Introduction

Tackling climate change is one of the most challenging issues facing the world today. Central to this task is the need for a rapid transition of the electricity sector from fossil fuels to low carbon sources of power.

There is no doubt that we will deploy wind and solar power at a huge scale. However, there is an ignored crisis within the crisis. What happens when the sun does not shine and the wind does not blow? These technologies need a low carbon back-up or we will fall back on fossil fuels or simply have to get used to blackouts. We need flexible electricity systems to mitigate against these risks.

One critical source of system flexibility is energy storage.¹ The primary source of stored energy on electricity grids today - at well over 90% of grid scale installations worldwide - is pumped storage hydropower (PSH).

PSH works on a simple principle, at times of low demand when electricity prices tend to be lower, water is pumped from a lower reservoir to an upper reservoir, and then released at times of high demand to drive a turbine and generate electricity. (See Figure 1 right.)

Historically, it was common practice for energy to be stored at night, as it was more efficient to keep sources of generation such as nuclear or coal running, and then released the following day in predictable cycles. With the increased deployment of variable renewables, storage becomes even more important as a means of avoiding wasted generation (i.e. curtailment² or what happens when the sun shines and the wind blows more than is demanded).

One key difference however is that these cycles are now much less predictable. Energy system planners have a good understanding of electricity generation throughout the year when using coal or nuclear, much less so when forecasting wind or solar a year in advance. This means that storage becomes even more important. Without adequate storage there is a very real risk that electricity grids of the future will not be able to provide reliable power without recourse to high carbon sources of back-up such as gas turbines. For short durations - fewer than 4 hours - technologies such as batteries can play their part. Unfortunately the weather is not always so accommodating,

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¹ Flexibility can and has been provided by a number of methods including interconnection between countries and grids, demand side management (for example paying consumers to reduce use at periods of stress) and the use of ‘dispatchable’ sources of power from sources such as reservoir hydropower or carbon intensive gas.
² Curtailment for electricity means that a system operator deliberately reduces the supply of electricity in order to balance the grid. Where storage does not exist, this means that renewable electricity is wasted and not stored for potential use in future.
and so long duration storage (i.e. for at least 4 hours and often much longer) is absolutely essential. The range of benefits that PSH provides include:

- supporting large volumes of wind and solar on electricity grids by compensating for their variability;
- providing large energy storage capacity to reduce curtailments during oversupply of variable renewables like wind and solar;
- providing inertia and other ancillary services to stabilise electricity grids;
- reducing the need for operating reserves from thermal power plants (typically high carbon coal and gas); and
- providing black start capability to restore the power system after a blackout.

However, despite being proven and cost-effective, the deployment of PSH is not keeping pace with the increased demand for both long duration storage and the other services that are needed to provide system flexibility. The specific reasons for this are complex and vary according to each market, but there are a number of high-level drivers.

In the discussion on the future growth of energy storage technologies, some reports have overlooked the potential of PSH with the misconception that the majority of viable PSH sites with suitable geographical conditions have already been developed. However, multiple studies have identified vast potential for PSH sites worldwide\(^3\). The potential is even greater when considering 'off river' PSH\(^4\).

Figure 2 below shows that whilst there is a sizeable pipeline under development / permitting, most PSH under construction is in East Asia, principally China.

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\(^3\) Further discussion on the potential for PSH can be found in "Innovative Pumped Storage Hydropower Configurations and Uses" report of the Capabilities, Costs & Innovation Working Group.

\(^4\) Off-river PSH are not designed to capture water beyond the initial reservoir fill so there is minimal impact on natural stream flows.
In common with other large low carbon infrastructure, much of the lifetime cost of PSH is incurred during construction, which has a high upfront capital cost; this means that without a degree of long-term revenue certainty, investors are unwilling to invest even if the technology is highly cost-effective and sustainable. Historically developers were governments, government owned businesses or vertically integrated utilities, and as such were able to consider the wide range of benefits provided by PSH in a holistic, system-wide manner, with some certainty as to revenues generated by long duration storage projects. But now, in liberalised markets in particular, it is difficult for investors to judge what sources of revenue will be available over the long lifetime of PSH assets.

To enable the transition to a renewable, low-carbon, reliable grid, and address the common challenges facing PSH development and increase awareness on the need for long duration storage, the International Forum on Pumped Storage Hydropower (IFPSH), jointly chaired by the United States Department of Energy and the International Hydropower Association, was convened in 2020. The Forum brings together governments, industry, financial institutions, academia and NGOs to develop guidance and recommendations on how sustainable pumped storage hydropower can best support the energy transition.

The work of the Forum was structured around three working groups on Policy and Markets, Sustainability, and Capabilities, Costs and Innovation, all under the direction of a Steering Committee. We are grateful to the sponsors of the Forum, the Steering Committee, the authors and contributing authors of the working group papers and other participants in the Forum for all their work and support.

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5 The full reports from each of the working groups are available online at https://pumped-storage-forum.hydropower.org/.
Policy and market frameworks

Pumped storage facilities typically take about seven to eight years to develop, from initial analysis and studies to construction and commissioning. Gas and coal plants typically take three to four years. Without appropriate policy and market mechanisms, there is a real risk that PSH as a highly cost-effective, low impact technology will not be deployed at the scale needed to support an efficient and reliable energy transition.

Seven key recommendations for action are:

1. Policymakers should assess the long-term storage needs of their future power system now, so that the most efficient options, which may take longer to build, are not lost.

2. Comparisons between energy storage and flexibility options must follow a consistent, technology neutral approach that considers all impacts and benefits.

3. Providers of essential electricity grid, storage, and flexibility services should be remunerated for all services that they provide.

4. Licensing and permitting arrangements must be timely, proportionate and take advantage of the range of internationally recognised sustainability tools.

5. Investors in long lasting assets, such as PSH, must have long-term visibility of revenues, with risk that is shared fairly to deliver the lowest overall cost to society in the long term.

6. Existing hydropower assets and prospective sites should be assessed and mapped for their potential to provide the most efficient long duration storage.

7. Green recovery programmes should include and support PSH, and green finance mechanisms should incentivise PSH.
Sustainability

PSH must be sustainable. Guidance and recommendations were developed to illustrate how the wide range of tools and methods available can help deliver this. PSH projects are highly site-specific in their performance, costs, and impacts. Therefore, it is important to focus on the processes that lead to sustainable systems, not just on PSH performance and cost indicators.

The key findings are:

1. PSH should be considered as a key enabler of the clean energy transition, alongside other energy storage technologies.

2. The development of PSH projects should rely on a multi-level approach, including an assessment of the storage, flexibility, and ancillary services that a given power system needs; an assessment of the options available to meet those needs; and, once selected, the PSH project should be managed to avoid, minimise and mitigate social and environmental impacts.

3. PSH projects are site-specific and sustainability cannot be defined by a simplistic classification. Existing sustainability tools for conventional hydropower projects are flexible and sophisticated to allow for these nuances.  

4. The application of Life Cycle Analysis to PSH projects is still nascent and mainly in the research domain. While potentially of value, specific attention must be given to the boundaries and functional units of the power system (e.g. the underlying energy mix). There is no evidence to suggest a material difference in GHG emissions from PSH reservoirs compared to those from conventional hydropower reservoirs which, on average, fall between those of wind and solar power.

5. PSH projects, as with many hydropower projects, can generate one-time or permanent local benefits, which should be considered in their sustainability assessment.

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6 Such as the Hydropower Sustainability Tools, governed by the Hydropower Sustainability Council, a multi-stakeholder group of representatives from energy companies, government agencies, financial institutions and social and environmental NGOs.

7 Median level figures as published by the IPCC in its Fifth Assessment Report.
Capabilities, Costs & Innovation

PSH is the only commercialised long duration energy storage technologies deployed at a large scale and has a higher round-trip efficiency compared to other long duration storage such as compressed air energy storage and hydrogen. PSH provides a range of essential grid services such as mechanical inertia, reactive power and black start which, with the phasing out of fossil fuel generation, will be difficult to obtain at the scale needed from other resources.

Figure 3 (below) shows a comparison of effective lifetime costs of energy storage technologies over 80 years. Crucially, simplistic capital expenditures (CAPEX) comparisons could be misleading. PSH has a much longer lifetime than many technologies which are better suited to short duration storage (such as lithium-ion batteries), so any comparisons need to take account of replacement life-cycles. Once the life cycle costs of storage are factored in, PSH is, even under cost predictions looking ahead to 2030, highly competitive.

While PSH is a mature technology, there are emerging innovations across three broad categories:

- Furthering PSH potential: installing PSH at disused mines, underground caverns, non-powered dams and conventional hydropower plants, as well as location agnostic underground PSH, off-river PSH and seawater PSH, represents vast untapped potential.

- Retrofitting and upgrading PSH systems: latest technological advancements, such as the use of variable speed pump-turbines and hydraulic short circuit, can enhance the services provided by existing PSH.

- Developing hybrid systems: coupling PSH with batteries, floating solar PV, heat storage and desalination can provide additional services with reduced costs and environmental impacts.
Where next

The work of the International Forum on Pumped Storage Hydropower has shown that there is a clear and increasing need for long duration storage on electricity grids, this need is being driven to a large degree by the essential deployment of huge amounts of variable renewable electricity i.e. wind and solar. Government intervention has been crucial in securing this deployment, with a wide range of tools used to share risk and encourage investment.

However, the most cost-effective sustainable long duration storage option available today, pumped storage hydropower, is not being built at the pace necessary to support the most cost-effective energy transition. Market and policy frameworks are, in many jurisdictions, not enabling the appropriate risk sharing necessary to support the deployment of this crucial low carbon technology.

The urgent need for long duration storage is beginning to be recognised: in April, the EU Taxonomy of Sustainable Finance recognised all types of PSH as making a substantial contribution to climate change mitigation, in June 2021 the International Energy Agency published a comprehensive hydropower market report calling for the expansion of pumped storage hydropower, in July 2021 the British government issued a call for evidence to better understand the barriers in place and how they may be addressed and in September 2021 the Chinese government set a new target for 120GW of PSH by 2030, which represents a fourfold increase in less than a decade. 

The International Forum on Pumped Storage Hydropower urges governments, regulators and all relevant stakeholders to act now to ensure that long duration storage - of which PSH is the most effective solution available today - can be deployed efficiently and effectively in time to support the integration of ever-increasing quantities of wind and solar.

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8 https://www.iea.org/reports/hydropower-special-market-report
10 http://www.nea.gov.cn/2021-09/09/c_1310177087.htm
Acknowledgements

Steering Committee

Sponsoring Partners

Working Groups

Policy and Market Frameworks Working Group led by GE Renewable Energy:

Sustainability Working Group led by EDF Hydro:

Capabilities, Costs and Innovation Working Group led by Voith Hydro:

We are grateful to the authors of each working group. A list of contributors is available for each report at https://pumped-storage-forum.hydropower.org/.
About the International Forum on Pumped Storage Hydropower

Launched in 2020 and jointly chaired by the U.S. Department of Energy and the International Hydropower Association (IHA), the International Forum on Pumped Storage Hydropower (IFPSH) is a multi-stakeholder platform that brings together expertise from governments, the hydropower industry, financial institutions, academia and NGOs to shape and enhance the role of pumped storage hydropower (PSH) in future power systems.

The Steering Committee of the IFPSH, comprised of governments, intergovernmental organisations and multilateral development banks, established three Working Groups (WG) covering ‘Policy and Market Frameworks’, ‘Sustainability’, and ‘Capabilities, Costs and Innovation’ to help address the common challenges facing PSH development.

The Policy & Market Frameworks WG, led by GE Renewable Energy, developed a global position paper to identify the current market and investment barriers and opportunities for PSH development, as well as recommendations to de-risk investment. With thanks to over 20 supporting organisations, country and region-specific recommendations were developed for the U.S., the U.K., Africa, Australia, Brazil, Latin-America and the Caribbean, Europe, Southeast Asia, India and China.

The Sustainability WG, led by EDF, aims to provide guidance and recommendations on mitigating adverse impacts that may occur in the development of PSH to ensure that it can best support the clean energy transition in the most sustainable way.

The Costs, Capabilities and Innovation WG, led by Voith Hydro, seeks to raise awareness on the role of PSH in addressing the needs of future power systems and deepen understanding about its potential, capabilities, costs, and innovation.

Disclaimer

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