THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

Valuing Flexibility in Evolving Electricity Markets: Current Status and Future Outlook for Hydropower

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Editors: Atle Harby, Audun Botterud, Alex Beckitt, Niels Nielsen and Luke Middleton **Main Authors:** Audun Botterud, Chris O'Reilley, Abhishek Somani **Authors:** Alex Beckitt, Osamu Kato, Magnus Korpås, Albert Cordeiro Geber de Melo, Luke Middleton, Linn Emelie Schäffer, Guillaume Jean Tarel, Elena Vagnoni, Donald Vaughan, Cesar Zani **Contributors and reviewers:** Hill Balliet, Sam Bockenhauer, Atle Harby, Lori Nielsen, Niels Nielsen, Zuzana Sadlova, Orkan Akpinar, Furkan Yardimci, Marja Rankila, S.S.Barpanda

SUMMARY

This second White Paper addresses the rapid expansion of variable renewable energy (VRE) resources, which combined with retirements of thermal generation, give rise to increasing needs for flexibility at transmission, distribution, and the individual resource levels in the power system. The fundamental challenges associated with VRE integration and corresponding power system flexibility needs are similar across the world. A number of different solutions are being developed to address these challenges, from infrastructure investments like flexible generation, increased transmission, energy storage, and demand-response, to enhanced algorithms for forecasting, planning and operations, and improved electricity market design. Hence, important lessons can and should be learned between countries and regions as part of the ongoing shift towards cleaner electricity systems with a lower carbon footprint and more variable resources.

A survey of flexibility services in 14 markets around the world showed that hydropower currently contributes to flexibility services across all timescales in most systems. This observation highlights the unique characteristics of hydropower in its ability to provide flexibility to the system, from short-term stability services to long-term seasonal storage. The survey also revealed that at least some flexibility services are being compensated across timescales, although compensation is less prevalent at the shortest timescale. However, there are planned new market developments across timescales for the power systems in the different regions, such as development of inertia and primary frequency response, and enhancement of market structures to support resource adequacy for flexible capacity.

Case studies from seven different systems provided more detailed insights. Among the challenges discussed in the case studies are a lack of consistent and commensurate long-term signals for investments in long-duration storage solutions such as hydropower. Systems that rely heavily on long-term contracts provide stability for investors, but with limited visibility to the cost and value of flexibility. The case studies also offer a number potential or replicable solutions for other regions, from standardized definitions of flexibility services to transmission expansion, that may facilitate a more efficient integration of VRE into power systems.

Future research and work should focus on the implications of changing hydropower operations in response to a changing climate, remuneration mechanisms for long-duration energy storage and the development of a set of more specific guidelines for the design of flexibility services and corresponding compensation mechanisms across the timescales in future electricity markets.

For policy makers, it is important to clearly understand the role of hydropower and its potential to deliver system services to enable an increased penetration of VRE resources. Market frameworks should send appropriate investment signals to ensure future investments in existing and new hydropower infrastructure. These signals should be designed to capture the value of flexibility services these assets can provide to the system across the timescales, from short-term stability to long-term storage and system balancing.

1 BACKGROUND

Variable renewable energy (VRE) generation is increasing rapidly across the globe as part of the ongoing shift towards cleaner electricity with a lower carbon footprint. Importantly with this shift to a predominance of VRE resources, such as wind and solar, is a corresponding increase in the need for flexibility in the power system.

This White Paper is a summary of the second publication in a series by the IEA Hydropower TCP (Annex IX, Phase 2) on the valuation of hydropower services. The first publication, White Paper No 1 entitled "Flexible Hydropower Providing Value to Renewable Energy Integration", discussed the role of hydropower in grid integration of VRE, emphasizing that hydropower is unique in its ability to provide system flexibility across timescales (see Table 1).

This White Paper presents the results from two research activities conducted by IEA Hydro Annex IX to investigate how flexibility services are defined, procured, and valued in current electricity markets, with a particular focus on the status and outlook for hydropower. Figure 1 shows the countries and regions included in the survey and case studies, which covered:

- A written survey of 14 countries/regions
- A collection of case studies from seven different electricity systems globallythat provide more detailed insights on the novel aspects of flexibility services, and the role of hydropower, in those countries

For a more in-depth review on these topics, the reader is directed to the full Report with the same title as this White Paper, which includes complete results of the survey and case studies, available online at IEA Hydro[1].

Table 1. *Different timescales of power system flexibility (Source: IEA 2018)*

Flexibility type	Short-term			Medium term	Long-term	
Time scale	**Sub-seconds to seconds**	**Seconds to minutes**	**Minutes to hours**	**Hours to days**	**Days to months**	**Months to years**
Issue	Ensure system stability	Short term frequency control	More fluctuations in the supply/ demand balance	Determining operation schedule in hour- and day-ahead	Longer periods of VRE surplus or deficit	Seasonal and inter-annual availability of VRE
Relevance for system operation and planning	Dynamic stability: inertia response, voltage and frequency	Primary and secondary frequency response	Balancing real time market (power)	Day ahead and intraday balancing of supply and demand (energy)	Scheduling adequacy (energy over longer durations)	Hydro-thermal coordination, adequacy, power system planning (energy over very long durations)

1 https://www.ieahydro.org/news/2021/6/annex-ix-report-published

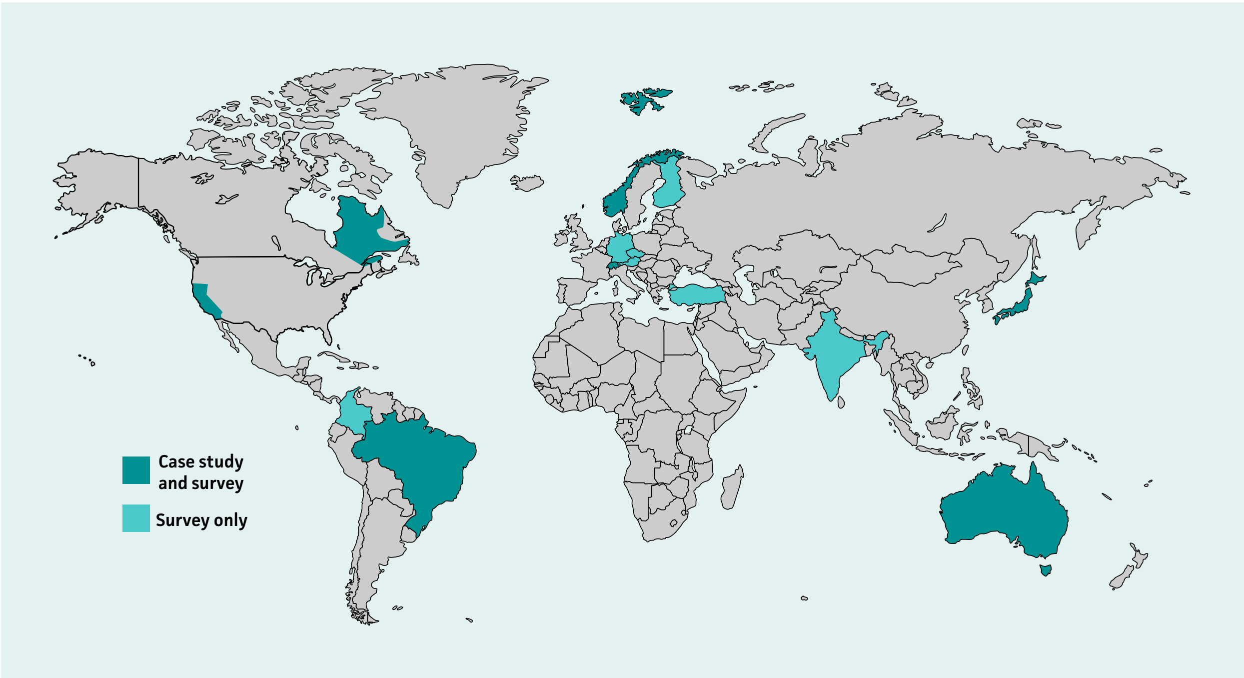

Figure 1. *Map of countries and regions included in case studies and surveys (Australia, Austria, Brazil, California (USA), Colombia, Czech Republic, Finland, Germany, India, Japan, Norway, Quebec (Canada), Switzerland and Turkey).*

2 IMPLICATIONS FOR POLICY-MAKERS

Global energy systems are undergoing rapid transformation. The International Energy Agency (IEA) in their 2020 World Energy Outlook (WEO) found that renewables would grow rapidly across all modelled scenarios, with renewables meeting 80 per cent of the growth in global electricity demand to 2030 under the Stated Policies Scenario (STEPS). The IEA's 2020 WEO[2] observes that hydropower remains the world's largest renewable source of electricity. As highlighted by IEA, it will play a key role in the energy transition, particularly due to its unique technological characteristics that provide clean baseload energy as well as balancing services for VRE - providing a range of short-, medium- and long-term system flexibility services.

Survey responses indicate that markets are evolving to increasingly recognize and incentivize flexibility services, particularly for the provision of services across shorter timeframes. This evolution can include:

- Pricing approaches
- Creation of new flexibility services
- Extension of compensation for flexibility services
- Technological developments

However, this is not to understate the challenges hydropower generation are facing. Urgent action is required by governments and policy makers to ensure hydropower is fully utilized and valued in global electricity markets. First, a greater recognition of several issues is needed, including:

- Clearly understanding the role of hydropower and its potential at the regional level - including delivering system services to **enable penetration of more variable and distributed renewables such as wind and solar.**

- Ensuring that measures are in place to incentivize the sustainability of assets suitable for the future. Specifically:
  - To ensure market frameworks send appropriate investment signals to underpin future investments in **existing and new hydropower** infrastructure relative to the value of flexibility services these assets can provide.
  - To investigate and implement appropriate **market mechanism(s) to value short term system security services** that had previously been in abundance as a natural by-product from operation of traditional synchronous generation sources.
  - To provide **valuing of medium to long term balancing of VRE** through specific storage incentives and innovative commercial tools such as contract spreads and caps.

- Formulating **suitable market frameworks, energy policies and regulatory approaches** to properly **incentivise all aspects of hydropower investment** to provide clear and transparent policies, market structures and remuneration, to **provide investor certainty**.

- Investing in specific hydropower technology research and development to achieve **optimized operations for enhanced energy flexibility, productivity and durability** in evolving power markets at existing and new hydropower plants.

2 https://www.iea.org/reports/world-energy-outlook-2020

3 SURVEY OF FLEXIBILITY SERVICES

The 14 systems included in the survey of flexibility services consist of a wide variety of generation mixes (Figure 2). The hydropower penetration varied between 4 and 96 percent and the VRE penetration between 0 and 28 percent among the surveyed power systems. These numbers compare to a hydropower electricity share of 16 percent and a total renewable electricity share of 26 percent at the global level in 2018.

Despite the large variation in generation mixes, the types of flexibility services identified by survey respondents were similar. This suggests that, in order to operate in a reliable manner, a large-scale power system relies on a set of fundamental grid services, regardless of the current generation mix. Table 2 shows a summary of the different flexibility services relevant for each timescale. It should be noted that the differences in generation mix and grid configurations will still influence what types of resources that are providing the different flexibility services across time-scales, as well as the amounts of grid services that are needed to maintain system reliability.

A key finding from the survey is that **hydropower currently does contribute to flexibility services across all timescales in most systems** (Figure 3). This observation highlights the unique characteristics of hydropower in its ability to provide flexibility to the system, from short-term stability services to long-term seasonal storage.

The respondents were requested to describe which procurement methods are used to obtain the different flexibility services broken into three categories:

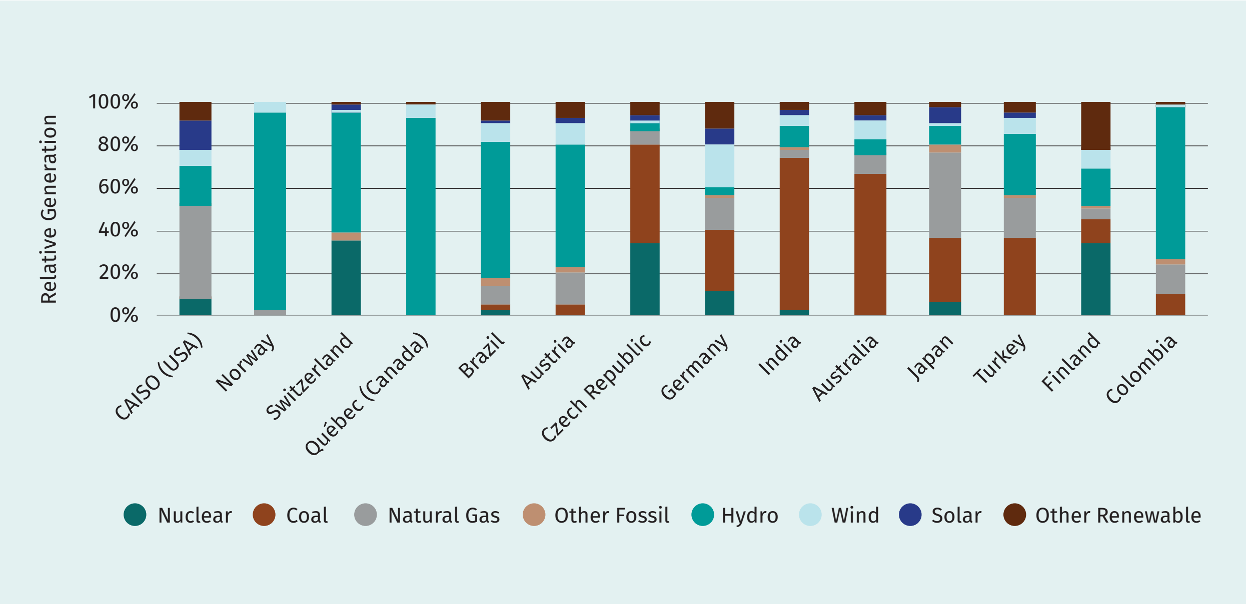

Figure 2. *Generating resource mix in 2019 for participating systems (Source: Survey inputs, IEA Data and Statistics (https://www.iea.org/data-and-statistics), EIA (www.eia.gov/international/overview/world).*

- Market-based procurement, normally through auctions
- Bilateral contracts between system operator and individual generators to provide a service for a certain time period
- Interconnection agreements where provision of a service is part of the agreement signed before connecting an asset to the system

Table 2. *Summary of flexibility service types by timescale. Some of these specific services have been consolidated for presentation. For instance, all frequency related services are pooled together.*

Timescale	Services	
Sub-second - seconds	1) Inertia 2) Reactive power 3) Voltage control	4) Frequency support 5) Spinning reserve 6) Special protection systems
Seconds - minutes	1) Frequency support	2) Last minute dispatch
Minutes - hours	1) Energy 2) Frequency support	3) Black start 4) Power unit dispatch
Hours - days	1) Energy 2) Ancillary services	3) Long term reserves 4) Demand response
Days-months; Months-years	1) Resource adequacy	2) Storage

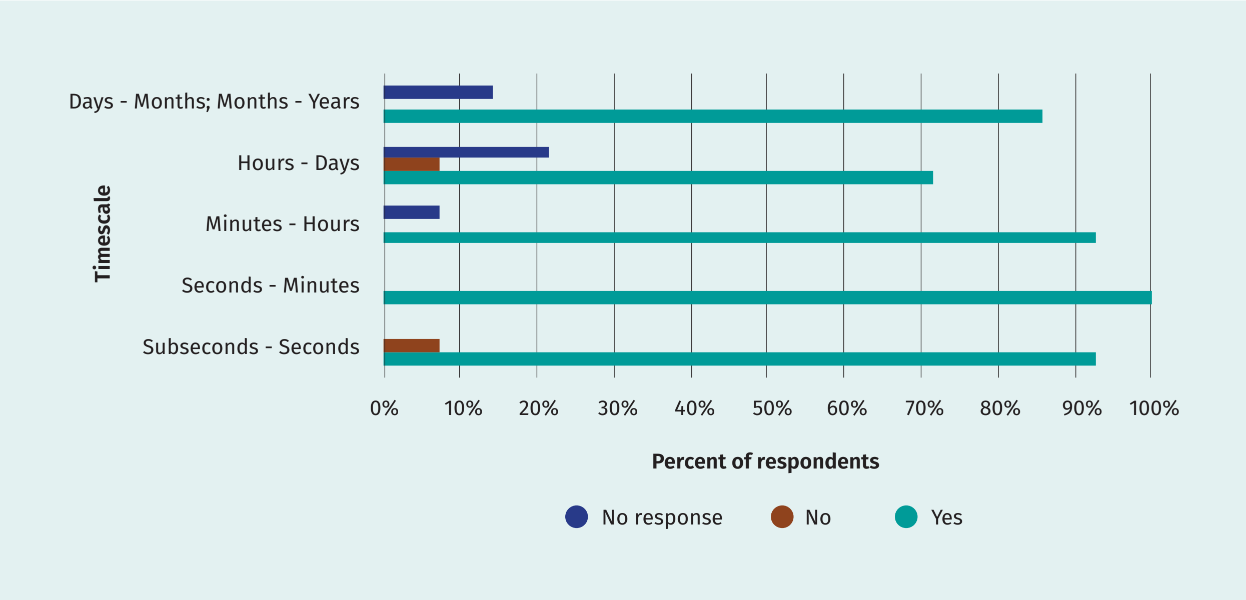

Figure 3. *Responses to the question of whether hydropower provides flexibility services across timescales. Percent of respondents answering yes, no, or no response.*

Figure 4 summarizes how flexibility services are procured within each timescale. All procurement mechanisms are in use across the timescales, with market-based procurement dominating during the medium timescales (seconds to days).

The survey respondents stated that **at least some flexibility services are being compensated across timescales, although compensation is less prevalent at the shortest timescale**. Prices and quantities for flexibility services are hard to compare directly across systems, due to variations in specific definitions.

There are planned developments for the power system across timescales in the different regions. The highest number of reported changes are at the shortest timescales. Developments include modifications to market design, pricing, adding new flexibility services, extending compensation of such services, along with various technology developments. In general, many of the ongoing changes are driven by the rapid change in generation mix, with increases in VRE and reductions in thermal generation capacity. This trend amplifies the need for other resources, such as hydropower, to provide flexibility services in future power systems.

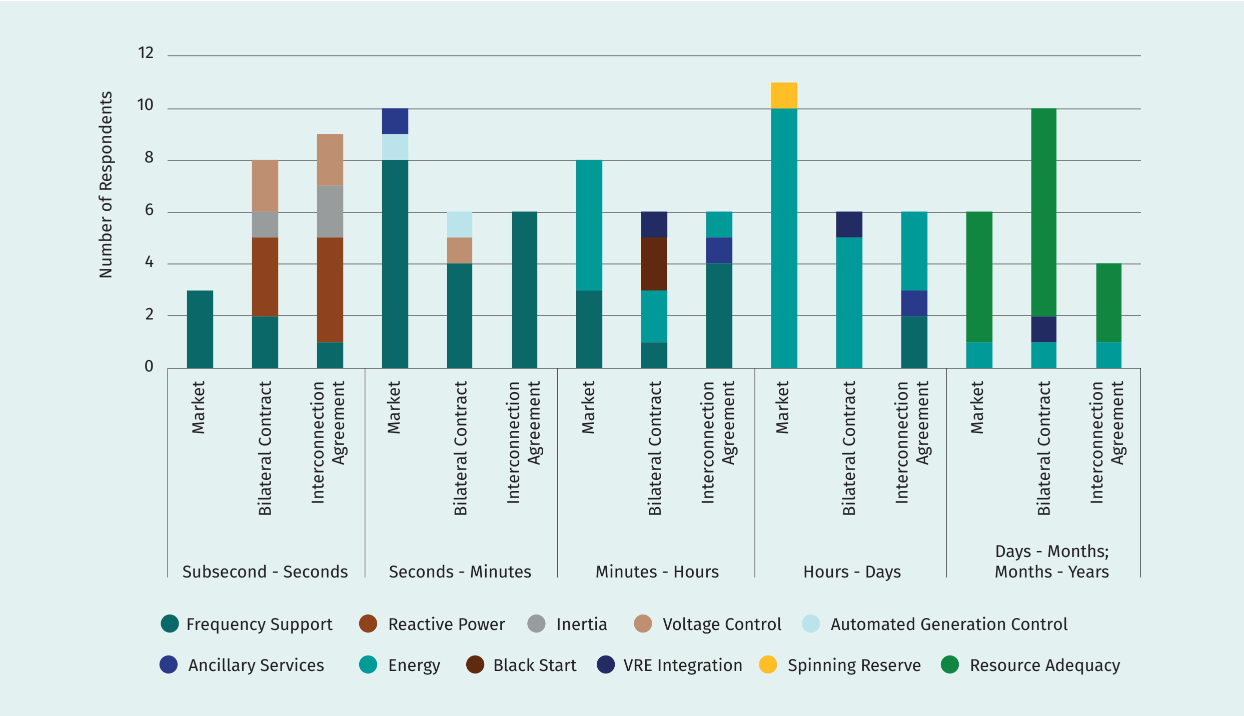

Figure 4. *Response summary of procurement methods by timescale, as reported by survey responders.*

4 CASE STUDIES OF FLEXIBILITY SERVICES

Case studies from seven different systems provided more detailed insights into specific challenges and solutions related to flexibility services, and the planning and operation of electricity markets and power systems more broadly. **Among the challenges discussed in the case studies** are a lack of consistent and commensurate long-term signals for investments in long-duration storage solutions such as hydropower (Australia). For systems that rely heavily on long-term contracts, there is limited visibility of the cost and value of flexibility (Hydro Québec, Brazil). In the short-term, systems with priority dispatching rules for VRE prevent pumped storage hydropower (PSH) from following an economically optimal energy arbitrage schedule (Japan). Environmental constraints also impact hydropower's ability to operate in a fully flexible manner (Norway). At the same time, provision of balancing services under higher VRE penetration leads to increased stress on hydropower plants, which may impact their economic viability (Switzerland, California ISO).

The case studies also offer a number of potential or replicable solutions that may facilitate a more efficient integration of VRE sources into power systems while also ensuring that hydropower and other technologies receive a fair compensation based on the services they provide. For instance, the examples from Switzerland and Norway both illustrate the advantages of using standardized product definitions for flexibility services across electricity markets, enabling trading and efficient exchange of services across wider geographical areas. Moreover, transmission capacity is a key enabling factor for hydropower. Transmission allows hydropower, a geographically constrained resource, to access regions that require its flexibility. HVDC lines can play an important role towards this end (Norway, Australia). There are a number of ongoing revisions in market products and rules due to changing system conditions. This includes the introduction of fast frequency reserve products (Norway) and the inclusion of flexibility ramping products and a higher time resolution in day-ahead markets (California ISO). Long-term contracts provide consistency and low risk for investors (Brazil and Hydro Québec). In particular, long-term power purchasing agreements organized through public auctions have provided substantial investments in new hydropower capacity in Brazil.

5 OVERALL FINDINGS

The survey results and case studies provided detailed insights into specific challenges and solutions related to provision of flexibility services, and the planning and operation of electricity markets and power systems with increasing shares of VRE in different parts of the world. Although regulatory structures and electricity market designs will always have a regional flavor based on the specific resource mix and policy conditions at hand, these examples provide a variety of solutions that may contribute towards a more efficient provision of clean electricity in future power systems. The examples from some systems may inspire adaptation or adoption of solutions in other regions. Below is a summary of key takeaways from survey results and case studies:

1) **Hydropower is an important contributor to essential reliability services:** A key finding from the survey is that hydropower currently contributes to flexibility services across all time-scales in most countries. This observation high-lights the unique characteristics of hydropower in its ability to provide flexibility to the system, from short-term stability services to long-term seasonal storage through management of hydropower reservoirs.

2) **Mechanisms for procurement and compensation of grid services vary across countries:** The survey results show that market-based mechanisms are the predominant means for procurement of grid services, especially the ones required over minutes-days. Interconnection agreements and bilateral contracts also play an important role, typically in the very short-term (sub-seconds-seconds) and longer-term (months-years) time-frames. Only a few systems currently use markets to procure and compensate services at the shortest timescale (sub-seconds to seconds).

3) **Lack of market signals for long-duration storage:** Among the challenges discussed in the case studies are a lack of consistent and commensurate long-term signals for investments in long-duration storage solutions such as those provided by hydropower. There are, however, ongoing initiatives (Australia, California ISO) that explicitly consider the amount of long-duration storage needed to meet regional renewable energy targets.

4) **Stored energy is presently compensated through markets for reserve and energy products:** Energy storage requires withholding energy generation, which is the primary revenue source in current electricity markets. Short-duration reserve products comprise one source of explicit compensation for stored energy in current markets. However, survey results show that the markets for reserve products tend to be under-developed, and as such, might not be able to support a business case for new pumped storage development. Energy storage is also incentivized through market-based energy arbitrage opportunities (or load shifting), which depend on market price differentials during daily, weekly, or seasonal timeframes. These energy markets represent the largest revenue opportunities for most hydropower assets, although intra-day price differentials may diminish as more storage is added to the grid.

5) **Market rules and regulations can distort market-based arbitrage signals for storage:** Systems with priority dispatching rules for VRE (Japan) prevent PSH from following an economically optimal energy arbitrage schedule.

6) **New market opportunities for flexibility services are emerging:** This includes the introduction of fast frequency reserve products (Norway), the inclusion of flexibility ramping products, and a higher time resolution of day-ahead markets (California ISO). The market availability of these services is limited, and the volume of services required for these services is likely to be very small., This alone may not provide sufficient

incentives for deployment of high capital cost assets, such as pumped storage.

7) **Flexibility services require increased cycling, which leads to accelerated wear and tear:** Provision of balancing services under higher VRE penetration could lead to increased stress on hydropower machinery and infrastructure, which may impact the economic viability of hydropower plants (Switzerland, California ISO). The increase in O&M costs and any cost of retrofitting assets to operate more flexibly will need to be balanced against the value of providing these flexibility services.

8) **Long-term contracts offer stability but mask the true cost and value of flexibility:** Long-term contracts provide consistency and low risk for investors (Brazil and Hydro Québec). In particular, long-term power purchasing agreements organized through public auctions have enabled substantial investments in new hydropower capacity in Brazil. However, long-term contracts can limit visibility into the cost and value of flexibility (Québec, Brazil).

9) **Standardized product definitions facilitate efficient use of resources across different markets:** The use of standardized product definitions for flexibility services across the industry is a basic requirement for the market development of these services, enabling trading and efficient exchange of services across wider geographical areas (Switzerland, Norway).

10) **Transmission capacity is a key enabling factor for hydropower:** Hydropower is a geographically constrained resource. Hence, transmission is oftentimes critical for hydropower to access regions with flexibility needs. HVDC lines can play an important role towards this end (Norway, Australia).

6 CONCLUSION AND FUTURE DIRECTIONS

There has been a rapid increase in VRE generation across the globe as part of the ongoing shift towards cleaner electricity supplies with a lower carbon footprint. The variability and uncertainty in VRE resources, such as wind and solar, increase the need for flexibility in the power system. This report reviews how flexibility services are defined, procured, and valued in current electricity markets, with a specific focus on the status and outlook for hydropower.

The review revealed that there is a wide range of solutions to address flexibility challenges in evolving power systems with high VRE levels. Although the definitions of flexibility services are similar in the 14 systems reviewed in this report, substantial variations exist in terms of how these services are procured and compensated. A common feature across the systems included in this review, is that hydropower plays an important role in providing flexibility services across all timescales. This observation highlights the unique characteristics of hydropower in its ability to provide the full spectrum of flexibility needs to the system, from short-term stability services to long-term seasonal storage through management of hydropower reservoirs. With the increasing penetration of VRE and corresponding retirements of traditional thermal generators, we expect that the value of flexible resources like hydropower will increase in the future. In order to take full advantage of the increasing value of flexibility, it is important that hydropower owners and investors understand that hydropower plants follow a different and less predictable operating pattern in systems with high VRE penetration.

The review reveals some important challenges for electricity markets in the evolution towards a different resource mix. Chief among them is the lack of compensation for some flexibility services, particularly in the very short timescale, and limited long-term incentives for investments in the long-duration storage required to maintain reliability in future power systems.

Finally, in order to advance the understanding of valuing flexibility in evolving electricity markets, the report highlights some important directions for future work:

Changing hydropower operations:

1) Assess what are likely to be the most important flexibility services for hydropower in future electricity markets
2) Assess impacts of climate change on reservoir inflows, hydropower operations and extreme events such as droughts and floods
3) Investigate implications on machinery wear and tear, required investments to upgrade and/or retrofit equipment and infrastructure
4) Conduct a survey of changes in hydropower operations with special emphasis on a) start/stops, b) cycling, c) ramping, d) pumping/generation cycles (arbitrage patterns), e) environmental effects (e.g. increased hydropeaking in rivers with hydropower plants)
5) Estimate the socio-economic value of hydropower flexibility to the grid in selected regions with high VRE shares, including contributions to short-term frequency and voltage stability, reduced risk of interruptions, less wear and tear on other resources, lower system operating costs, and reduced carbon emissions

Long-duration energy storage:

1) Identify instances of long-duration energy storage solutions being provided by hydropower
2) Survey ongoing initiatives to set mandates/targets and requirements for long-duration energy storage
3) Review potential remuneration mechanisms for long-duration energy storage (e.g. availability or capacity payments for flexibility services), recognizing that this resource may be unused for extended periods of time while providing critical services to the grid during other periods

Electricity and power market design:

1) Develop a set of more specific guidelines for the design of flexibility services and corresponding compensation mechanisms across the timescales in future electricity markets
2) Investigate price formation in a zero marginal cost world and its implication for different types of hydropower plants

It is also recognized that improved consistency in the terminology (taxonomy) used in hydropower and electricity markets is generally needed, particularly in relation to flexibility services. This can be achieved via multi-disciplinary international collaboration.

Lastly, there are lessons to be learned between countries and regions around the world. Although the fundamental flexibility challenges are similar in a changing power system, solutions differ. International comparisons, like those presented in this study, are an important contribution towards improved solutions for future electricity markets. Continued international engagement and cooperation is a must.