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A Spatially Explicit Planning of Pumped Hydro Energy Storage in Kenya's Long-Term Decarbonisation Pathways

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This study addresses the potential role of Pumped Hydro Energy Storage (PHES) within the Kenyan electricity system pathways by combining high-resolution geospatial analysis for the site suitability and spatially explicit energy system optimisation model (ESOM) to evaluate optimal power system expansions to 2050. The modelling framework further incorporates a Gaussian copula-based Bayesian network to represent uncertainties related to demand and market pricing for net-zero target scenarios.
The study brings together three elements of PHES technologies by quantifying site-specific capital costs based on topology, implementing and optimising their scale and spatial patterns in future power systems, and addressing known uncertainties. Initially, techno-economically viable PHES sites are explored in Kenya by applying geospatial operations and redeveloping existing water bodies. Considering the country's distinctive geography, climate, land use, and water supply, the potential sites have been assessed within the nexus framework. The results indicate that Kenya offers considerable potential for PHES, with unit capital expenditures ranging from $750/kW to $6000/kW, with many options being comparable to the lower end of global cost ranges. This spatial heterogeneity of PHES potential motivates a spatially explicit dispatch and expansion analysis to identify which sites are cost-effective, where, and at what scale in future electrification pathways.
For this purpose, the study introduces a spatially explicit ESOM, termed PyPSA-KE, based on the open-source PyPSA-Earth framework. The model is calibrated using Kenya-specific data and applied to investigate optimal power system expansion pathways to 2050 under carbon tax-based net-zero scenarios. Closed-loop PHES sites identified in the Global Atlas of PHES (Stocks et al., 2021) are represented explicitly, with site-specific capital costs and grid-connection distances derived from local topography. Results indicate a substantial potential for PHES deployment across Kenya for both daily and multi-day storage, complemented by battery storage to ensure peak demand is met. The absolute amounts of storage required in 2050 are highly sensitive to uncertain exogenous socio-techno-economic factors, most notably future electricity demand, battery cost trajectories, and the stringency of carbon taxation. Although the ESOM is deterministic, explicitly accounting for such uncertainty is essential, in line with a growing shift towards global sensitivity analysis in the literature (Yue et al., 2018). To this end, the study proposes a Bayesian framework enabling probabilistic characterisation and rapid exploration of long-term scenarios. A Gaussian-copula-based Bayesian network is constructed using Monte Carlo

samples of PyPSA-KE outputs, generated by imposing probability distributions on key uncertain inputs. Despite limitations associated with network structure and the use of bivariate Gaussian copulas, the approach demonstrates strong potential to extract robust insights and inform policy discussions on long-term power system planning under deep epistemic uncertainty.

Stocks, M., Stocks, R., Lu, B., Cheng, C., & Blakers, A. (2021). Global Atlas of Closed-Loop Pumped Hydro Energy Storage. Joule, 5(1), 270–284. https://doi.org/10.1016/j.joule.2020.11.015
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