *Big Storage* scenario the conditions favour a large volume of balancing from Norway, they favour a medium volume in *Small Storage*. The conditions vary between favourable and unfavourable for large volumes of balancing among the different factors in *Nordic Storage*. The dominance of favourable conditions on the diagram's left part in the *Niche Storage* scenario reflects the less favourable conditions on the European side in this scenario, while ambitions in Norway are high. In Appendix A5, tables giving an overview of all uncertainties and options for each scenario are included.

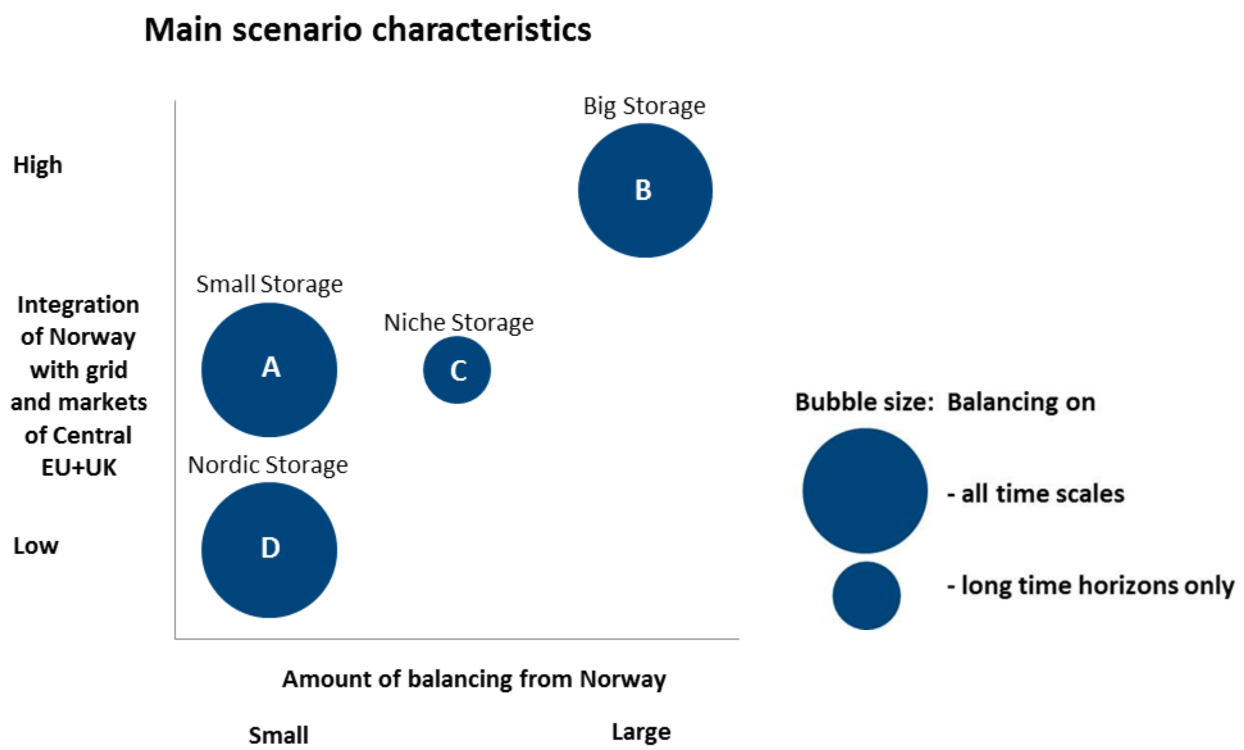

Figure 10: Illustration of the main differences between the four HydroBalance scenarios.

[1] Note that regarding the option "Support of VRES in Norway" the differentiation between a favourable and unfavourable condition for a large volume of balancing from Norway is not as clear as for the other factors. Here, we assumed that high deployment of RES in Norway is less favourable than limited RES development, because VRES in Norway will require additional reserve capacity in the Norwegian power system. However, the capacity required for reserve capacity to back up VRES, given as proportion of the total installed VRES capacity (assuming wind power), would be low, corresponding to less than 5 % of the installed wind capacity for a wind penetration of up to 30 % of the gross demand [4]. This means that the effect of VRES development in Norway on the volume of balancing that can be provided by Norway is not as large as it seems in the radar diagrams.

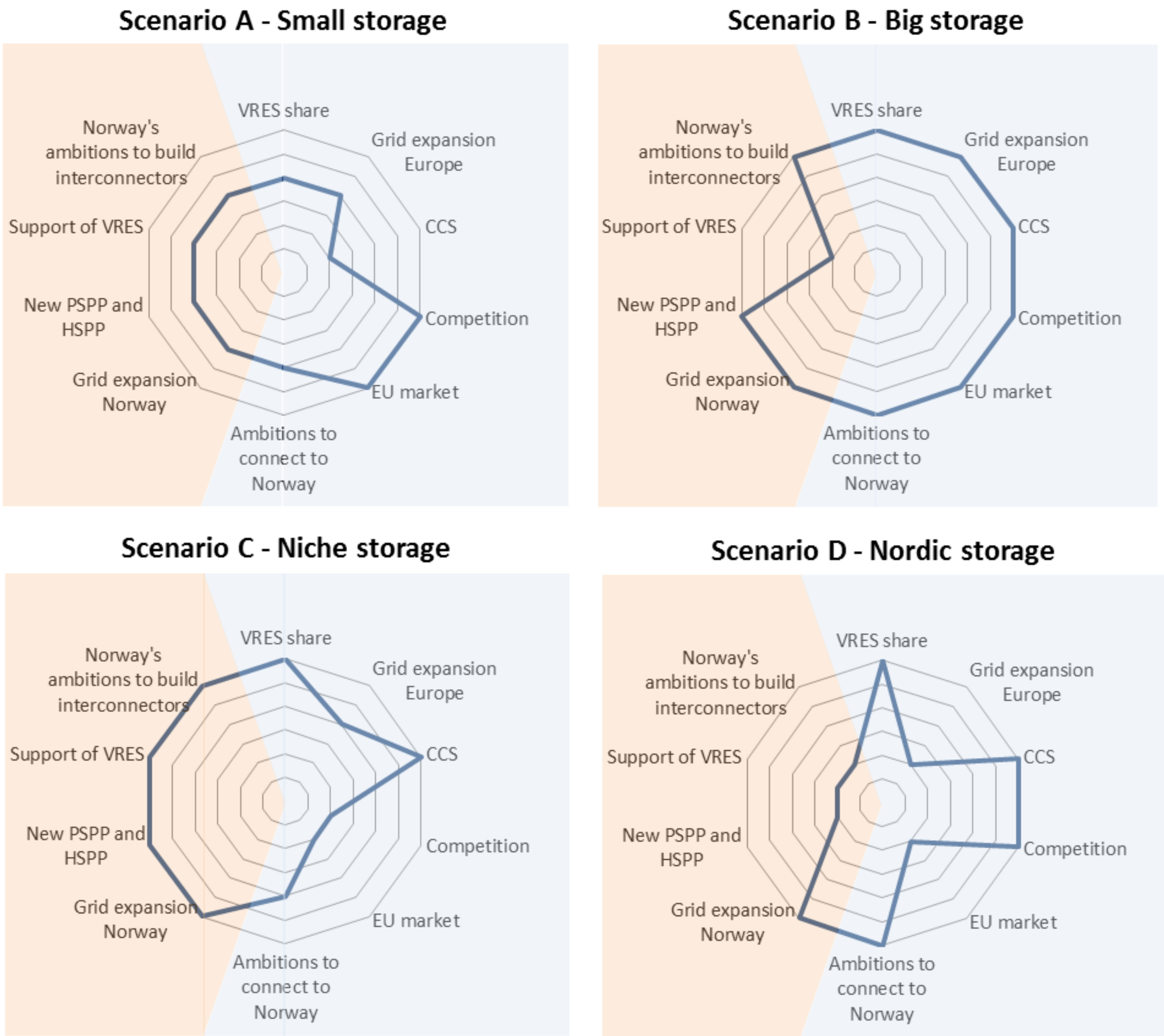

Figure 11: Illustration of the four HydroBalance scenarios. The chosen values of all uncertainties of a future as well as all options of a strategy are displayed in the radar diagrams. Conditions are in favour for large volumes of balancing from Norwegian hydropower towards the outside of the circles, while they are less favourable towards the inside. Options are shown in the left parts of the circles (yellow), uncertainties in the right parts (blue).

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7 Consistency with other scenarios

In the following sections we evaluate to what extent the four HydroBalance scenarios are complementary with scenarios from other relevant studies. We chose to examine one global, one European and one Nordic study: IEA Energy Technology Perspectives 2014/World Energy Outlook 2013, EU Energy Roadmap 2050 and NORSTRAT, respectively. On the basis of this evaluation, general factors like demography, economic growth and prices for fuels and CO_2 may be chosen for the HydroBalance scenarios when quantifying them. The reviewed studies may also be used as benchmarks for comparing portfolio parameters, such as installed capacity or electricity generation.

Economic and population growth in all EU Roadmap 2050 and ETP 2014 scenarios lie in the same range as the values of many other energy scenarios: 1.5 % to 2.0 % annual economic growth and 495 to 515 million inhabitants in 2050, respectively [1]. In contrast, scenarios show a large variation in fuel and CO_2 prices, ranging from 71 to 149 USD (2010) per barrel oil equivalent for oil, 46 to 99 for natural gas and 12 to 34 for hard coal, and 42 to 310 Euro (2008) per ton for CO_2, respectively [1].

7.1 IEA Energy Technology Perspectives

The IEA uses three main scenarios in its Energy Technology Perspectives (ETP) [5]: The *6 Degree Scenario* (*6DS*), *4DS* and *2DS*. They are associated with an expected global average temperature rise of at least 6 ºC, maximum 4 ºC and maximum 2 ºC, respectively. The *6DS* largely complies with the *Current Policy Scenario* of the IEA's yearly World Energy Outlook up to the year 2035 [6], while the *4DS* is consistent with the *New Policies Scenario*, and the *2DS* with the *450 Scenario*. In addition, there are three variants of the *2DS* exploring paths to achieve the 2 ºC target with even more renewable energy (*2DS hi-Ren*), electrification of transport (*2DS-ET*) or electrification of buildings (*2DS-EB*). Important points of the ETP scenarios are:

- Decarbonisation of the electricity sector by means of renewable energy (Figure 12), energy efficiency and CCS (Figure 13).
- Electrification, mainly in the heating and transport sector.
- Increase in global electricity demand between 80 and 130 %, but decrease of emission intensity (carbon dioxide emissions per unit electricity).
- The power sector contributes most to emission reductions among energy sectors (ca. 40 %).
- RES and energy efficiency contribute most to emission reductions among energy technologies (ca. one third each).
- Cut of GHG emissions in the EU by 10 % (*6DS*), 33 % (*4DS*) and 69 % (*2DS*).
- All include the use of CCS to varying degree (Figure 13), although it is stated that the future of CCS is uncertain because the technology has advanced slowly.
- Gas power plays an important role: First of all in the *2DS* gas-fired generation replaces coal-fired generation; gas power plants provide the main source for flexible generation and are regarded as the bridge technology for the integration of VRES.
- Storage applications are not regarded as a driver for the transition of the energy system, but are expected to be increasingly used with rising RES share to exploit the value of their flexibility, first of all with respect to frequency regulation, load following and off-grid applications in the near to medium term.

Table 8: Summary of the three main scenarios of IEA's Energy Technology Perspectives. Source: [5].

Scenario	Description
6DS	Projection of current trends: Too little efforts to reduce global GHG emissions cause a rise of

Scenario	Description
	the global average temperature of at least 6 ºC in the long term. Global increase in energy use and GHG emissions of more than two thirds by 2050.
4DS	Consideration of recent pledges by countries to reduce GHG emissions and increase energy efficiency. Global average temperature rise limited to 4 ºC.
2DS	Description of changes in the energy system required to limit the global average temperature rise to 2 ºC. Includes 50 % reduction in GHG emissions by 2050 compared to 2011.

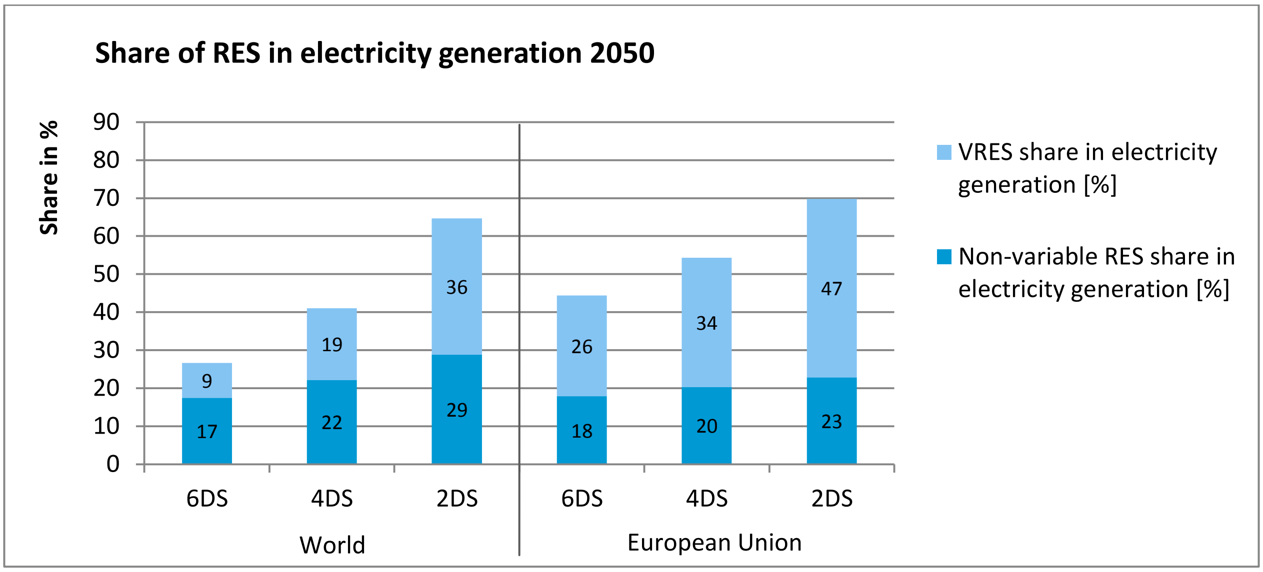

Figure 12: Share of RES in total electricity generation by the year 2050 in the three main ETP scenarios for the world (left) and the EU (right), split in variable (here: wind and solar power, excl. small hydropower) and non-variable RES (hydropower, biomass, waste, geothermal). Source: [5].

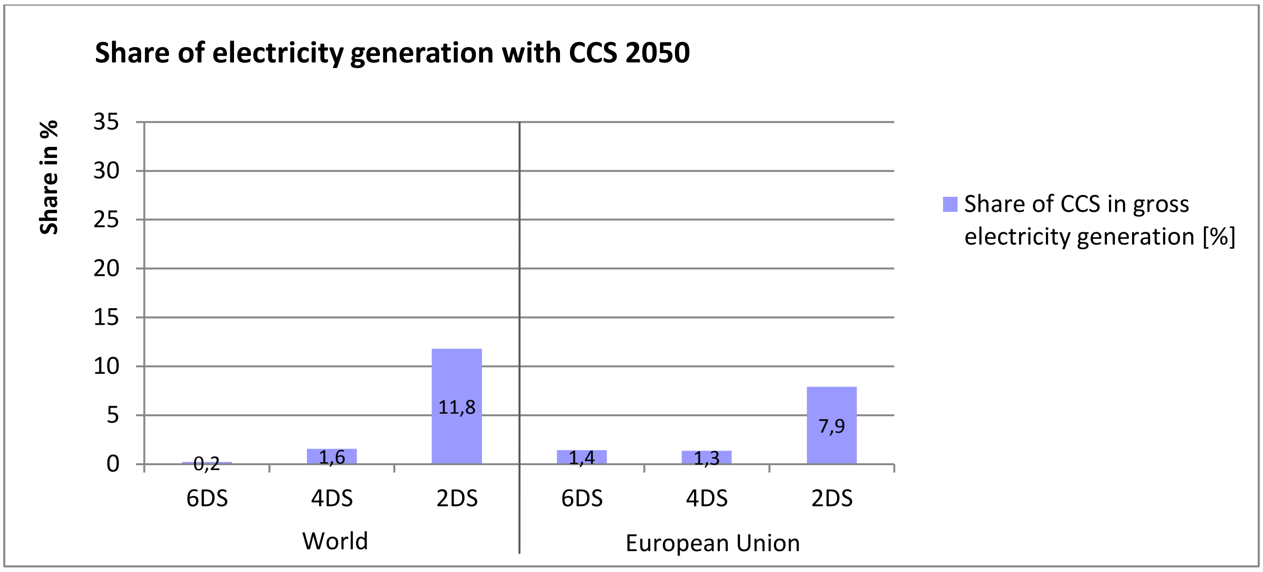

Figure 13: Share of electricity generation with CCS in gross electricity generation by the year 2050 in the three main ETP scenarios for the world (left) and the EU (right). Source: [5].

Similarities with/differences to specific HydroBalance scenarios are as follows:

- None of the HydroBalance scenarios complies with the *6DS*, because this scenario is a "business as usual" scenario leading to an increase in world-wide GHG emissions and only small GHG emission reductions in the EU. Furthermore, all HydroBalance scenarios assume a medium to high VRES share while the *6DS* has a low VRES share. Similar applies to the *4DS*: Even though it has a higher VRES share and larger GHG emission reduction, the values are lower than it is assumed for the HydroBalance scenarios.
- The *2DS* fits in terms of a medium to high VRES share as well as a GHG emission reduction that is almost as large as assumed in the HydroBalance scenarios (69 % versus 80 %). However, it does not comply with the HydroBalance scenarios with respect to the deployment of CCS. The *2DS* assumes 8 % of the European electricity generation to have CCS, while we included CCS deployment only in one of the HydroBalance scenarios (A – *Small storage*).

In addition, the IEA published a technology roadmap for the world-wide development of the hydropower sector until the year 2050 (Technology Roadmap Hydropower, [7]). This roadmap includes the expected installed capacity of pumped storage for two scenarios from the ETP, the *2DS* and *2DS hi-Ren* (Figure 14). According to [7], about half of the technical hydropower potential in Europe has already been developed. The remaining undeveloped potential is 660 TWh per year, of which 276 TWh are located in EU member states, 200 TWh in Turkey and 184 TWh in other countries. Taking into account environmental restrictions, feasibility and economic viability, the authors state that the technical potential will certainly not be fully exploited, but an increase from about 590 TWh annual hydropower generation in Europe in 2011 to 915 TWh in 2050, and from 210 GW to 310 GW installed capacity, respectively, is regarded as feasible.

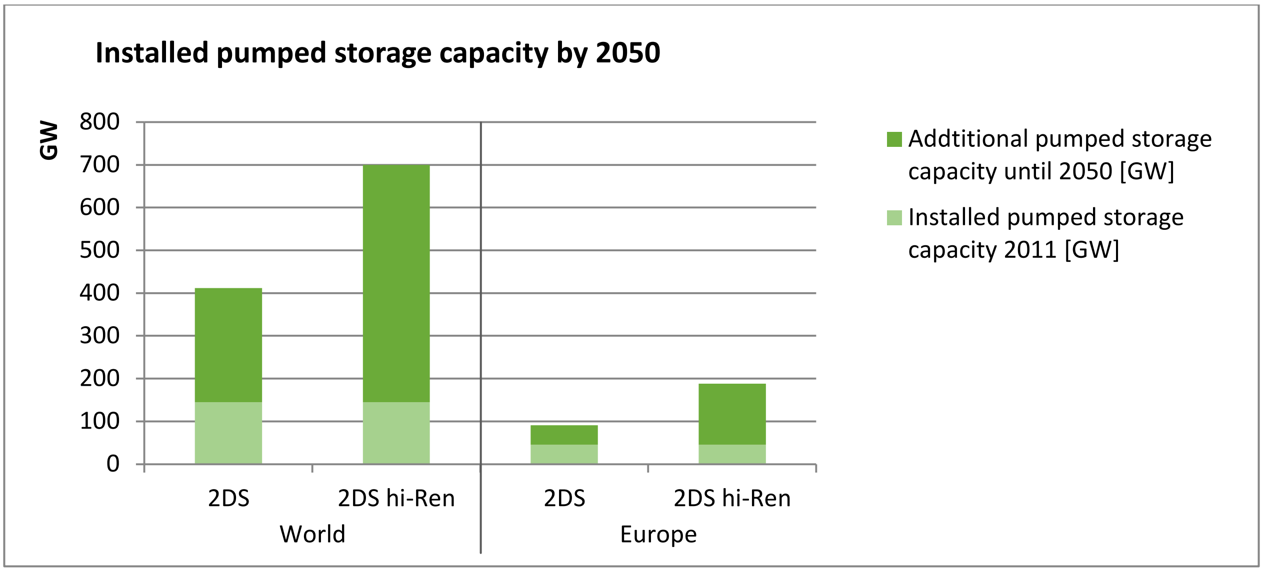

Figure 14: Installed capacity of pumped storage hydropower by the year 2050 in the ETP scenarios *2DS* and *2DS hi-Ren* for the world (left) and Europe (right). Source: [7].

7.2 EU Energy Roadmap 2050

The Energy Roadmap 2050 [8], published by the European Commission in 2011, comprises the EU-27 countries. The document describes pathways to a low-carbon economy with a reduction in GHG emissions of 80 to 95 % compared to 1990 emissions by the year 2050. Building upon the Europe 2020 strategy [9], this roadmap examines seven scenarios, of which two are "business as usual developments" and five aim at achieving at least 80 % reduction in total GHG emissions. The main characteristics of the five low-carbon scenarios are briefly described in Table 9. Common to all five low-carbon scenarios are the following aspects:

- Reduction of energy-related CO_2 emissions by 85 % compared to 1990 emissions.
- Increase in electricity consumption between 16 and 31 % from 2005 to 2050 (Figure 15).
- Medium to high share of RES in electricity generation, 59 to 83 % (Figure 16).
- Policies for development of RES and support of all low-carbon technologies including nuclear, CCS and RES with required infrastructure.
- Energy storage and transmission: Increased pumped storage hydropower, grid transmission expansion, power to gas with feed into gas grid (indirect storage) and hydrogen storage with transformation back into electricity are used to balance generation from VRES.
- All include the use of CCS, but to varying degree (Figure 17).

Table 9: Characteristics of the five low-carbon scenarios of the EU Energy Roadmap 2050. Source: [1], [8].

Scenario	Description
High Energy Efficiency	Based on political commitment to very high primary energy savings by 2050 and stringent implementation of the Energy Efficiency Plan (20 % energy savings by 2020), followed by additional strong minimum requirements for appliances of different product groups and for energy generation, transmission and distribution; high refurbishment rate of existing buildings; passive house standard for all new buildings; obligations of energy utilities to achieve energy savings; wide use of smart grids and smart metering; and high penetration of decentralised RES units.
Diversified Supply Technologies	Market-based development driven by carbon prices and carbon values in both ETS and non-ETS sectors. Assumes confidence in and acceptance of CCS and nuclear power; no additional policies besides competition of all energy sources based on economic viability and carbon prices.
High RES	Aims at achieving very high overall RES share and penetration of RES in the electricity sector by implementing RES facilitating policies, e.g. shorter lead times in construction and greater progress on learning curves. Market integration allows for more trade, including increased cross-border transmission capacities, cooperation mechanisms and exploitation of offshore wind power in the North Sea. Policies facilitate low-carbon solutions in the power generation, heating and transport sector. Decentralised and micro power generation is supported. Energy storage is provided by pumped storage hydropower, concentrated solar power and hydrogen. DSM is established for peak/off-peak shifting.
Delayed CCS	Due to low public acceptance of carbon storage and transportation, CCS is assumed to be deployed from 2040. Otherwise similar to *Diversified Supply Technologies* scenario including high acceptance of nuclear power.
Low Nuclear	Due to low public acceptance of nuclear power no new nuclear plants are built, except from the ones currently under construction; no lifetime extension of nuclear plants after 2030. Otherwise similar to *Diversified Supply Technologies* scenario, but nuclear power is substituted by fossil generation with CCS.

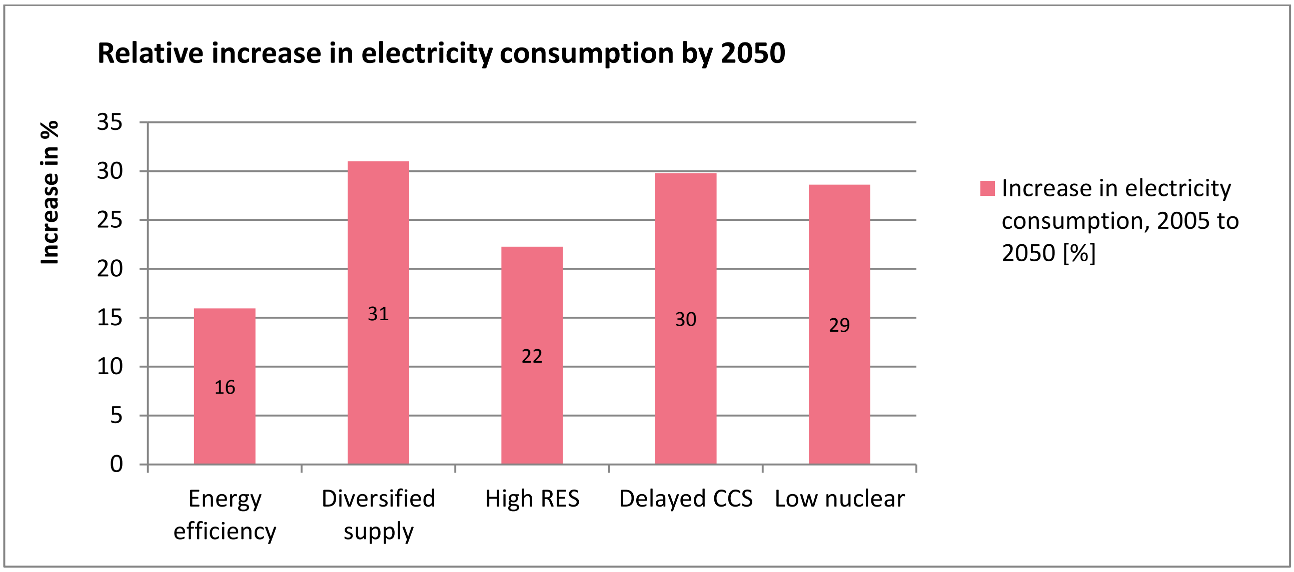

Figure 15: Relative increase in electricity consumption from 2005 to 2050 in the five low-carbon scenarios. Source: [8].

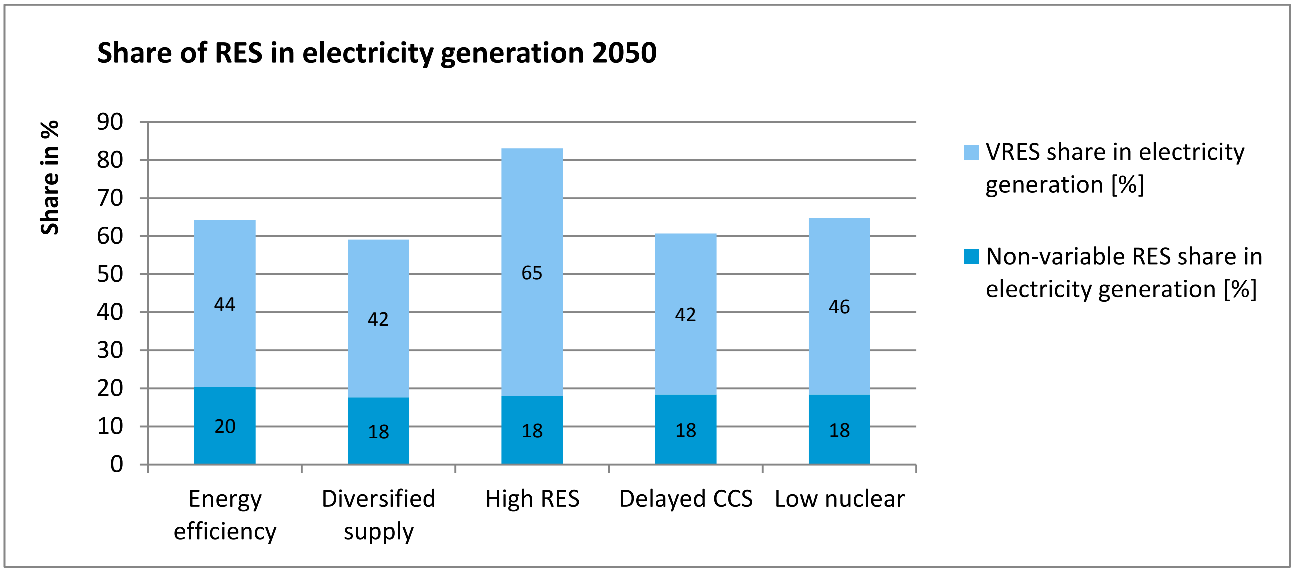

Figure 16: Share of RES in total electricity generation by the year 2050 in the five low-carbon scenarios, split in variable (here: wind and solar power, excl. small hydropower) and non-variable RES (hydropower, biomass, waste, geothermal). Source: [8].

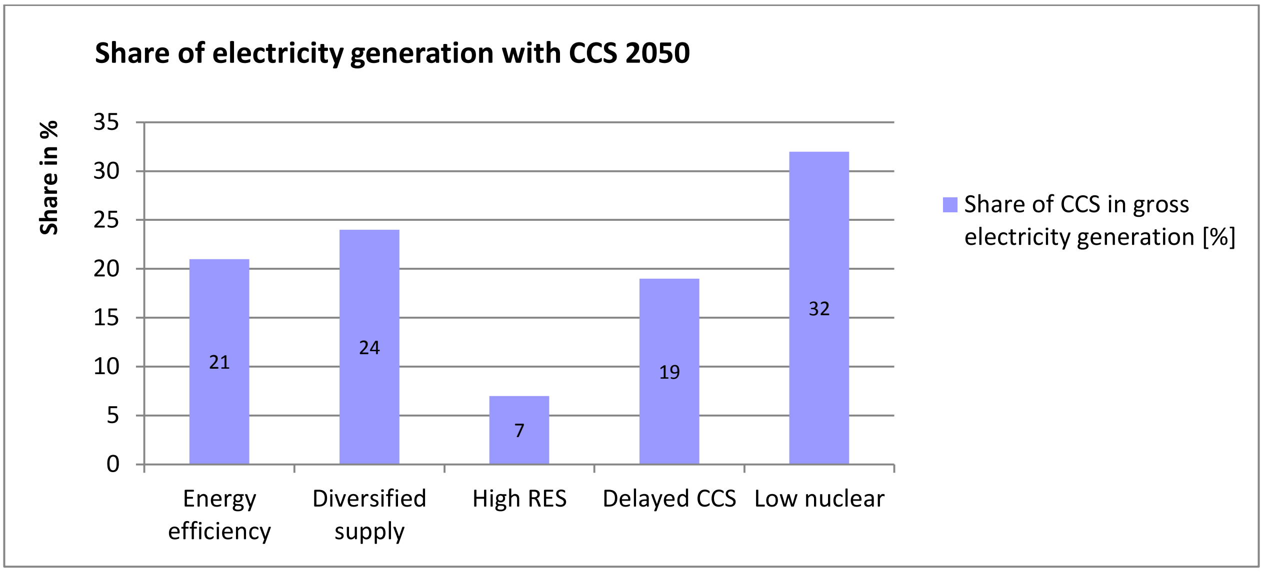

Figure 17: Share of electricity generation with CCS in gross electricity generation by the year 2050 in the five low-carbon scenarios. Source: [8].

The four HydroBalance scenarios share the following aspects with all five low-carbon scenarios of the EU Energy Roadmap 2050:

- Reduction in total GHG emissions of at least 80 % compared to 1990 emissions.
- Increase in electricity consumption.
- Medium to high share of VRES in electricity generation, 42 to 65 %.

The four HydroBalance scenarios are different from the five low-carbon scenarios in terms of:

- Centralised energy storage: In all EU Energy Roadmap 2050 low-carbon scenarios electricity generation from VRES is balanced by increased pumped storage hydropower, grid transmission expansion, power to gas with feed into gas grid (indirect storage) and hydrogen storage with transformation back into electricity. However, HydroBalance scenarios A, B and D assume low competition from alternative flexible technologies. Hence, they do not consider other centralised storage than pumped storage to be economically viable. Even in scenario C, which assumes high competition with Norwegian hydropower and economic viability of both decentralised and centralised storage, we expect Norwegian hydropower to have economic advantage over hydrogen storage and power-to-gas on long time horizons for balancing (days, weeks).
- Decentralised generation and storage, DSM: First of all the *High RES* scenario of the EU Energy Roadmap 2050 assumes large penetration of decentralised or micro power generation and DSM. This would create high competition with Norwegian hydropower as a provider of balancing, at least on short time horizons. For the HydroBalance scenarios we assumed that decentralised storage is available in all scenarios, but it may be used in a passive or active way providing weaker (B – *Big Storage*) or stronger (C – *Niche Storage*) competition: e.g. batteries with PV installations or electric cars for smoothing the load versus participation in day-ahead market acting as storage that enables integration of VRES. Corresponding applies to DSM.
- Use of CCS: All EU Energy Roadmap 2050 scenarios include deployment of CCS technology, although to different degree, while we assume economic viability of CCS only in HydroBalance scenario A – *Small Storage*.

Similarities and differences with specific HydroBalance scenarios are as follows:

- *Diversified Supply Technologies* and A – *Small Storage*:

  The *Diversified Supply Technologies* scenario is similar to the future *Medium Demand* of the *Small Storage* scenario because of medium VRES share, CCS deployment, full power market integration and lower volumes of grid transmission expansion and electricity trade. However, the two scenarios are not consistent in terms of competition of alternative flexible technologies with Norwegian hydropower (see above).
- *High RES* and B – *Big Storage* and C – *Niche Storage*, respectively:

  The *High RES* scenario seems to fit to these two HydroBalance scenarios because of its high RES/VRES share, low CCS deployment and power market integration. In addition, it complies well with the *Big Storage* scenario in terms of strong transmission grid expansion, while this is moderate in *Niche Storage*. It also complies well with the *Niche Storage* scenario in terms of high competition, while this is low in *Big Storage*.
- Scenario D – *Nordic Storage* does not comply with any of the EU Energy Roadmap 2050 scenarios, since this scenario includes situations with critical security of supply in Central Europe arising from the combination of a high VRES share with too little transmission grid expansion. Such a development is not desirable, but is nevertheless interesting to analyse.

7.3 NORSTRAT

The NORSTRAT project defined scenarios for developing a carbon-neutral energy system in the Nordic region by the year 2050, as described in [10]. Four scenarios were developed for Denmark, Finland, Norway and Sweden along two main aspects:

1. Degree of integration of the Nordic power system with the rest of the European system
2. Volume of new renewable electricity generation

The scenarios are summarised in Table 10, as well as illustrated in Figure 18.

Table 10: Summary of the four NORSTRAT scenarios. Source: [10].

Scenario	Description
Carbon Neutral	The Nordic power system is carbon-neutral with transmission capacities to the rest of Europe as in the reference year 2012, plus currently planned projects. 100 to 150 TWh per year of the existing plans for new generation from RES are developed, so that fossil generation can be phased out.
Purely Renewable	Includes 200 to 250 TWh per year new generation from RES. This allows phasing out both fossil and nuclear generation in the Nordic Countries. Transmission capacities to the neighbouring countries basically remain as today.
European Hub	This is the most ambitious scenario with 200 to 250 TWh per year new generation from RES in the Nordic region and 20 GW new balancing capacity in the Norwegian hydropower system. Fossil generation is phased out. Transmission capacities to the rest of Europe are increased to profitable level. This enables export of green energy from the Nordic region on large scale.
European Battery	Includes 100 to 150 TWh per year new generation from RES and 20 GW new balancing capacity in the Norwegian hydropower system. Fossil generation is phased out. Transmission capacities to the rest of Europe are increased to profitable level to supply balancing services in the medium to long-term range.

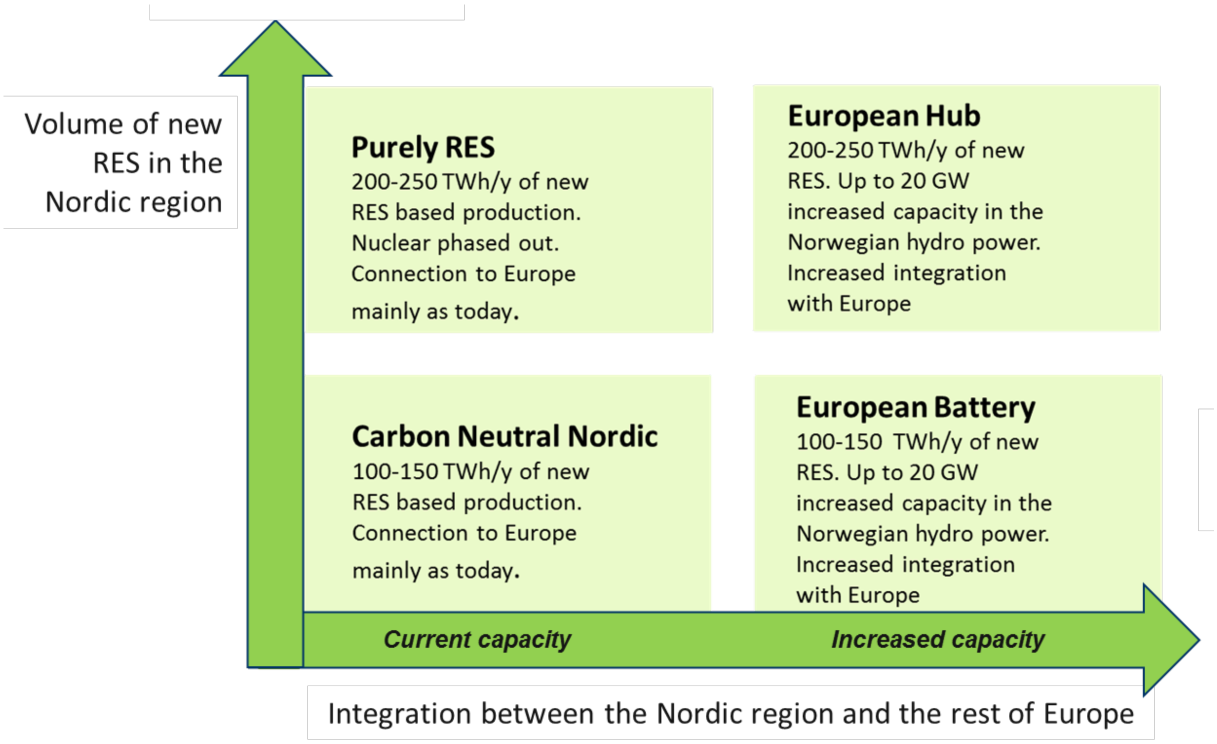

Figure 18: Four scenarios for a carbon-neutral Nordic energy system by 2050. Adopted from [10].

The HydroBalance scenarios are in line with the four NORSTRAT scenarios in terms of the power system of the Nordic region: The Nordic power system is assumed to be fully integrated. While none of the NORSTRAT scenarios fits well with the *Small Storage* scenario, similarities with other HydroBalance scenarios are as follows:

- NORSTRAT scenario *European Hub* shares similarities with the *Big Storage* scenario. In the Nordic Countries a large amount of electricity comes from RES. Transmission capacities between the Nordic Countries and the rest of Europe are increased. Norway strongly expands its hydropower capacity with new pumped and hydro storage to provide both balancing and energy export (net export). All fossil generation is phased out in the Nordic power system.
- NORSTRAT scenario *European Battery* shares the following aspects with the *Niche Storage* scenario: Moderate development of RES in the Nordic Countries; transmission capacities between the Nordic Countries and the rest of Europe are strongly expanded. Additional capacity of pumped storage and hydro storage are developed for balancing towards Europe at medium to long-term range (no net export). All fossil generation is phased out in the Nordic power system.
- NORSTRAT scenario *Purely Renewable* is similar to the *Nordic Storage* scenario regarding the Nordic region: In the Nordic Countries a large amount of electricity is generated from RES, transmission capacities between the Nordic Countries and the rest of Europe are limited to the expected increase until 2020, and both fossil and nuclear generation are phased out in the Nordic power system.

7.4 Conclusions regarding scenario consistency

Considering the amount of information and the complexity related to various energy scenarios across different geographic scale, it is difficult to track similarities as well as discrepancies and find matches among scenarios. The larger the number of factors, i.e. level of detail taken into account, the more difficult this becomes. However, looking at the main scenario characteristics, such as GHG emissions, RES/VRES share, electricity demand, CCS, storage technologies etc., we pointed out overall similarities and discrepancies.

Despite some deviations between the HydroBalance and other reviewed scenarios, similarities are large enough to use selected scenarios as benchmark for general parameters, such as economic growth, demography, fuel and CO_2 prices. The same applies for specific parameters, such as transmission capacities, electricity generation and installed capacity for each technology, etc. The overview of these parameters will be important when the HydroBalance scenarios are quantified and translated into data sets. Specifically, the following scenarios may be used when quantifying the HydroBalance scenarios:

- Energy Technology Perspectives' *2DS*:
  - all HydroBalance scenarios
- EU Energy Roadmap 2050:
  - *Diversified Supply Technologies* and A – *Small Storage*
  - *High RES* and B – *Big Storage* as well as C – *Niche Storage*
- NORSTRAT:
  - *European Hub* and B – *Big Storage*
  - *European Battery* and C – *Niche Storage*
  - *Purely Renewable* and D – *Nordic Storage*

8 Summary and further work

We developed four scenarios for using the flexibility and storage potential of the Norwegian hydropower system to balance generation and load in a European power system with medium to high share of VRES in the year 2050. The four scenarios evolved from four futures and four strategies for potential roles of Norwegian hydropower in the European power market. We identified eleven uncertainties for defining the futures, including the VRES share in electricity generation, expansion of the European transmission grid, deployment of CCS, competition of alternative flexible technologies with Norwegian hydropower, EU regulatory framework and market integration, ambitions of countries to connect with Norway, GHG emission reductions in Europe, electricity consumption, and maturity of RES, DSM as well as energy storage technologies. As basis for the strategies we selected four options, including the expansion of the Norwegian transmission grid, upgrade of existing and construction of new hydro storage and pumped storage power plants, support of VRES development, and ambitions of Norway to build interconnectors.

In the four developed scenarios Norwegian hydropower plays the following different roles: In the scenario *Small Storage* Norway provides small volumes of balancing over various time horizons to the North Sea Countries. In *Big Storage* Norwegian hydropower plays an important role in integrating VRES into the European power system by providing large volumes of balancing over various time horizons to the North Sea Countries. In *Niche Storage* the role of Norwegian hydropower is limited to balancing on long time horizons, while other countries cover their demand for balancing on short time horizons themselves. Finally, *Nordic Storage* is a scenario with low integration between the Nordic Countries and the rest of Europe, and Norway delivers small volumes of balancing on various time horizons primarily to the Nordic Countries.

The next step will be to quantify the scenarios. The resulting data sets will be used as input to energy system and power market modelling. These simulations will be performed to assess alternative solutions for covering the need for balancing in the European power system. While this task analyses possibilities for Norwegian hydropower from the system perspective, another task on business models for Norwegian hydropower will address opportunities from the perspective of a single power producer. Market simulations based on the scenarios are expected to analyse payback for investors as well as future operational regimes of reservoirs. The impacts of these operational regimes through water level fluctuations on the abiotic and biotic environment of reservoirs will be assessed by ecological and hydrodynamic modelling of the aquatic environment. Regarding the regulatory framework and public acceptance aspects in the project, the scenarios may be used to communicate potential future roles of Norwegian hydropower to stakeholders, e.g. when performing interviews to analyse acceptance of balancing from Norwegian hydropower. Based on the scenarios and results from the mentioned tasks we will develop a roadmap for large-scale balancing from Norwegian hydropower.

9 References

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Appendices

A1 List of abbreviations

CAES	Compressed air energy storage
CCS	Carbon capture and storage
DSM	Demand side management
ETP	Energy Technology Perspectives
EU	European Union
GHG	Greenhouse gas
HSPP	Hydro storage power plant
IEA	International Energy Agency
PSPP	Pumped storage power plant
PV	Photovoltaics
RES	Renewable energy sources
VRES	Variable renewable energy sources

A2 List of used terms

Balancing	Balancing here refers to the use of flexible generation, storage and capacity for balancing generation and load on various time scales.
Centralised storage	Storage units which are connected to the transmission grid level and can store electricity at medium to large scale.
Decentralised storage	Storage units which are connected to the distribution grid or end user level and can store electricity at small to medium scale.
Demand side management	Measures taken to influence amount or timing of electric usage by consumers.
Energy storage	Storage units which are connected to the grid and store electric energy for later use, either to convert it back into electricity or into heat.
Flexibility	The capability of units in the electric system to balance generation and load, either via flexible generation or smoothing the load.
Flexible generation	Electricity generation from units which are both technically and economically suitable for varying their power output within short time, i.e. milliseconds, seconds, minutes and intra-hour.
Hydro storage	Hydropower facilities that use water from reservoirs with storage capacities that last for weeks, months or years.
Interconnector	Transmission grid connection between countries
Nordic Countries	Scandinavia and Finland, i.e. including Norway, Sweden, Denmark and Finland, but here neither Iceland nor their autonomous regions.
North Sea Countries	Countries around the North Sea: Norway, Sweden, Denmark, Germany, Benelux, the United Kingdom, France.
Pumped storage	Hydropower facilities that use pairs of reservoirs and have the capability to pump water from the lower to the upper reservoir.
Time horizons for balancing	
Short time horizons	Milliseconds, seconds, minutes, intra-hour, hours; typically traded in the intra-day and balancing market
Long time horizons	One day, days, weeks; typically traded in the day-ahead market (spot market)
Variable renewable energy sources	Renewable energy sources with varying electricity generation as a consequence of the fluctuating nature of their power source; generation units with direct dependency on weather conditions, in particular photovoltaics, wind power and small hydropower.

A3 Workshop agenda

CEDREN
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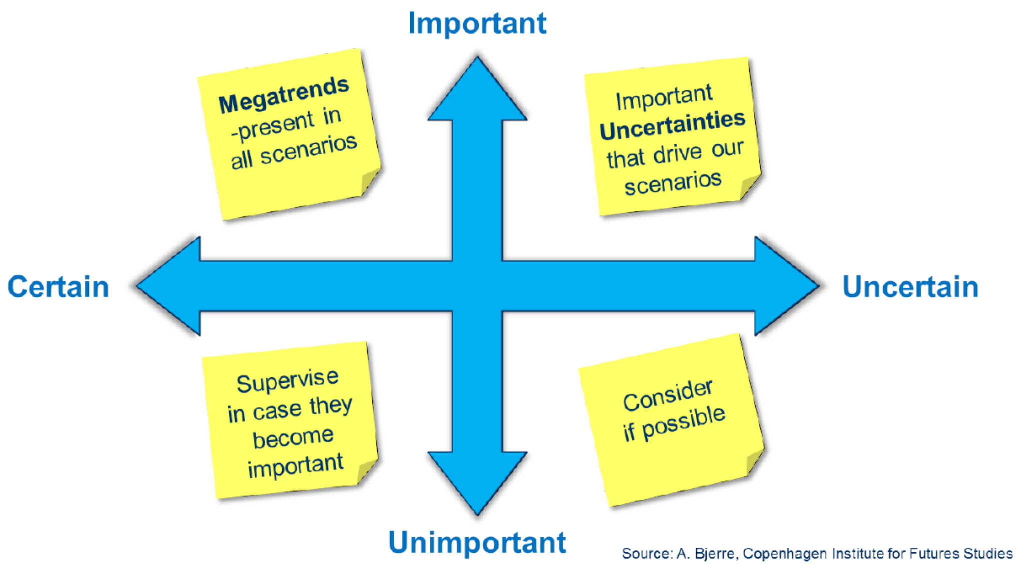
Tuesday, 25 March

08.30-08.45	Introduction to group work II
08.45-10.45	Group work II: Selection of main drivers and description of possible futures
10.45-11.00	Break
11.00-11.45	Summary of group discussions in plenary
11.45-12.00	Discussion and wrap-up of scenario group work in plenary
12.00-13.00	Lunch
	Session on business models
13.00-13.25	Plans for HydroBalance work package 3 - Business Models *Ove Wolfgang, CEDREN/SINTEF Energy Research, Norway*
13.25-13.50	Utilization of hydropower's flexibility, and transmission capacity allocation *Hege Eiken Hartveit, Statkraft, Norway*
13.50-14.15	ECN's approach and methodology for analysing the value of flexibility *Ozge Ozdemir, ECN, Netherlands*
14.15-14.30	Break
14.30-16.00	Discussion on WP3: - Participants' interest and views - Methodologies and focus - How can alternative scenarios be addressed in practice?
16.00	End of workshop

A4 Group work tasks

Group work I

Scenarios are inherently uncertain. They are a means to deal with uncertainty, structure trends, prioritise or weigh influencing factors, simplify the real world, and handle assumptions consistently. The first group work task will address both uncertainty and importance of various influencing factors. These factors can be divided into four categories along the two scales: from uncertain to certain and unimportant to important (see figure below).



Task: Discuss the uncertainty and importance of the given factors in relation to the key research question [Which role can energy balancing and storage by Norwegian hydropower play in the future European electricity market?]

Which changes would you make, and why?

Are there any factors missing that you would consider?

CEDREN

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Group work II

Selection of important uncertainties (main drivers) and definition of possible Futures:

a) Based on the results from group work I, identify the two or three most important, uncertain drivers. Combining the main drivers will result in possible Futures.
b) How do the main drivers affect the HydroBalance project? Describe the possible Futures resulting from combinations of the main drivers qualitatively/in words.

A5 Overview of uncertainties and options for each scenario

Table 11: Uncertainties and options in scenario A – *Small Storage*.

		Small Storage
Uncertainties in future 1	**Possible values**	***Medium Demand***
Technology		
VRES share in electricity generation	High/Medium	Medium
Expansion of European transmission grid	Strong/Moderate/Limited	Moderate
Deployment of CCS	Yes/No	Yes
Market		
Competition from alternative flexible technologies	High/Low	Low
EU regulatory framework and market integration	Fully integrated/Day-ahead only	Fully integrated
Policy		
Ambitions of countries to connect with Norway	Strong/Moderate	Moderate
Options in strategy 2	**Possible values**	***Moderate Expansion***
Expansion of Norwegian transmission grid	Strong/Moderate	Moderate
New PSPP and upgrade of existing HSPP	Strong/Moderate/Limited	Moderate
Support of VRES development	Strong/Moderate/Limited	Moderate
Ambitions of Norway to build interconnectors	Strong/Moderate/Weak	Moderate

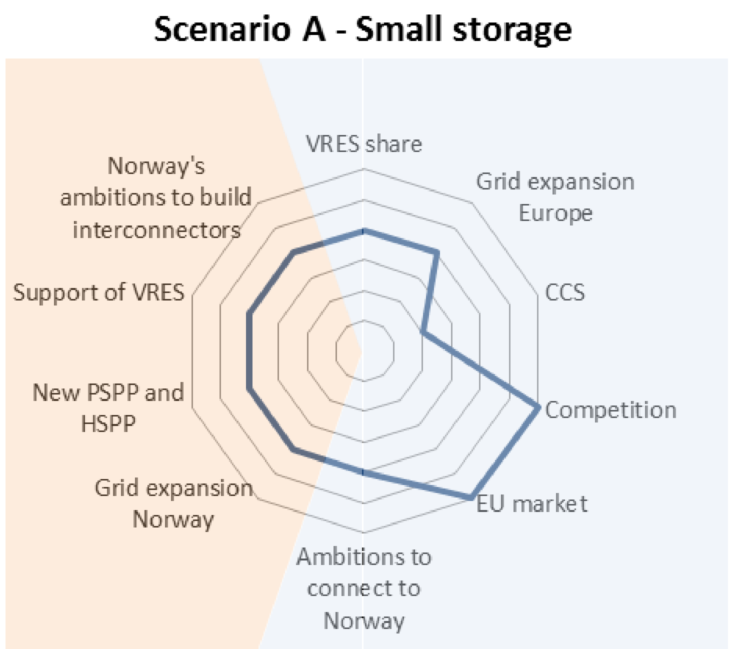

Table 12: Uncertainties and options in scenario B – *Big Storage*.

		Big Storage
Uncertainties in future 3	**Possible values**	***Various Flexibility***
Technology		
VRES share in electricity generation	High/Medium	High
Expansion of European transmission grid	Strong/Moderate/Limited	Strong
Deployment of CCS	Yes/No	No
Market		
Competition from alternative flexible technologies	High/Low	Low
EU regulatory framework and market integration	Fully integrated/Day-ahead only	Fully integrated
Policy		
Ambitions of countries to connect with Norway	Strong/Moderate	Strong
Options in strategy 1	**Possible values**	***Active Climate Policy***
Expansion of Norwegian transmission grid	Strong/Moderate	Strong
New PSPP and upgrade of existing HSPP	Strong/Moderate/Limited	Strong
Support of VRES development	Strong/Moderate/Limited	Strong
Ambitions of Norway to build interconnectors	Strong/Moderate/Weak	Strong

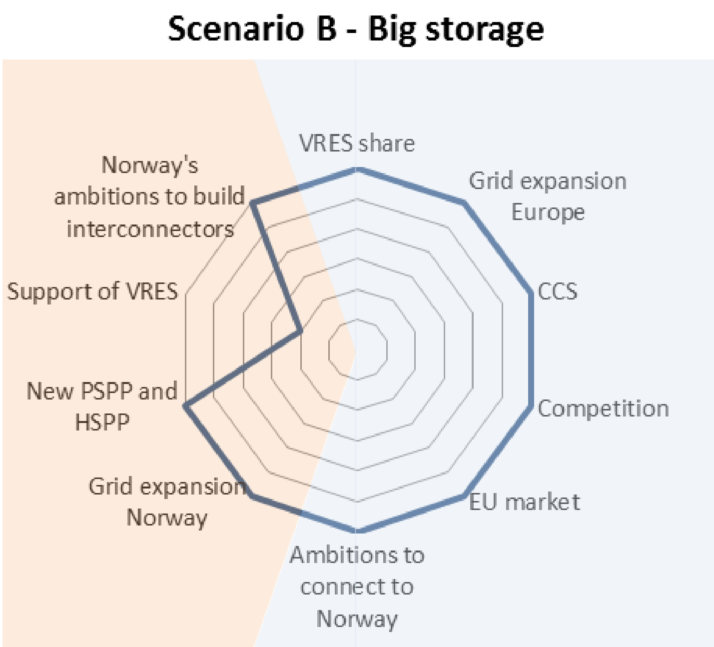

Table 13: Uncertainties and options in scenario C – *Niche Storage*.

		Niche Storage
Uncertainties in future 2	**Possible values**	***Niche Market***
Technology		
VRES share in electricity generation	High/Medium	High
Expansion of European transmission grid	Strong/Moderate/Limited	Moderate
Deployment of CCS	Yes/No	No
Market		
Competition from alternative flexible technologies	High/Low	High
EU regulatory framework and market integration	Fully integrated/Day-ahead only	Day-ahead only
Policy		
Ambitions of countries to connect with Norway	Strong/Moderate	Moderate
Options in strategy 3	**Possible values**	***Value Creation***
Expansion of Norwegian transmission grid	Strong/Moderate	Strong
New PSPP and upgrade of existing HSPP	Strong/Moderate/Limited	Strong
Support of VRES development	Strong/Moderate/Limited	Limited
Ambitions of Norway to build interconnectors	Strong/Moderate/Weak	Strong

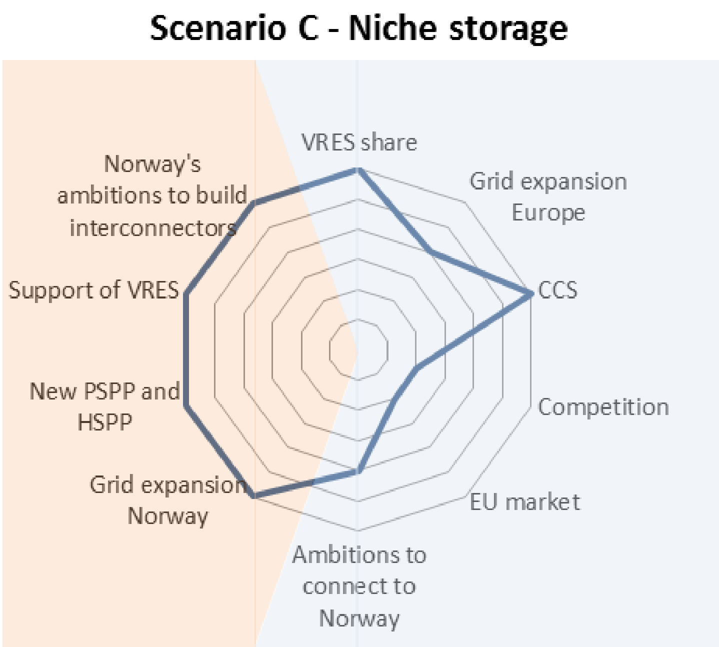

Table 14: Uncertainties and options in scenario D – *Nordic Storage*.

		Nordic Storage
Uncertainties in future 4	**Possible values**	***Critical Supply***
Technology		
VRES share in electricity generation	High/Medium	High
Expansion of European transmission grid	Strong/Moderate/Limited	Limited
Deployment of CCS	Yes/No	No
Market		
Competition from alternative flexible technologies	High/Low	Low
EU regulatory framework and market integration	Fully integrated/Day-ahead only	Day-ahead only
Policy		
Ambitions of countries to connect with Norway	Strong/Moderate	Strong
Options in strategy 4	**Possible values**	***Nordic Only***
Expansion of Norwegian transmission grid	Strong/Moderate	Strong
New PSPP and upgrade of existing HSPP	Strong/Moderate/Limited	Limited
Support of VRES development	Strong/Moderate/Limited	Strong
Ambitions of Norway to build interconnectors	Strong/Moderate/Weak	Weak