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DOI
10.5194/egusphere-egu25-17072

Publication date
2025

Document Version
Final published version

Citation (APA)
Abraham, E., & Pieruzzi, A. (2025). *Integrating Floating Photovoltaics in Long-term Energy Planning of Eastern Nile Basin Countries: Synergies Between Water Conservation, Land Use, and Emissions Reduction*. Abstract from EGU General Assembly 2025, Vienna, Austria. https://doi.org/10.5194/egusphere-egu25-17072

EGU25-17072, updated on 19 Mar 2025
https://doi.org/10.5194/egusphere-egu25-17072
EGU General Assembly 2025

Integrating Floating Photovoltaics in Long-term Energy Planning of Eastern Nile Basin Countries: Synergies Between Water Conservation, Land Use, and Emissions Reduction

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This study addresses the pressing need for sustainable energy infrastructure in the Eastern Nile Basin region, focusing on the integration of Floating Solar Photovoltaics (FPVs) in long-term energy planning. FPVs offer advantages over land-based photovoltaics, such as reducing capital costs by utilizing existing infrastructure at hydropower dams and reducing evaporation. Given the region's growing population and high competition for water, our research introduces a novel framework that explores the dual benefits of water conservation and reduced land use, alongside policy targets for lowering carbon emissions through increased integration of renewables in the power mix.

The study advances existing models by incorporating FPV technology into the OSeMOSYS tool, an open-source model for optimizing national energy generation mixes. Our research presents a spatially explicit framework for long-term energy system planning that integrates land use and water conservation metrics at reservoirs within the energy planning process. The role of FPVs in the region's energy pathways is evaluated by endogenizing the costs of CO_2 emissions and land use, while considering water savings. Our analysis develops and implements a new methodology for land-use accounting and pricing, and assesses the potential of FPVs to reduce evaporation across a network of hydropower reservoirs. This expanded modeling framework is then utilized to analyze various scenarios, including different hydrological regimes under CMIP climate change projections and policy measures such as the introduction of taxes on carbon emissions and land-use, and regional electricity trade links.

Results indicate that FPVs can cost-effectively provide up to 3% of the region's electricity generation by 2065, saving up to 376 million cubic meters of water annually. Scenarios introducing carbon and land-use taxes increase FPV's share in the power generation mix to 4.5% and enable earlier FPV deployment. While climate impacts minimally affect FPV's role, the technology slightly reduces CO_2 emissions (0.4%) and land use (1.6%) in the baseline scenario without taxes. A carbon tax alone reduces emissions by 11-23% but raises land use by up to 8% due to increased wind, hydro, and solar deployment. Land tax alone reduces land use by 5-8% with minimal impact on emissions. However, combining land and carbon taxes reduces emissions (by 12% to 22%) and land use (a decrease of 1.6% or an increase of 1.2%). The optimal locations for FPV deployment are

identified as Lake Nasser (2.1 GW), Renaissance Dam (6.4 GW), and Merowe Dam (1.2 GW), leveraging existing hydropower infrastructure. These findings demonstrate that FPVs represent a promising adaptation strategy for energy planning offering multiple co-benefits including reduced water evaporation, efficient land use, and emissions mitigation, particularly when supported by appropriate environmental pricing policies.