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AWESOME

WATER-ECOSYSTEM-FOOD

Meso - level DAF

Future scenarios

Results

In this factsheet, we present the structure of the meso-level **Decision Analytic Framework** used to design efficient portfolios addressing the tradeoffs among Water, Energy, Food, and Ecosystem **Nexus** components under current and projected conditions. This search relies on state-of-the-art multi-objective optimization methods coupled with advanced visual analytics tools, which enable the exploration of large multidimensional spaces to navigate tradeoffs between hydropower generation and irrigation supply across Ethiopia, Sudan, and Egypt, and to negotiate potential compromise solutions.

WP4 - MESO LEVEL MODELS

Study of water supply: surface water, new water, food production technology

Multi-objective design of WEF planning portfolios

Identification and analysis of WEF portfolios

Meso-level DAF

The **Decision Analytic Framework** (DAF) is composed of a **strategic model**, conceptualizing the main natural processes and human decisions at the river basin scale, coupled with an **optimization engine** (Fig. 1).

The strategic model developed for the **Nile River Basin** integrates two main modules:

- **Water Supply model** - focused on simulating the operations of water infrastructures (e.g., reservoirs and irrigation diversions) combined with an aggregated water demand reduction (Fig. 2, left panel)
- **Water Demand model** - focused on describing the water use downstream of the High Aswan Dam, including both residential and industrial demands, as well as the irrigation requirements of the eleven districts in the Nile Delta (right panel, Fig. 2)

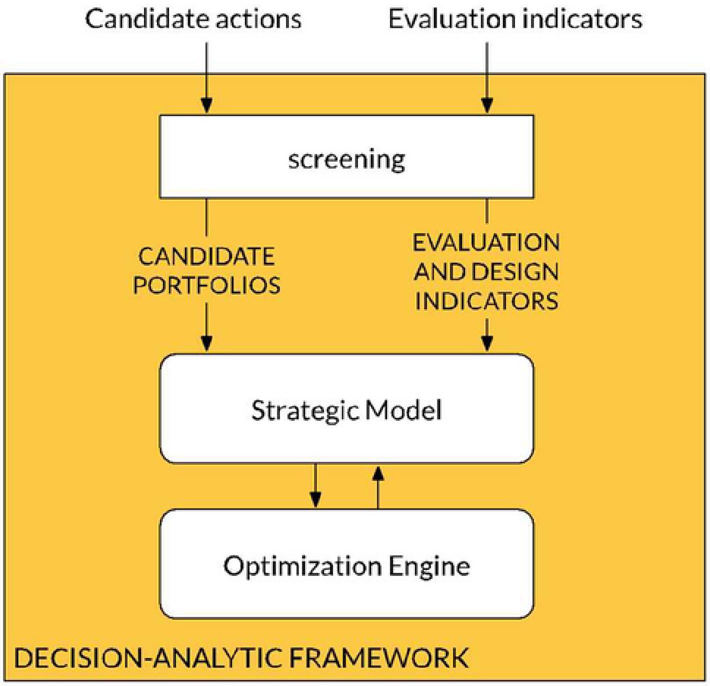
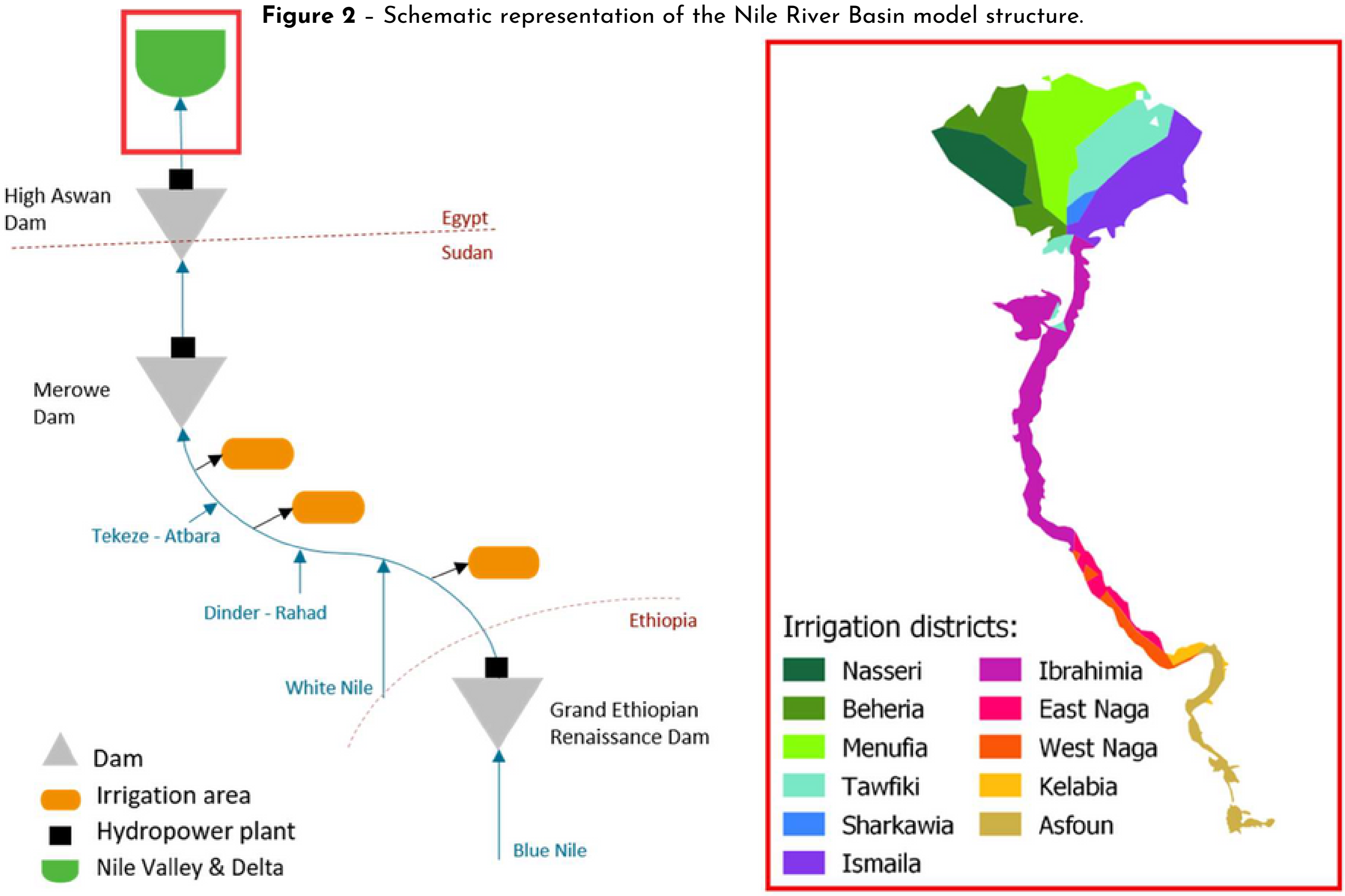


Figure 1 – Strategic DAF model at the meso level.

Figure 2 – Schematic representation of the Nile River Basin model structure.

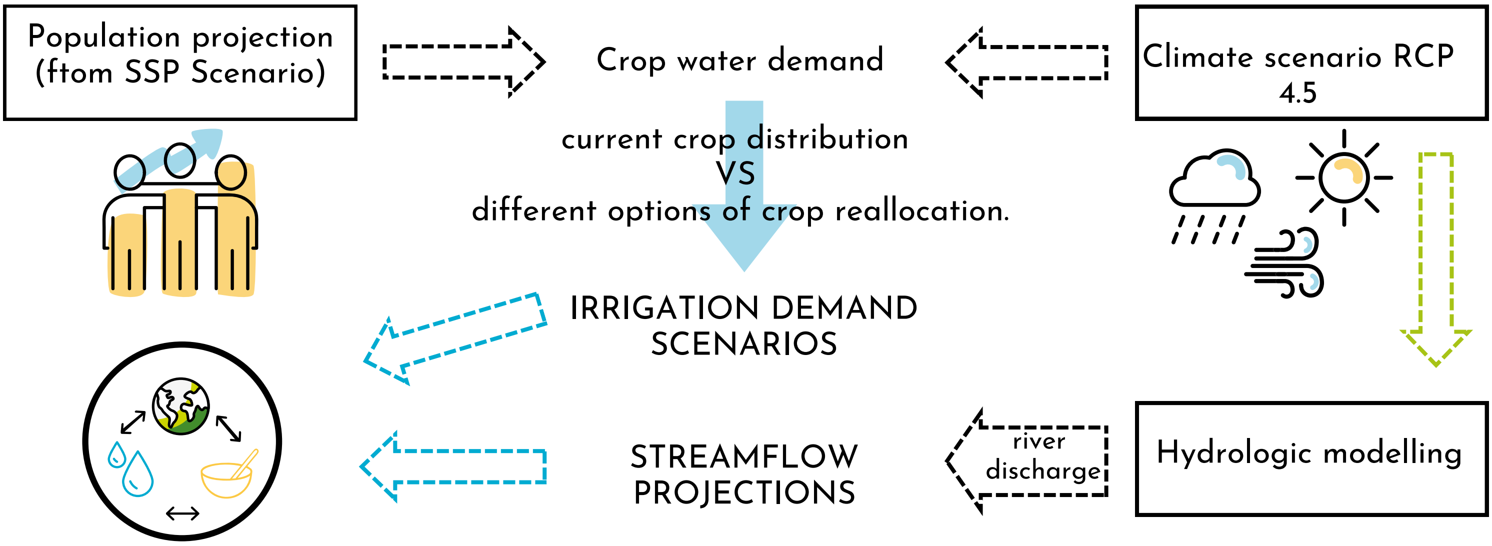


The **Water Supply** optimization maximizes the total hydropower production at the basin scale and minimizes the irrigation deficit in the three districts in Sudan as well as the total water supply deficit of Egypt.

The **Water Demand** optimization minimises the annual reuse of drainage water, the volume of groundwater extraction weighted by the distance from the Mediterranean Sea to avoid groundwater intrusion; capital and operational expenses of switching from traditional agriculture to aquaponics, cost of construction and operation of desalination plants .

Future Scenarios

Water Supply and Water Demand models are optimized both for a **historical scenario**, representing historical water availability and demand, and for a **future scenario**, which includes projections of hydroclimatic and socio-economic conditions. Climate projections are based on the **Representative Concentration Pathway** (RCP) 4.5: a business-as-usual scenario, where the radiative forcing rises until 2050 to stabilise in the second half of the century. Future domestic and industrial water demands depend on population projections based on the **Shared Socioeconomic Pathway** (SSP) 2: medium development scenario, whereby population, economic and technological trends do not deviate strongly from historical ones. The irrigation demand depends on the projected climate and population in the basin.



Population projection
(ftom SSP Scenario)

Crop water demand

Climate scenario RCP 4.5

current crop distribution
VS
different options of crop reallocation.

IRRIGATION DEMAND SCENARIOS

Hydrologic modelling

river discharge

STREAMFLOW PROJECTIONS

Results - the role of international cooperation

We first explored alternative solutions for the Water Supply model contrasting a **fully cooperative scenario** (maximizing system level performance) vs a **non-cooperative one** with Ethiopia pursuing national targets. Looking at Fig. 3, only GERD hydropower production is higher in the non-cooperative scenario (yellow lines) than under full cooperation (blue lines), while all downstream sectors are penalised. Interestingly, this additional production of the GERD is lower than the missed hydropower production in Sudan and Egypt, confirming the **need of moving towards an international agreement across riparian countries** to ensure a sustainable management of the Nile River.

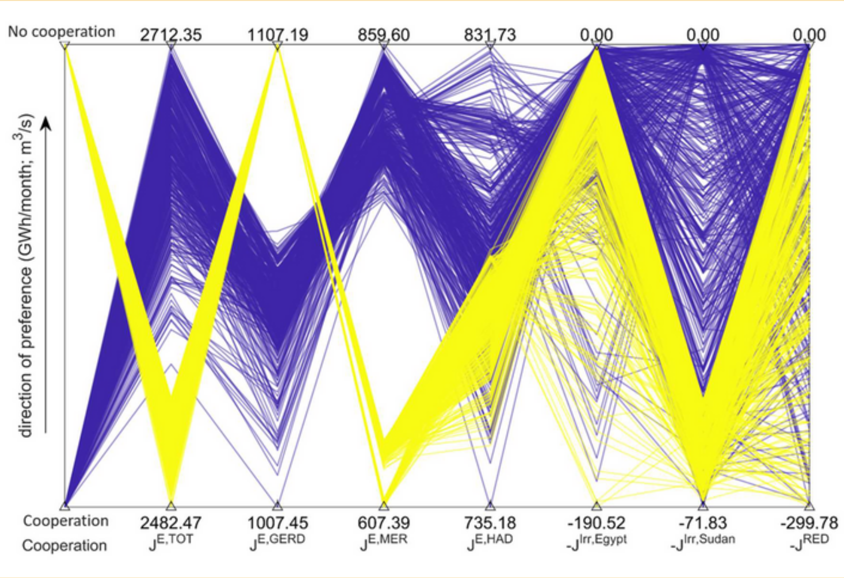


Figure 3 - Optimization of the Water Supply model under climate change for cooperative scenario (blue lines) and noncooperative scenario (yellow lines). For every solution is reported the hydropower production at the basin scale, in Ethiopia, Sudan and Egypt, Egypt irrigation deficit, Sudan irrigation deficit and water reductions below (x axis, from left to right).

Results - portfolios for the water supply system

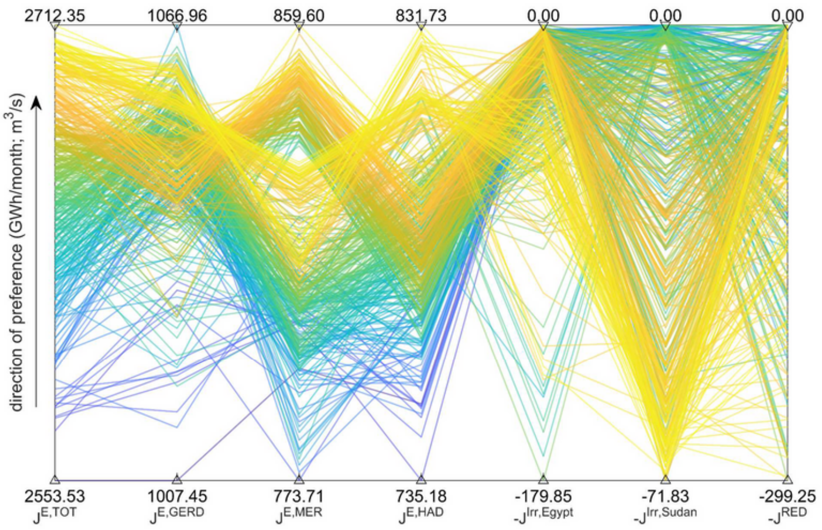


Figure 4 - Performance of the Pareto efficient portfolios for the Water Supply System. Results are shown in terms of hydropower production at the basin scale and for the three dams GERD, MER and HAD, the irrigation deficits of Sudan and Egypt and the water demand reductions below HAD (x axis, from left to right).
Each solution is represented as a horizontal line crossing the seven vertical axes at the value of the corresponding performance, with the optimal solution that would be represented by a line crossing all axes at the top.
The colour are assigned according to the level of energy produced at the basin scale (J-E,TOT), where yellow line corresponds to high energy productions and blue lines to low one.

The efficient portfolios for the Water Supply System under the cooperative scenario (Fig. 4) show a **strong trade-off between hydropower production in the entire river basin and irrigation supply in Sudan**. Portfolios that favour the latter are associated with large irrigation abstractions that reduce the water available for hydropower generation at both Merowe and High Aswan Dam. Conversely, the trade-off between hydropower production and water supply in Egypt is less important. In this case, the consumptive use located downstream of the hydropower plants makes most of the water flowing into the Nile Delta also productive for electricity generation. Our results demonstrate how **the reduction of water demand is the key lever in portfolios that achieve high hydropower production and low water supply deficits** in both Sudan and Egypt.

Results - portfolios for the water demand system

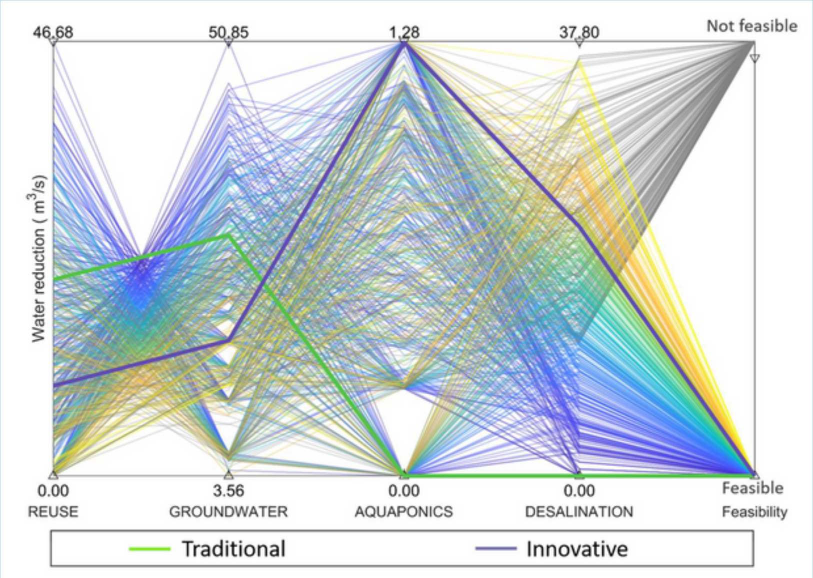


Figure 5 - Parallel plots of Water Demand optimization for water reduction equals to 50.9 m3/s, showing the volumes of water allocated to reuse, groundwater, aquaponics and desalination and the feasibility of the solution. The colours are assigned according to the desalination total capacity of every solution (yellow - high, blue - low, grey - unfeasible). The solution with high volumes of reuse and groundwater is highlighted in light green and the solution with high volumes of aquaponics and desalination in purple.

Two solutions reducing the Egyptian water demand are selected and optimized using the water demand model. The contributions of the different water demand measures - groundwater, reuse, aquaponics, and desalination - attaining an overall reduction of 50 m3/s are illustrated in Fig. 5. Results show a **clear trade-off between desalination and groundwater reuse**, suggesting that this technological solution could replace more traditional practices. Aquaponics is also promising although constrained in our experiments by the maximum water savings obtained by switching the current cultivation of lettuce from traditional to soilless practices.