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Vries, David de; Thakur, Jagruti Ramsing; Martin, Viktoria; Annor, Frank; Abraham, Edo

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Investigating the potential role of pumped hydro storage in the Ethiopian energy system transitions to 2050 using OSeMOSYS

David de Vries[1], Jagruti Ramsing Thakur[2], Viktoria Martin[2], Frank Annor[3,1], and Edo Abraham[1]
[1]TU Delft, Water Management, Netherlands (davidvri@hotmail.com)
[2]KTH Royal Institute of Technology, Sweden
[3]Trans-African Hydro-Meteorological Observatory (TAHMO), Nairobi, Kenya

Ethiopia's energy demand is expected to increase sevenfold in the coming 30 years, resulting in increased variable renewable electricity (VRE) production by solar PV and wind. Energy storage acts as a buffer that mitigates the effects of over- or under-capacity in production by VRE. With 97% of global bulk energy storage, pumped hydro storage is the most widely used and mature energy storage technology. With its long operational life, high round-trip efficiency (80%) and stable cost trajectory, it is a competitive option for many VRE-rich (future) energy systems. However, barriers to pumped storage include heavy technical, site-specific restrictions, long construction times and high initial capital investment requirements.

This study investigates if Ethiopia's energy pathways benefit from adding pumped hydro storage, suitable regions for PHS, and to what extent storage would increase system resilience. The long-term energy planning tool OSeMOSYS is used, which allows for detailed investigation into system dynamics whilst parallelly minimising costs. OSeMOSYS enabled the investigation into Ethiopia by looking at an extensive host of techno-economic specifications and supply and demand dynamics from the electrification of transport and integration of variable renewables to residential cooking demands.

This research studies thirteen scenarios which are separated into three main categories: Base Case (3), Emission Penalty (EMI) (6) and Varying Wind Capacity and Seasonality (WND) (6). The base case introduces pumped storage to the energy pathways, and the EMI scenario characterises three pathways for carbon pricing. In the WND scenario, wind power's capacity factor and seasonality are altered to investigate the potential effects of using more accurate local data or prioritising some supply zones on the energy system configuration. Additionally, the most favourable locations for solar PV and wind are combined with potential PHS locations to find optimal sites for storage construction.

The results of the research show that pumped hydro storage is adopted into the energy system in all scenarios, following both a diurnal and seasonal (dis)charge pattern. Variable renewable integration increases by an average of 10% from the addition of storage (78 GWh). The emission penalty increases the electrification of residential cooking demand and boosts VRE penetration but does not integrate storage integration further than the base case due to reaching the upper limit of the storage capacity set in the planning experiments.

Pumped hydro storage was found to increase the resilience of the modelled energy systems to climate-driven seasonal uncertainties and prices due to fossil fuel and carbon price uncertainties by making them less dependent on fossil fuels, decreasing vulnerability for potential emission penalties, and seasonal capacity fluctuations. The introduction of PHS was also found not to increase overall system costs, making it, combined with the stable levelised cost of storage and high maturity, a prime candidate for large-scale energy storage in Ethiopia.

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