EVALUATING HYDROPOWER AND IRRIGATION DEVELOPMENT IN SUDAN UNDER CLIMATE CHANGE UNCERTAINTIES

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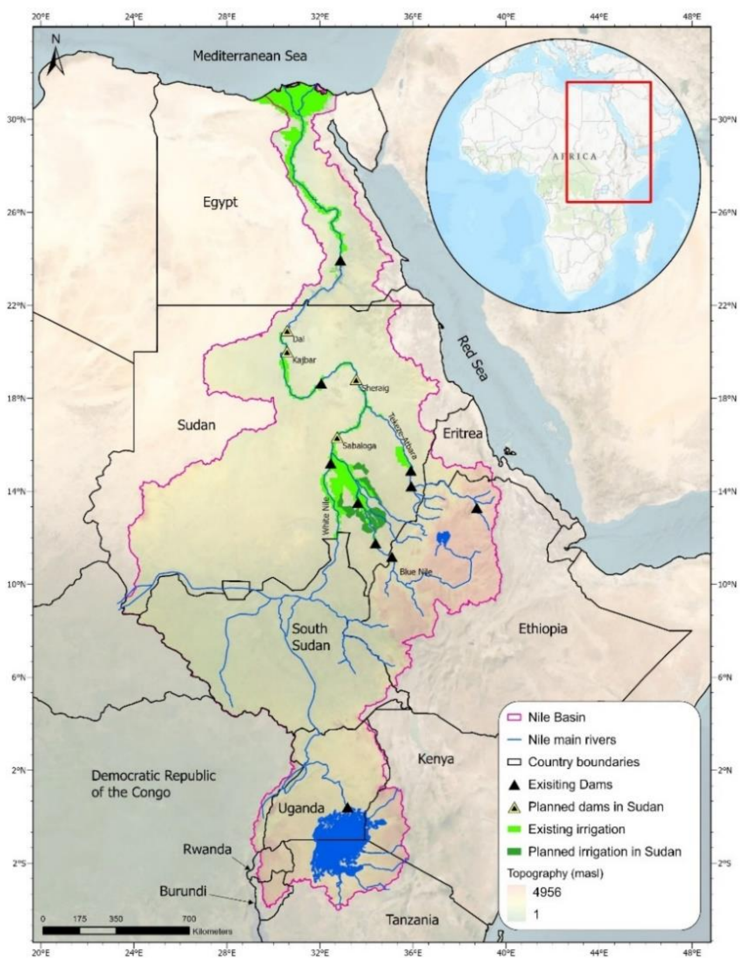
Hydropower and irrigation development on the Nile in Sudan can help meet growing food and energy needs. However, these potential infrastructures must be evaluated considering climate change uncertainties and multisector socioeconomic trade-offs. Increased streamflow combined with the recently constructed Grand Ethiopian Renaissance Dam would provide reliable irrigation water supplies in Sudan under most climate change scenarios but there are distributional impacts.

Background

Sudan, which encompasses around 40% of the Nile Basin area (Figure 1), faces challenges in meeting water, energy, and food needs. To help address these challenges, the country has plans to construct four large dams on the Nile with a combined capacity of 1,500 MW and expand irrigated agriculture on the Blue Nile by one million hectares (Basheer et al. 2024; ENTRO 2014). These plans aim to increase electricity access and reduce reliance on food imports, which constitute 22% of its import bill (Central Bank of Sudan 2021).

Climate change poses uncertainties for the development of infrastructure on the Nile. Projections indicate that climate change will alter the Nile streamflow with a wide range of uncertainties in impacts (Basheer et al. 2023; Beyene et al. 2010; Tariku et al. 2021), necessitating stress-testing development plans to ensure that investments are robust to alterations in streamflow and irrigation needs. To assess climate change impacts on planned infrastructure, we developed an integrated analytical framework (Figure 2), combining climate change projections and hydrological, river system, and economywide models of the Nile. This framework was used to evaluate the potential biophysical and economywide impacts of phased hydropower and irrigation development pathways for Sudan until 2050 under diverse climate change scenarios.

Figure 1 The Nile Basin and its major tributaries, existing dams and irrigation, and planned dams and irrigation in Sudan



Source: Authors.

Key findings

Hydropower and irrigation potential under climate change

Climate change projections to 2050 from the Coupled Model Intercomparison Project 6 (CMIP6) reveal an overall increase in water availability across the Nile River Basin. Precipitation is expected to rise in the Ethiopian Highlands under most climate scenarios. However, some climate models project drying in the southern regions of the Nile basin. Temperature projections from most scenarios indicate consistent warming across the basin, with the northern areas experiencing the highest temperature increases.

The 16 examined climate change projections show a general increase in naturalized flows for the main tributaries of the Nile (Figure 3). The 15-year average naturalized streamflow of the White Nile, Blue Nile, and Tekeze-Atbara are projected to increase by 0.6–10.8%, 4.0–62.5%, and 15.2–115.6% by 2050, respectively. These increases provide favourable conditions for expanding hydropower and irrigation infrastructure but require robust planning to address potential socioeconomic trade-offs and reductions in downstream flows to Egypt.

A set of phased infrastructure development scenarios in Sudan, in which hydropower dams and new irrigation development are added every five years over the simulation period starting from 2030, would increase hydropower generation by 5.6–8.1 TWh by 2046–2050, compared to a baseline in which no new infrastructure is implemented (Figure 4).

Expanding Sudan's irrigated areas by 1 million hectares (with 98% wheat and 2% sugarcane acreage) would increase wheat- and sugarcane-cultivated areas by 283% and 24%, respectively. The projected increase in Nile streamflow due to climate change

Figure 2 Climate-driven analytical framework for evaluating the biophysical and economywide impacts of irrigation and hydropower development in Sudan

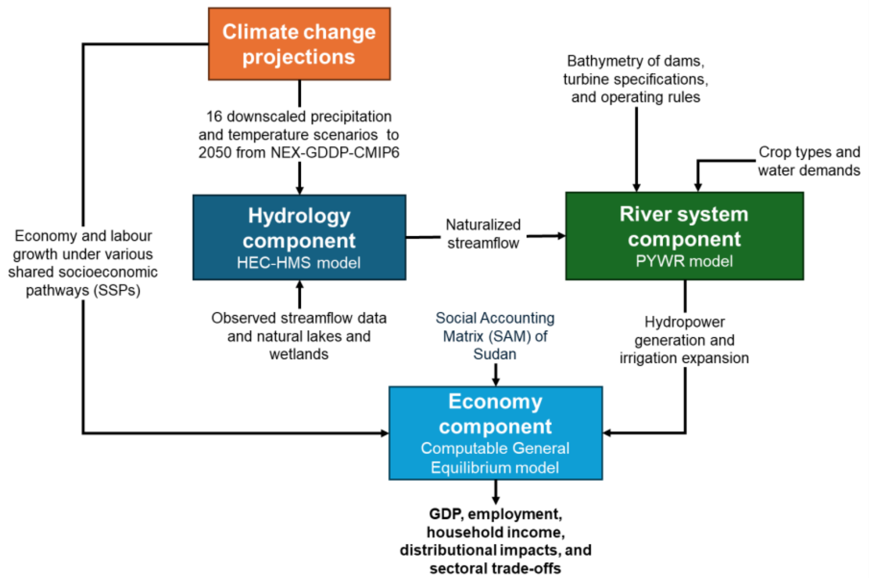


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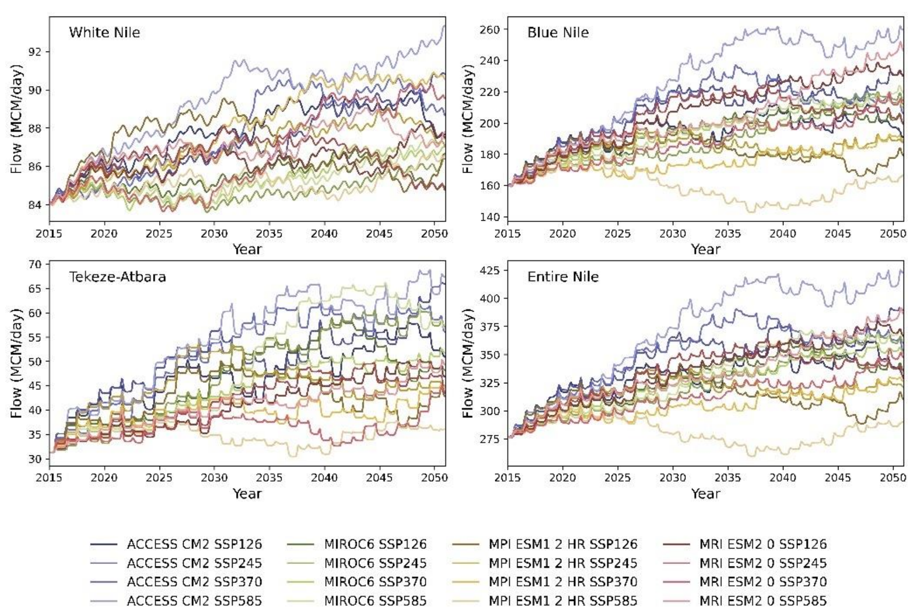
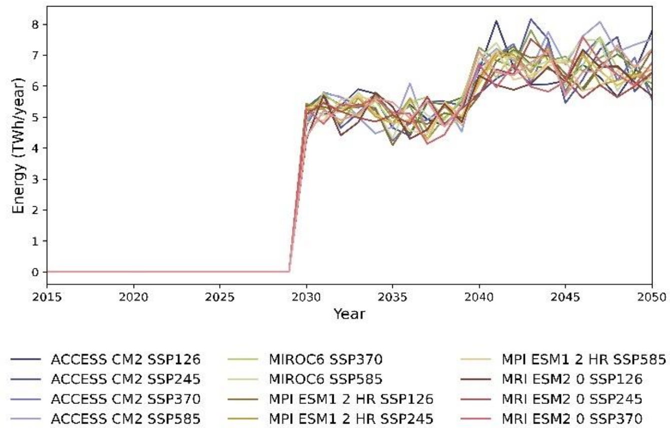
Figure 3 15-year moving averages of the monthly naturalized streamflow of the Nile based on four climate models and four shared socioeconomic pathways.



Source: Authors.

combined with the recently constructed Grand Ethiopian Renaissance Dam would provide reliable irrigation water supplies under most climate change scenarios. However, the expansion in irrigation poses trade-offs with downstream flows to Egypt, with annual reductions estimated between 0.2 and 7.2 billion cubic meters during 2030–2050. Despite this projected reduction in downstream flows from infrastructure development, increased streamflow due to climate change is expected to keep overall downstream flows above historical averages.

Figure 4. Projected changes in annual hydropower generation in Sudan assuming gradual dam and irrigation development under 16 climate change projections



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Economywide effects of hydropower and irrigation development in Sudan

Hydropower and irrigation development under the examined development scenarios present economic opportunities, but also have distributional challenges (Figure 5).

- Changes to the electricity sector: The hydropower sector shows an increase in aggregate GDP, with gains ranging from US$ 3.4-4.3 billion until 2050. This growth is driven by the expansion of hydropower production, which partially displaces thermal power generation, reducing its GDP by US$ 1.2-1.8 billion.

- Agricultural sector: "Wheat and Barley" and "Sugarcane" sub-sectors exhibit GDP benefits due to increased cultivated land based on the simulated cropping pattern. The aggregate gains of the wheat and barley sectors range from US$ 0.9-1.1 billion, while sugarcane gains are US$ 0.5-0.6 billion.

- Impacts on export-oriented sectors: Sectors like "Coal and lignite”, "Other mining," and "Petroleum products" experience GDP declines due to exchange rate dynamics. The appreciation of the domestic currency reduces the competitiveness of exports from these sectors.

- National GDP changes: National GDP begins to increase in 2030, with surges every five years due to phased infrastructure expansions. Annual changes in GDP range from US$ 0.1-0.4 billion, with cumulative changes of US$ 3.9-4.8 billion until 2050.

- Household income distribution: Aggregate real income of household groups increases by 0.14% to 0.38%. Urban households see higher income gains due to enterprise ownership, while rural households' gains are dampened by declining land rents. Income trends vary by economic growth pathways, with urban households benefiting more in high-growth scenarios.

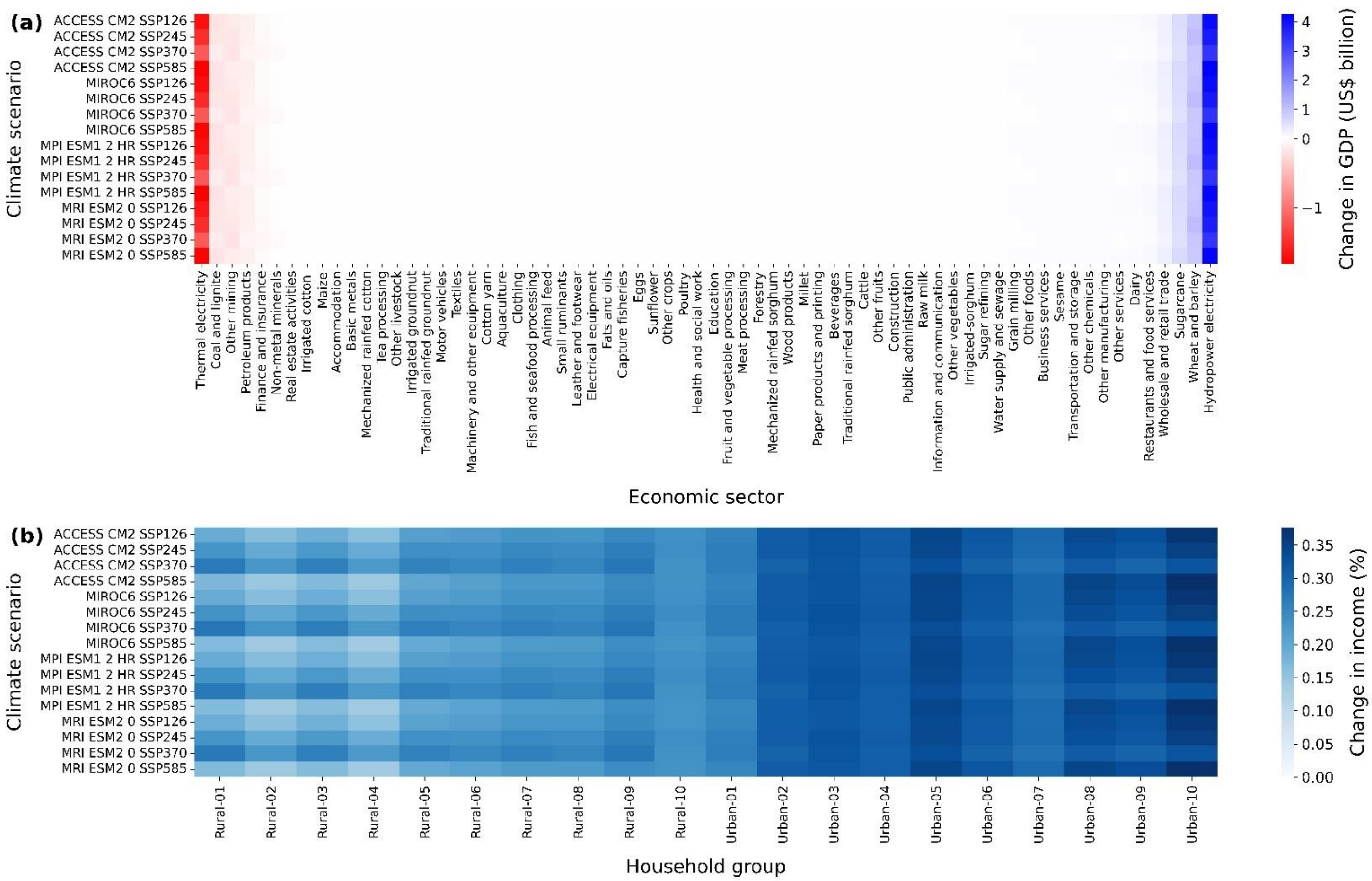
These findings highlight that careful planning is required to manage sectoral trade-offs, climate change uncertainties, and equitable benefit distribution across rural and urban populations.

Ways forward

To fully capitalize on the potential benefits of hydropower and irrigation development in Sudan, an integrated planning approach is essential. This approach must balance biophysical, economic, social, and environmental factors, particularly in the context of climate change uncertainties, which also include extreme climatic events, such as droughts and floods that are not fully captured here.

- Integrated planning: Adopting a holistic planning framework that incorporates a wide range of climate and socioeconomic scenarios is crucial to designing resilient infrastructure that can withstand the negative impacts of climate change.
- Transboundary cooperation: Collaborative planning with upstream and downstream nations can ensure more equitable resource utilization and foster regional stability. Such cooperation can help mitigate potential conflicts over water resources and promote shared benefits.
- Social and environmental considerations: Thorough assessments of the social and environmental impacts of dam and irrigation projects are needed. This includes evaluating their effects on local communities, such as displacement and changes in livelihoods, as well as the potential impacts on aquatic ecosystems and wildlife. Implementing measures to mitigate these negative impacts is essential for achieving a balanced and sustainable approach to infrastructure development.

Figure 5 Economywide performance of Sudan under the phased development scenarios compared to a baseline to 2050: (a) absolute change in aggregate GDP of various sectors, (b) percentage change in aggregate real household income.



Notes: Shown values are not discounted. In panel a, the sectors are ranked based on the magnitude of change from right to left (dark blue to dark red); in panel b, household groups are divided into deciles from poorest, 01, to richest, 10.
Source: Authors.

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