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POLICYBRIEF

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The need for water as energy storage for better integration of renewables

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Highlights

Water as energy storage, when managed in a holistic way, has to take other uses of water and of water infrastructure into consideration. The close inter-linkage of water with energy and food security requires a nexus approach to managing the underlying resources, water and soil in the first place, but also waste. The water-energy nexus is one important "branch" of this multi-dimensional nexus and the particular role of hydropower for balancing variability of other renewables and for storing energy adds yet another facet to it. The planning, operation and management of storage or pumped storage hydropower, besides addressing new challenges imposed by the required shift to renewable energies, thus needs to adopt a nexus perspective. Exploring how to make use of synergies and minimize trade-offs between competing water uses is a scientific task, but even more a question of governance. Some case studies clearly show the opportunities of water as energy storage while considering other water uses. However, much more remains to be done and policy has to provide the framework and incentives to facilitate further progress.This policy brief aims to highlight some of the issues which need to be considered when developing water as energy storage for better integration of renewables.

The challenge

The rapid development and increasing share of renewable energy from wind and photovoltaic power world-wide raises new challenges to energy systems. The challenges are related to the variability of wind and solar output, and the potential imbalance between power production and electricity demand. This imbalance increases the need for energy storage. Hydropower with reservoirs is the only renewable energy storage in wide commercial use. Hydropower reservoirs and pumped hydro are used for storing energy at multiple time horizons, ranging from minutes up to several years. It still needs to be explored, however, how we can better use water reservoirs to improve integration of all renewables, while at the same time serving the needs for the secure supply of water for human consumption, agriculture, industry and the environment. Furthermore, reservoirs are also increasingly utilized to help manage floods and droughts, adding to the value of the water storage component of reservoirs. This paper will focus on the need for storage of both water and energy, the potential for better operation of existing reservoirs to meet the varied needs and the possibilities of retrofitting existing reservoirs to optimize the water use for all sectors.

The role of hydropower in delivering energy services while considering other water needs

Hydropower is a mature technology that has been advancing for more than a century. Today, hydropower provides around three quarters of the world's renewable energy generation. In addition, hydropower provides 99% of the world's electricity storage for transmission systems, a service that is growing in importance as deployment of renewables grows. In the last two years, for the first time ever, more money was spent on investment in renewables generation than either fossil or nuclear technologies.

Hydropower exploits the energy differential between two water bodies. There are two important components to this: the difference in elevation, and the quantity of water available that can be exchanged between the water bodies. Hydropower can be divided into three typologies, based on the different kinds of water storage – run-of-river, storage and pumped storage. Hydropower can be used to produce continuous electricity ('base load') where the water continuously flows. Or, it can be switched on rapidly to produce electricity at times of peak demand, and switched off at other times storing the water for later use when it is needed by the electricity system.

In a weekly cycle of energy demand, there are peaks during each day when a lot of electricity is consumed and also troughs, when very little is used (for example at night). To compensate for the natural variability of other renewable technologies, water can be released to balance the electricity system when demand outstrips supply. Similarly, when there is too much energy in the system, i.e., electricity supply is greater than demand, pumped storage facilities can use the surplus electricity to pump water from the lower body back to the upper body to be used for generation purposes when needed. This process consumes about 15% of the electricity, but it provides a crucial balancing service to electricity systems where supply must equal demand at all times.

There is a growing need for electricity for power, transport and heating/cooling. For example, there is an expectation that electric vehicles will become the norm in the road transport sector, as it is already for railways. We are increasingly using electricity to manage the temperature in our homes and workplaces.

> This increased demand for electricity will drive further development of hydropower and other renewables, making the needs for storage and balancing services even greater.

Beyond the range of energy services provided by storage and pumped storage hydropower, reservoirs provide critical water management services, an example can be found in the world's largest power station, the China Three Gorges Dam. The Yangtze River is exposed to extreme floods, and during the flood season there can be up to four or five serious events each year. A single flood event in 1999 that passed through the site before the dam existed caused economic losses to the region of US$26 billion – the Three Gorges Dam itself cost about the same amount to build. When a similar flood passed through the site in 2003, it was absorbed by the reservoir, averting major economic damage downstream. In addition, the navigation lock built around the dam allows the Three Gorges reservoir to be utilized for bringing goods upstream to municipalities that were previously inaccessible. The value of goods that travel through that ship lock on an annual basis exceeds the value of the electricity produced by the power station.

Water for energy storage can support the integration of solar and wind power

With respect to the electricity grid, short-term storage and system balancing requirements are also changing. We are seeing a shift from a daily, predictable change to one where there is an increasing proportion of variable input from wind and solar, and the timeframes in which supply and demand have to be matched are getting tighter. Consequentially, there is a need for more and more advanced equipment to keep the system reliable.

Hydropower's unique combination of generation and storage can play an important role in balancing systems with high penetration of variable renewables.

Storing potential energy through the water in a reservoir behind a hydropower plant can be used at multiple time horizons, ranging from hours up to several years. Hydropower technology is evolving to meet this need, with development and deployment of turbines that can respond rapidly to changes in the electrical grid at very short time scales.

Pumped-storage hydropower plants are often designed with a relatively high power capacity to operate in turbine or pumping mode only for short periods. Future challenges for pumped-storage development are connected to technical improvements to increase flexibility of operation, as well as business models, grid connection, environmental and societal issues related to the increasing need for energy storage and balancing services driven by the increased deployment of variable, renewable energy sources.

Results from a case study on large-scale energy storage and balancing services from Norwegian hydropower to exchange with the European grid where large shares of renewables have been integrated, show the technical potential to develop 20,000 MW of new hydropower plants of which about 10,000 MW includes pumping (Harby et al. 2013). This additional power capacity can be developed with no new dams as it is sufficient to use the existing reservoirs. The additional power capacity will only be installed in power plants discharging into large reservoirs or the sea, hence the environmental impacts will be moderate as no rivers will be directly affected.

The transmission capacity needs to be increased to allow more power exchange, and new business models need to be developed to foster investment in the required capacity.

Overall, hydropower offers a compelling option to meet storage and flexibility needs in the future energy mix.

Water storage serving multiple uses calls for a nexus approach

Water and the associated storage infrastructure often serve multiple uses besides water for energy: water is needed for irrigation for crop production, for domestic and industry use, ecosystem services, recreation and navigation. In addition, storage capacity is required for flood control and drought management.

All of these concurring and partly competing water uses need to be considered to maximize co-benefits, minimize trade-offs and deliver services in a synergetic way.

This balancing needs to take the temporal variability of water demands as well as site-specific priorities into account.

Looking beyond water as a resource and emphasizing the close linkage with energy and food security, the approach that integrates management and governance across sectors and scales has been termed a *nexus approach* (Hoff 2011). Taking a resources perspective, it turns into a nexus approach to managing water, soil (basis for food and biomass production) and waste (recycling of nutrients and organic matter, reuse of «grey» water, etc). This dimension of the nexus approach also emphasizes that it is not only the water quantity, which needs to be managed, but also the water quality (strongly driven by land-use and waste management), since many of the water uses require a certain water quality standard. These inter-linkages make reservoirs an ideal showcase for adopting and applying a nexus approach.

The complex task of nexus-oriented management requires appropriate management and modeling tools. While many such tools are available, it may be challenging to find or develop the most suited one, since there is no single best option depending on (i) the water uses to be considered, (ii) specific issues and challenges within the watershed and (iii) the availability of data. In order to facilitate the choice of the best-suited model (or ensemble of models) a web-based interactive data base of modeling tools is currently developed by UNU-FLORES and accessible on the institute's homepage (*https://data.flores.unu.edu/projects/ntp*).

Appropriate monitoring schemes, providing data on water quantity and water quality need to be implemented, in the best case directly feeding into a model framework. This should allow visualization and prediction of the outcome of applying management options and of global change scenarios.

Adapted management options and retrofitting existing reservoirs may serve various purposes and use different approaches, including the installation of pumped storage to increase management options. Depending on site-specific characteristics such as basin morphology, the volume ratio of pumped water, depth of water withdrawal and release, pumped storage may affect water quality and ecosystem functions. To evaluate the best options and anticipated effects, scenario analyses should be applied, using appropriate modeling tools.

In conclusion, development of hydropower and pumped storage needs to be done in a nexus context, considering other renewables and water uses to promote synergies. Tools for integrated management need to be developed, as well as monitoring strategies to provide the required data. This is particularly challenging in developing countries.

Case study: *The island El Hierro, Spain: 100 per cent renewable energy by integrating wind and solar energy with pumped hydro on a small scale*

El Hierro is the westernmost of Spain's Canary Islands, located in the Atlantic Ocean. It is small (278 km²), volcanic, has a population of about 11,000 and was declared a UNESCO Biosphere Reserve in 2000 due to its rare and unique flora and fauna.

Prior to the implementation of a renewable energy system, the island relied upon imported diesel to produce 45 GWh/year via nine diesel units (13.36 MW total) located in the Llanos Blancos power station with a peak production of 7 MW. The annual diesel consumption is 40,000 barrels, with emissions of 18,700 tonnes of CO_2, 100 tonnes of sulphur dioxide and 400 tonnes of nitrogen oxides.

In an effort to remove El Hierro's reliance on diesel, the role of the principal generator has been transferred to a wind power plant of five 2.3 MW Enercon E-70 wind turbines – total power 11.5 MW. This is backed up by a pumped-storage hydropower system comprising an upper reservoir of total 500,000 m³ at an elevation of 715 m in a natural caldera, and a lower man-made reservoir of 226,000 m³ at an elevation of 54.5 m. In generation mode the station's four 2.83 MW Andritz Pelton turbines (total 11.32 MW) benefit from a gross head of about 655 m at a flow rate of 2 m³/second. In pumping mode, the two 1,500 kW and fourteen 500 kW pump sets provide a pumping capacity of up to 10 MW.

In addition to providing electricity to the domestic and commercial sectors, the wind/hydro system also powers the island's three desalination plants linked to the lower reservoir. With this link the El Hierro case not only provides a compelling example of how water storage supports energy security based on renewables, but also an example of the water-energy nexus in practice.

The diesel units remain in an operational condition to act as a backup. It is unclear whether these will be routinely or exceptionally needed – one source claims that the wind-hydro system will provide 75% of the island's electricity (with 100% in some seasons), while others imply that all electricity will be served by the renewable, hybrid system.

The plant, working according the scheme given below, was commissioned on 27 June 2014, and it has been claimed that a thousand islands globally could use the same model.

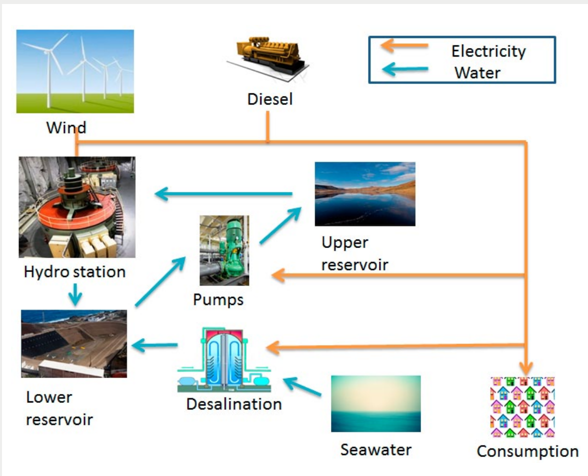

Figure 1: *Schematic view of the wind-hydro system of El Hierro showing the flows of electricity and water*

Case study contributed by Alex Trembath, IHA

Case study: *Integration of wind and hydro power in Ethiopia: Large opportunities for a developing country*

Ethiopia has huge potential of renewable energy sources for electricity production, especially wind and hydropower. A study by HydroChina confirmed the high potential for wind power in the northern and southern parts of the country, particularly in the Somali region, with a huge estimated wind energy potential of 1.3 TW. The potential for hydropower is estimated to 45 GW from inland and transboundary rivers.

The present electricity consumption of the country is insignificant compared to the available potential energy resources and in 2013, the total annual electricity consumption of the country was around 8.5 TWh where nearly 93% of the consumption was met by large storage reservoir hydropower plants. According to Ethiopia's energy sector plan, by the years 2015 and 2030 the electricity supply will reach 11,600 MW and 25,000 MW, respectively. The figure below illustrates the present and future probable electricity generation growth.

Recently, Ethiopia has emphasized the development of the available renewable resources to create sustainable and sufficient electricity supply. It is recognized that hydro dominated systems can be severely affected in cases of dry-hydrologic conditions. In order to make the power system more resilient to hydrological variability, diversifying the generation mix is a widely accepted solution. Diversifying the generation sources will mainly create stable electricity supply in the country and also will help to export excess energy to generate foreign revenue. The large storage hydropower reservoirs in the country will help to mitigate the shortage of electricity that can happen during dry hydrologic conditions and low wind speeds.

In conclusion, the electricity generation mix has a great contribution in sustaining energy supply and buffer fluctuations resulting from hydrological conditions and intermittent character of the wind speed. The hydropower dominated generation will also help to balance the neighbouring countries' wind and solar power systems as Ethiopia has already started exporting power to Djibouti, Sudan and Kenya. The East African Power Pool is thought to be balanced by Ethiopia's large hydropower reservoir plants, which is cheaper than other renewable sources. This hydropower capacity will thus contribute to affordable electricity price levels in the neighbouring countries.

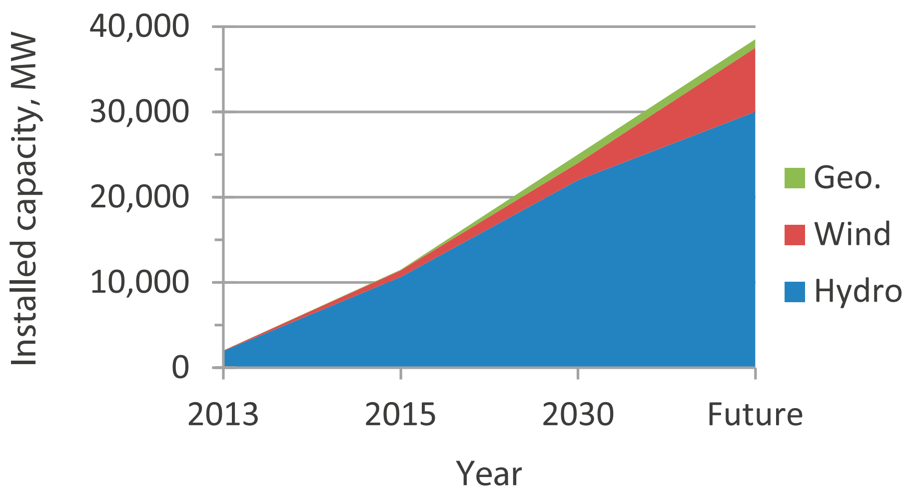

Figure 2: *The current and future possible electricity consumption composition (main sources) in Ethiopia*

Case study contributed by Tolawak Gurmessa Amenu and Ånund Killingtveit, Norwegian University of Science and Technology, Norway

Case study: *Hydro as a carrier for both off- and on-grid electrification and as energy storage for better integration of renewables in Mozambique*

Mozambique is one of the fastest-growing economies in sub-Saharan Africa, with an average annual growth rate of 7% for the past decade. Despite the strong growth, about 54% of Mozambique's population still lives below the poverty line. As a response, the government re-organized its development agenda line with the United Nations Millennium Development Goals (MDG): Access to energy has been made a national priority, by defining access to adequate and affordable energy services to households, rural schools, administrative offices, hospitals and rural enterprises as a key driver to economic growth and poverty alleviation. As a result access to grid electricity has been growing in the country, as it can be seen from the Figure below.

Renewable Energies have a very high potential to help to achieve a widespread access to modern energy services by Mozambican populations. Mozambique has almost all types of renewable energy potentials, including solar, wind, hydro, biomass, geothermal and ocean. From the different renewable energy sources hydro plays an important role in Mozambique, due to the following reasons: (i) hydro covers a wide range of capacities from tens of watts up to units of GW, like in Cahora Bassa which has a capacity of about 2 GW; (ii) hydro offers possibilities for both off grid and on grid systems; (iii) hydro has the highest potential in Mozambique, of about 18 GW (which is four times higher than that of wind energy), from which less than 5 GW has been developed so far; (iv) hydro offers a possibility of being less variable in comparison with other renewable energies, if appropriate infrastructures are established; (v) hydro represents a storage platform for other renewable energy supply systems, when these are feeding to the grid, contributing for balancing the energy matrix; and last but not least (vi) hydro brings synergies with other socio-economic uses, like flood and droughts protection, irrigation and water supply.

In order for renewable energies, in general, and hydro, in particular, to play a major role in socio-economic development of Mozambique there are some challenges which have to be faced: (i) addressing climate change issues, which can lead to less availability of water; (ii) responding to increasing demand, as a result of both population and economic growths; (iii) increasing storage capacities, by constructing new dams where appropriate; (iv) fostering implementation of integrated water resources management (IWRM) measures with collaboration among the different stakeholders (v) dealing with trans-boundary issues, calling for a regional cooperation and (vi) enhancing research and capacity development in water and energy nexus, climate change and socio-economic issues related to water uses.

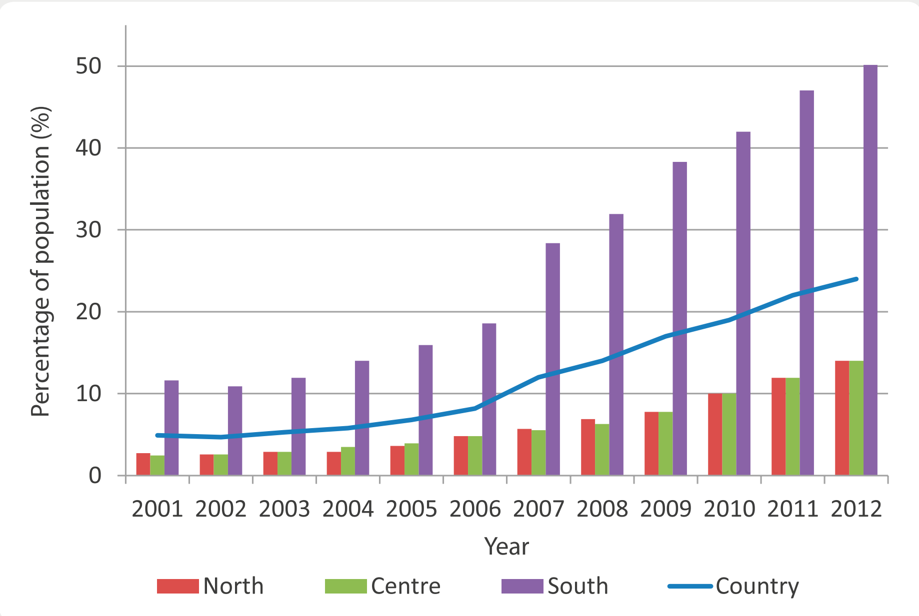

Figure 3: *Evolution of access (% of population) to on grid electrical energy in Mozambique by region and country (EDM 2013)*

Case study contributed by Boaventura C. Cuamba,
Eduardo Mondlane University, Mozambique (case study Mozambique)

Lessons from Case studies

What is obvious from all case studies presented is that hydropower in general has high potential within the energy mix and a special role among other renewables due to its storage capacity and synergies with other societal demands. Many developing countries, similar to Ethiopia and Mozambique, have particularly high potentials for hydropower to be developed in a coordinated way with other renewables and with energy systems of neighbouring countries to increase energy security at a regional level. This would be similar to the potential role Norwegian hydropower could play within the European grid. Typically, storage hydropower will be implemented, offering opportunities for synergies with other water uses. Pumped storage may play an important role in specific systems, such as El Hierro, where the potential of other renewables compared to power demand is high.

Policy recommendations

1. The role of reservoir hydropower and pumped storage in the effective functioning of the energy system through regulation, balancing and energy storage should be acknowledged as an essential part of clean energy systems, and appropriately incentivized by policymakers.
2. Reservoir and pumped-storage hydro are ideal for balancing, storage and back-up services to wind and solar power plants at multiple time scales, and there is a strong need for increased reservoir capacity world-wide. Further development must be enhanced, also in the light of other needs for increased water storage.
3. The true value of the full range of water services provided by reservoir infrastructure, including energy storage as well as flood control, domestic and industry use, irrigation, ecosystem services, recreation and navigation, should be considered in a dynamic and adaptive way. This implies strengthening/implementing mechanisms for integrated, nexus-oriented management and governance.
4. Developing and enhancing integrative monitoring of river basins with water storage infrastructure needs more attention and capacities, to enable adapted management and better evaluation of measures taken.
5. Cross-border market solutions are needed to enable increases in storage and transmission capacities by building new infrastructure, or by looking for opportunities to modify existing assets.
6. Sustainability assessment tools should be used to ensure the acceptability of hydropower and associated infrastructure.

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