ROBUST INFRASTRUCTURE SEQUENCING AND MANAGEMENT FOR GROWING FOOD ENERGY AND WATER DEMANDS IN THE ZAMBEZI RIVER BASIN

POLITECNICO MILANO 1863

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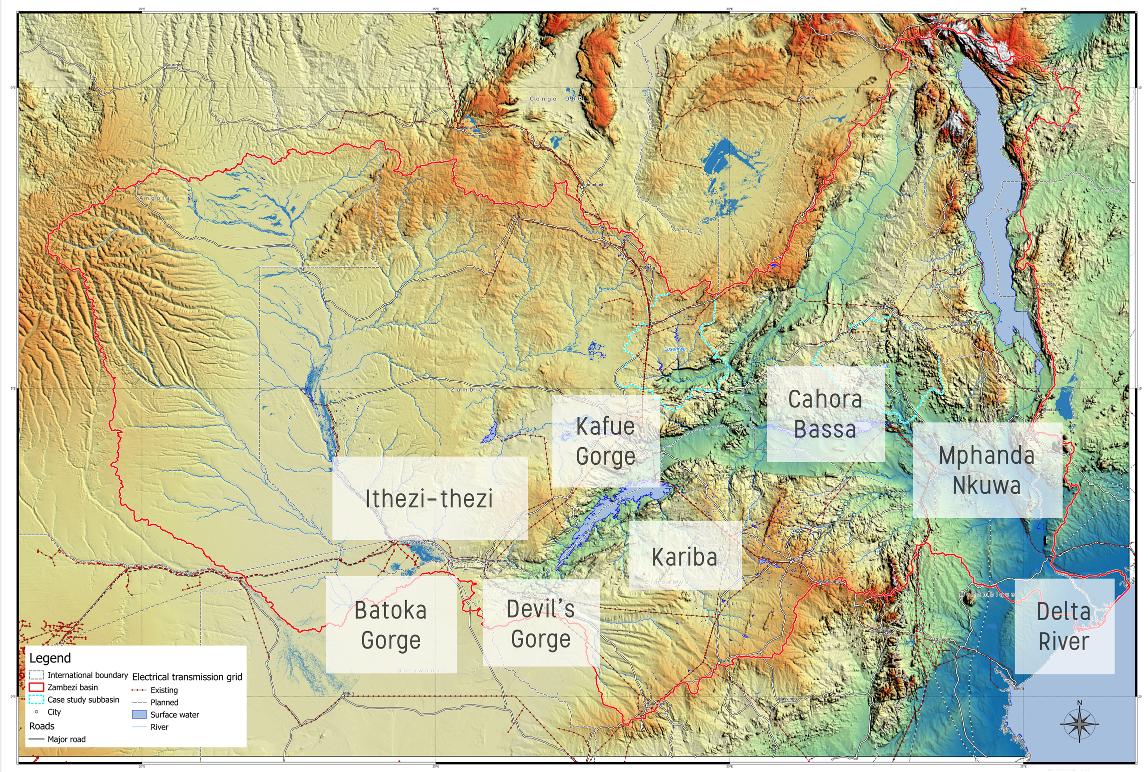
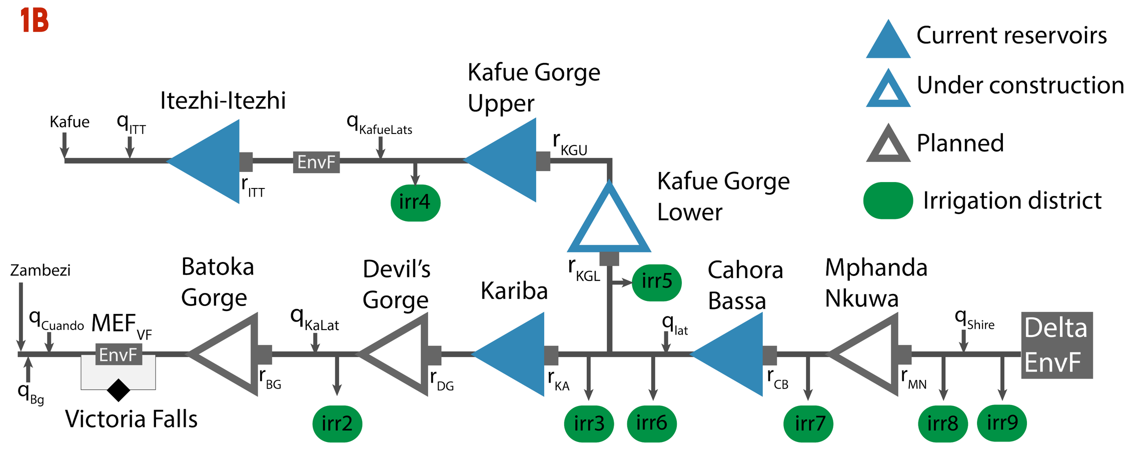
1 WATER INFRASTRUCTURE EXPANSION CHALLENGES IN FAST DEVELOPING COUNTRIES: THE ZAMBEZI RIVER BASIN CASE

1A



1B



We introduce a decision framework for efficient infrastructure expansion sequencing with embedded adaptive reservoir operations to foster sustainable economic growth. The study is motivated by growing energy and food demands in fast-developing economies. The framework is demonstrated in the Zambezi River Basin (ZRB) where major dam developments are currently set in motion [1].

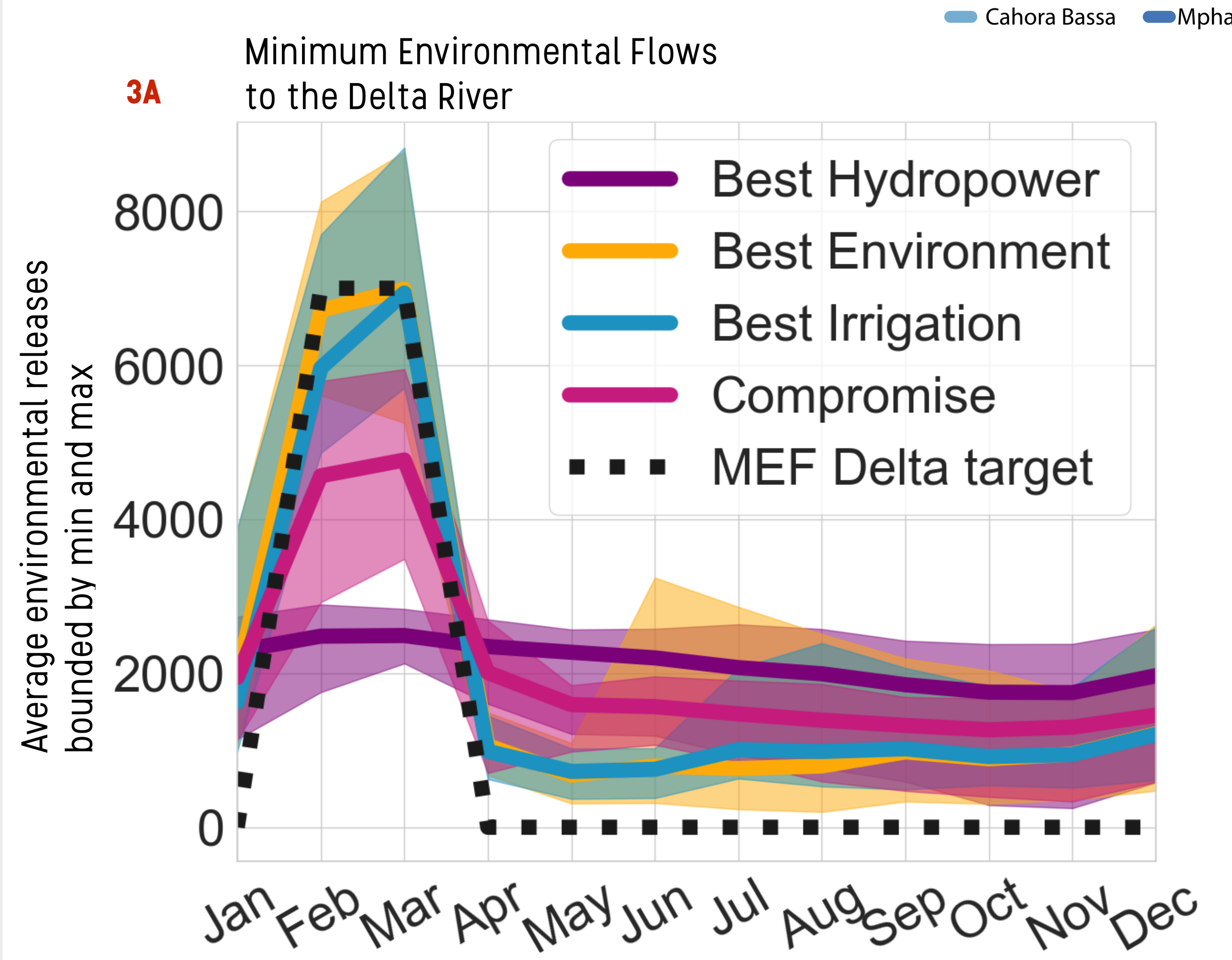
Highlights:

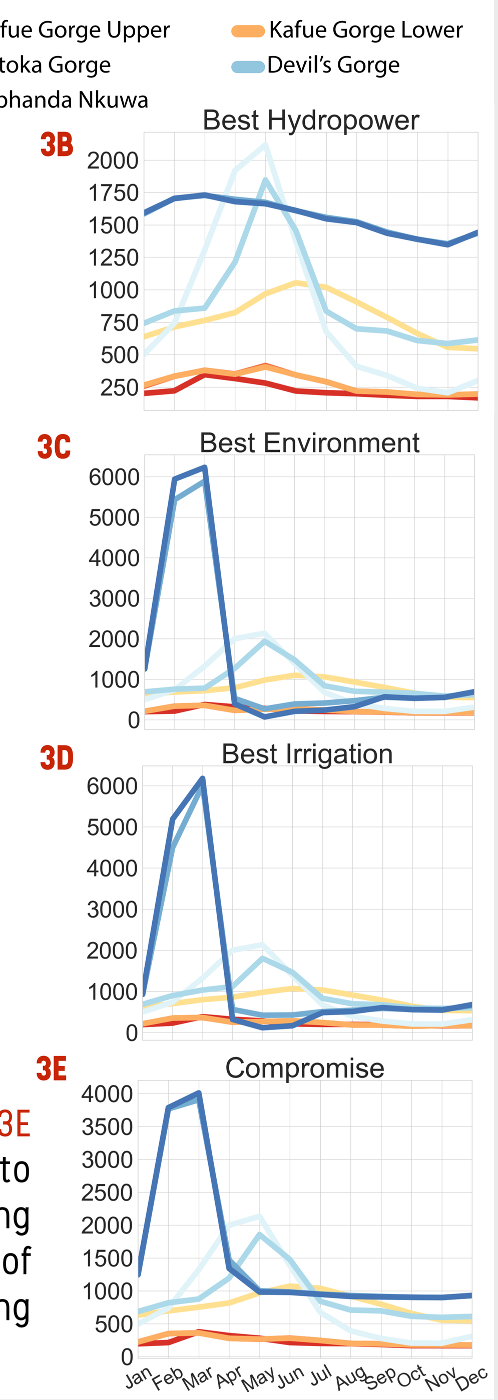
-Coordinated planning and management are key to meet basin-wide food, energy and environmental demands.

-Projected population growth in the ZRB signals the need for all dam investments to meet future hydropower demands. A stark tradeoff is observed between hydropower production and environmental flows to the Zambezi Delta.

3 COOPERATIVE RESERVOIR OPERATIONS AND ECOSYSTEM SERVICES IN THE ZAMBEZI DELTA

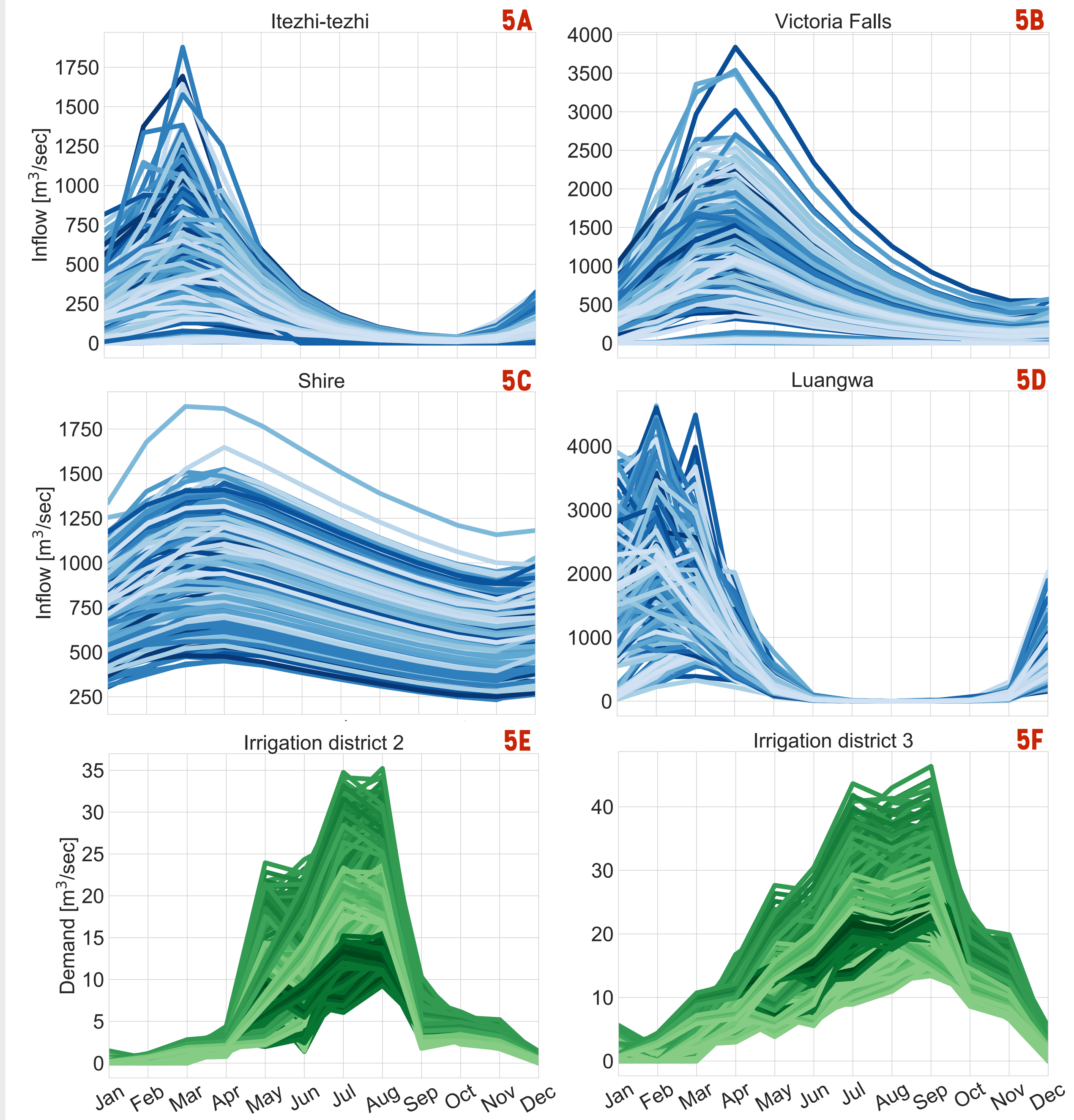
3A





Panel 3A, shows the releases to the Zambezi Delta, where Panels 3B -3E show these releases disaggregated by reservoir from upstream (dark red) to downstream (in dark blue). We observe that a hydropower maximizing policy will fail to meet environmental releases. Cooperative management of the existing and planned infrastructure has potential of strengthening environmental sustainability and economic growth in the ZRB.

5 PROJECTED IRRIGATION DEMAND AND STREAMFLOW SCENARIOS RCP 4.5



Projected streamflow scenarios in four different sub-catchments in the ZRB over 2020-2060 (Panel 5A-5D), where different shades of blue represent different scenarios. We observe that Luangwa sub-catchment is extremely low during the dry period from July to October across all scenarios.

Panels 5E-5F show synthetically generated scenarios for two representative irrigation districts over the time period (2020-2060), considering two efficiencies, 45% and 67% perturbed by ±5% and ±10%.

2 ADAPTIVE AND SUSTAINABLE PLANNING FRAMEWORK FOR GROWING ENVIRONMENTAL, IRRIGATION AND ENERGY DEMANDS

1. INFRASTRUCTURE EXPANSION PLANNING

- Which dam project to build?
- When to build?

Drivers

How to operate existing and new infrastructure?

2. BALANCE CONFLICTING DEMANDS

Stakeholder involvement

- Water: Minimize downstream flow deficit
- Food: Minimize irrigation deficit
- Energy: Minimize hydropower deficit

3. TRANSBOUNDARY MANAGEMENT

- Centralized decision maker is assumed to be in charge of basin-wide management.
- Analysis of planning and management strategies through visual analytics.

4. HANDLING UNCERTAINTY

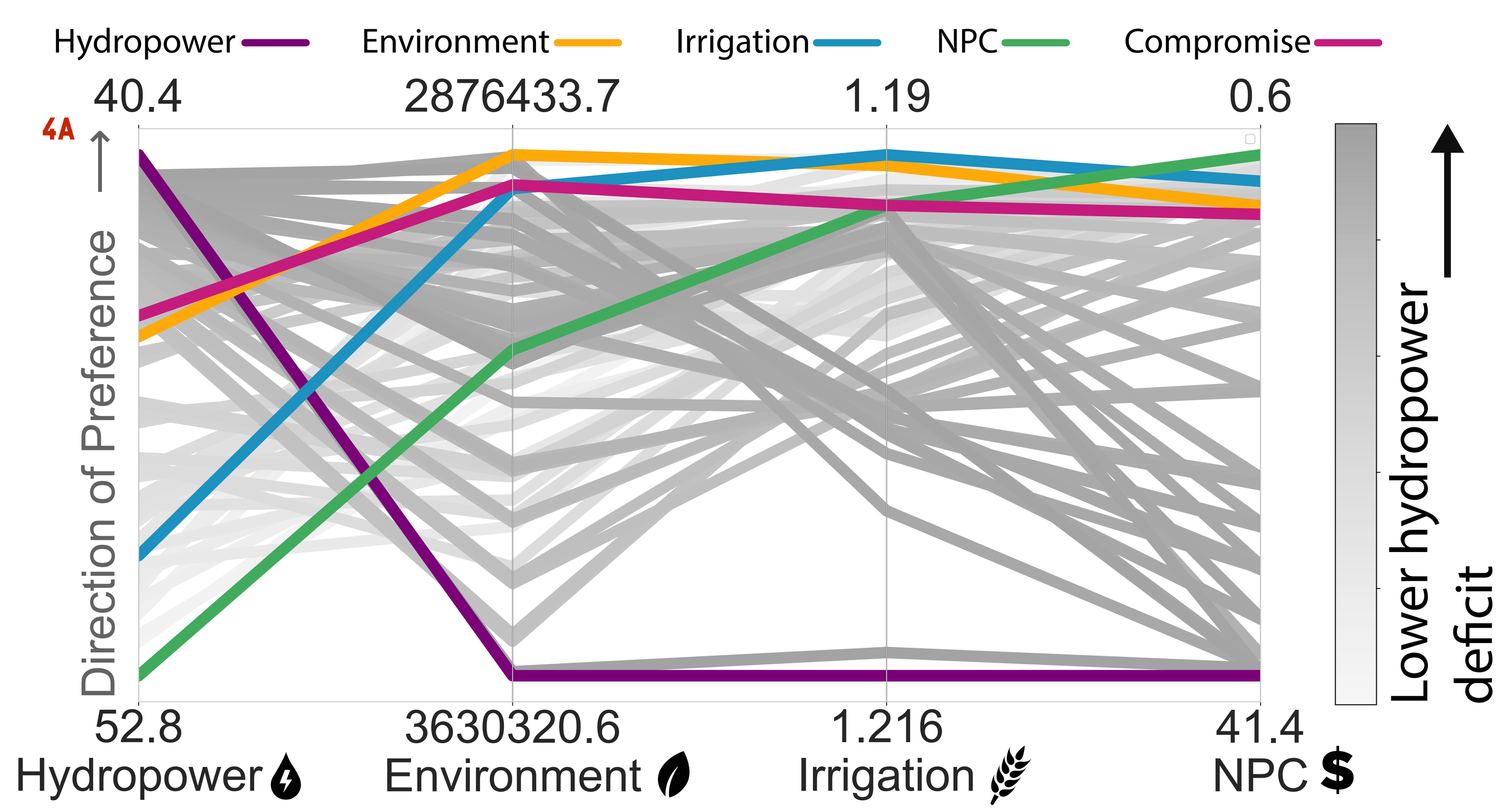
ADAPTIVE AND ROBUST PATHWAYS

- Dynamic selection of operating policies as demand increases over time.
- Sequencing over a broader set of future demand and streamflow scenarios.

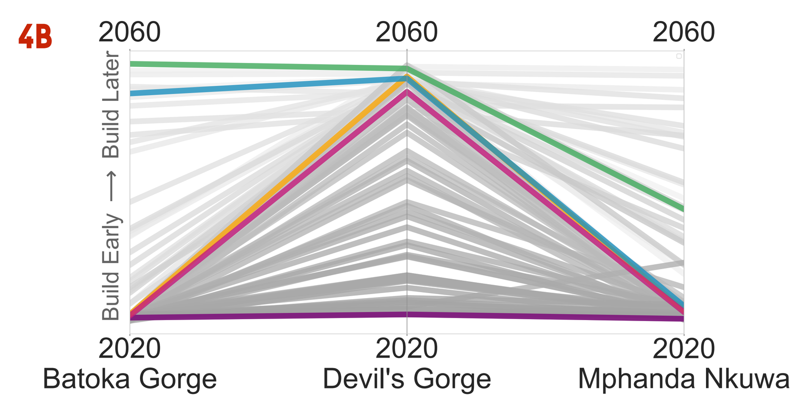
The decision analytic framework considers four key aspects of infrastructure expansion investments. First, in Panel 1, the construction time of each dam project is explored across the entire planning horizon driven by population growth and streamflow. Panel 2 highlights the participatory approach which enabled stakeholder involvement to define water, food and energy objectives. Panel 3 assumes a cooperative approach across existing dams newly built dams. Finally, we test the discovered Pareto efficient expansion pathways across a broader suite of demand and streamflow scenarios in Panel 4.

4 PARETO APPROXIMATE TRADEOFFS FOR THE ZAMBEZI RIVER BASIN: HIGHLIGHTING EXTREME AND COMPROMISE POLICIES

4A

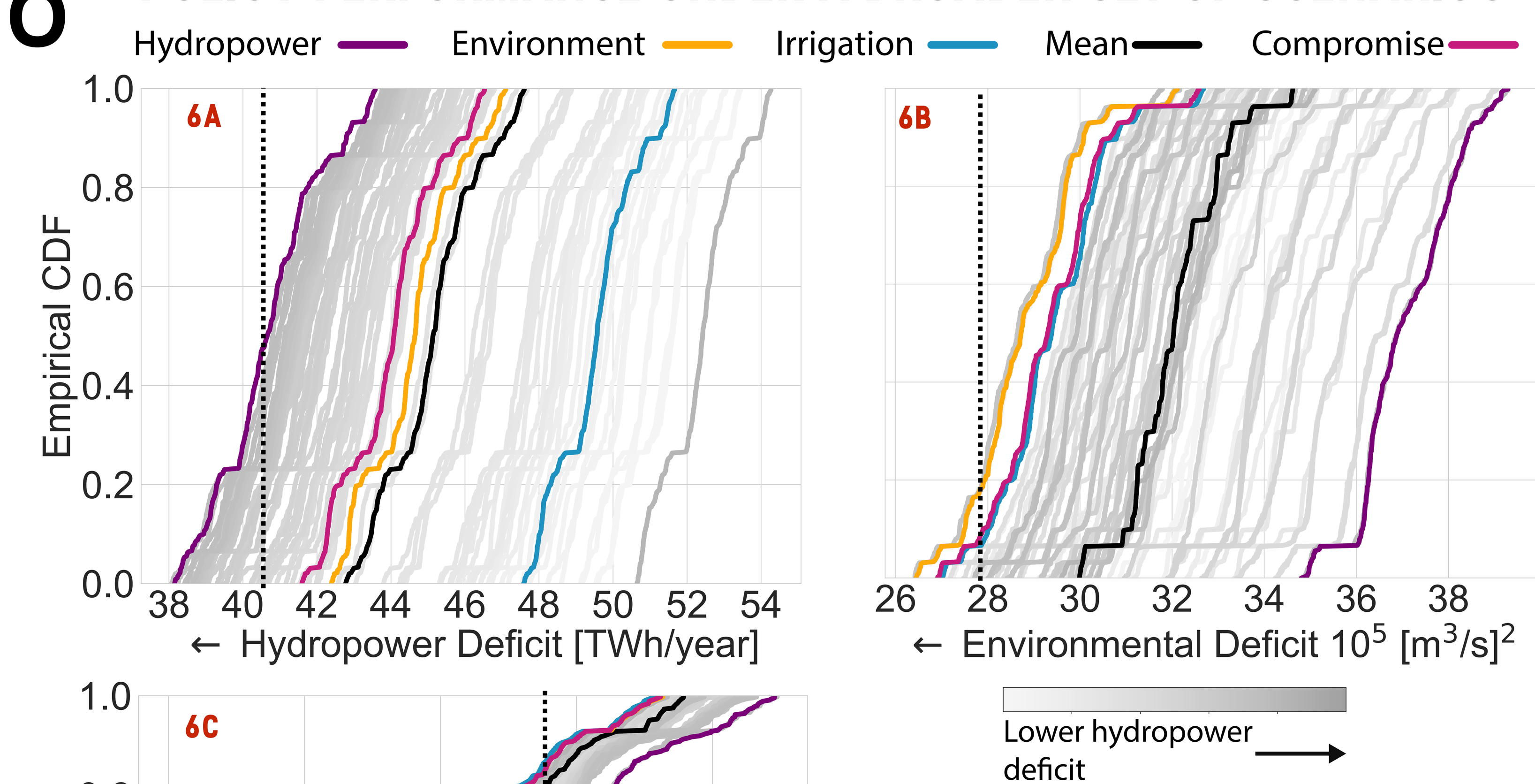


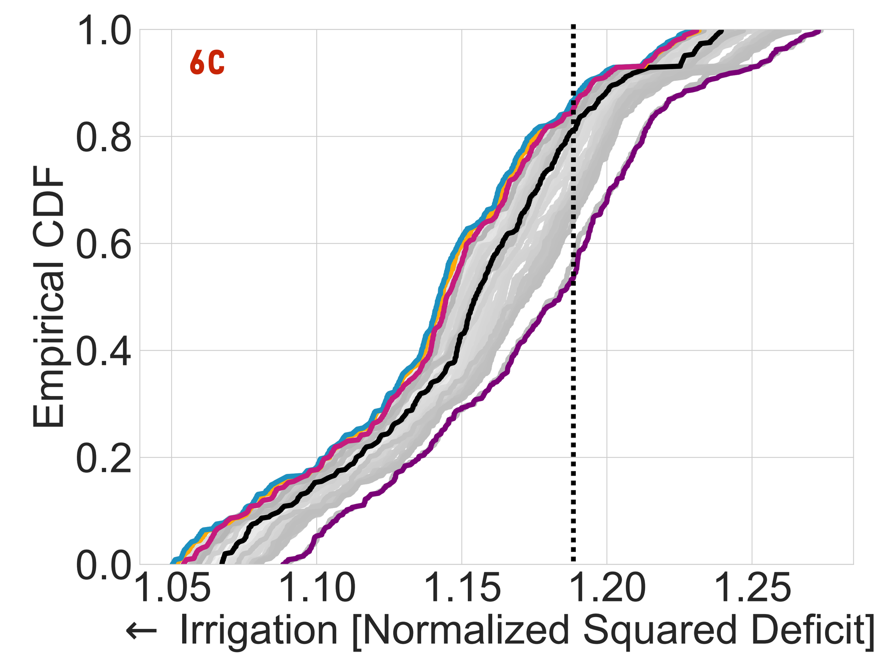
4B



The population growth driver is signaling the construction of all the planned dams within the 2020-2060 time horizon to minimize deficit of expected hydropower and irrigation demands. Where the best hydropower policy favors an earlier dam construction despite high net present cost (NPC).

6 POLICY PERFORMANCE UNDER A BROADER SET OF SCENARIOS





The performance of the Pareto approximate tradeoffs in Panel 4 was tested under a broader set of streamflow projections and irrigation demands (in Panel 5). Tracking the extreme policies, we observe that their ECDF keep the lowest deficit ranges within their own preference. We also observe that a hydropower maximizing policy will yield poor environmental flows (Panel 6B), whereas the compromise policy yields acceptable performance across all the scenarios.

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