A Real Options-Based Decision-Making Framework for Hydraulic Infrastructure Investments

Hamidreza Rezazadeh[1] and Amaury Tilmant[1]

[1] Department of Civil and Water Engineering, Laval University, Québec, Canada

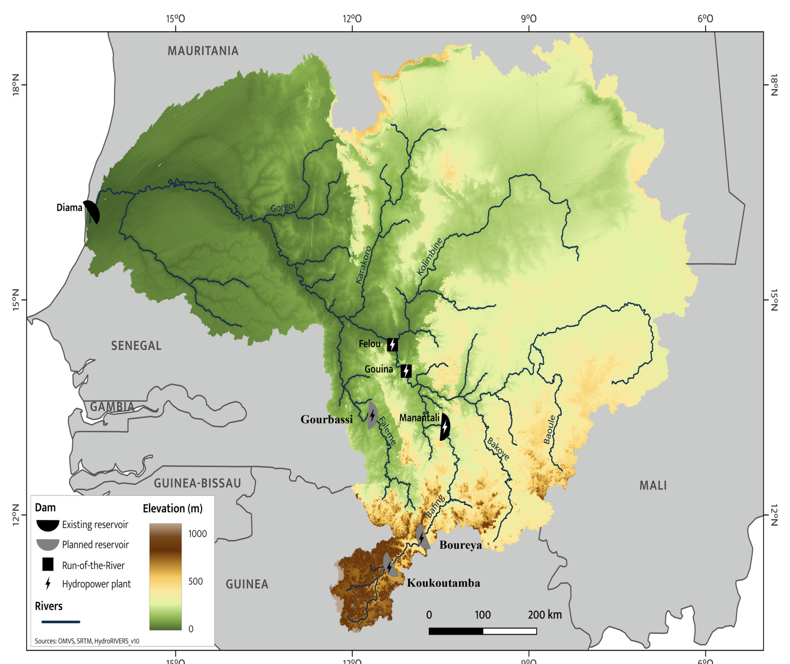
Contact: Harek2@ulaval.ca

1 Introduction

- Hydraulic infrastructure planning is challenging due to the uncertain evolution of future demands and supplies, and the deep uncertainty associated with climate change.
- Traditional planning approaches are based on well-characterized statistical distribution and are thus ill-suited under deep uncertainty.
- This has led to the emergence of a new paradigm, "prepare and adapt," which focuses on developing robust and adaptive systems that can perform well under a wide range of futures.
- The main objective of this research is to develop a methodology for planning new hydraulic infrastructures in deeply uncertain and rapidly changing environments. To achieve this, we integrates real options, deep uncertainty, and temporal multicriteria analysis (TMCA) to address issues related to the timing, sequencing, and operating of infrastructure under uncertain future hydroclimatic conditions.

2 Case study

- Senegal River Basin (SRB) is the second largest transboundary in West Africa.
- The basin is largely under-developed.
- Main water uses:
  - Food production (irrigated + flood recession agriculture)
  - Energy production
  - Fisheries
  - Navigation
  - Drinking water
- Candidate infrastructures (dams):
  - Koukoutamba (K)
  - Gourbassi (G)
  - Boureya (B)



Senegal River Basin - Planned and existing reservoirs

Acknowledgements

This project was supported the GoNEXUS project, which is funded by the European Union Horizon Programme call H2020-LC-CLA-2018-2019-2020 - Grant Agreement Number 101003722. The participation of Canadian researchers to GoNEXUS was made possible by the New Frontiers Research Fund program (Canada) (grant NFRFG-2020-00430) and by the Fonds Nouvelles Frontieres en Recherche (Quebec) (grant 2022-FNFR- 310131).

Scan me

3 Methodology

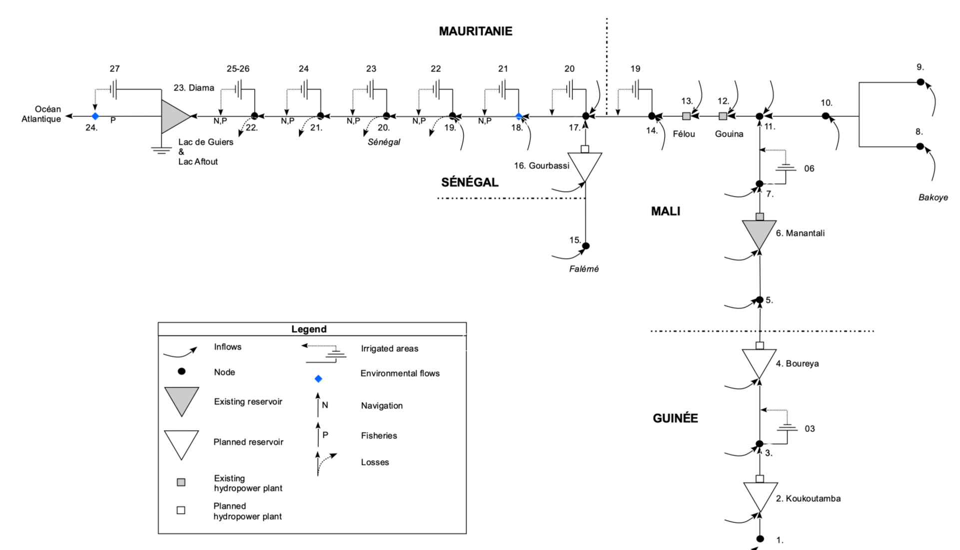
I. Real options analysis (ROA)

- Derived from financial options theory, real option provides a method to consider flexibility in decision-making.
- Real option represents the right, but not the obligation, to undertake certain business initiatives, such as deferring, abandoning or expanding investments in a project.
- ROA is ideal for projects with high uncertainty and where future conditions may significantly influence current decisions.

- **Decision tree**
  - The decision tree is constructed by incorporating real options (delay and configuration). It consists of three decision stages (10 years each) followed by 30 years.
- **Assumptions**
  - Irrigation increased every 10 years by 25 kha.
  - Two different allocation policies are considered:
    - Energy security (Maximize the energy generation)
    - Food security (Implement an artificial flood to sustain flood recession agriculture and fisheries)
  - Historical flows

II. Hydro-economic model

- Each node of the scenario tree: allocation policies determined by an optimization-based hydro-economic model.
- Maximizes expected basin-wide net benefits taking into account the hydrologic uncertainty



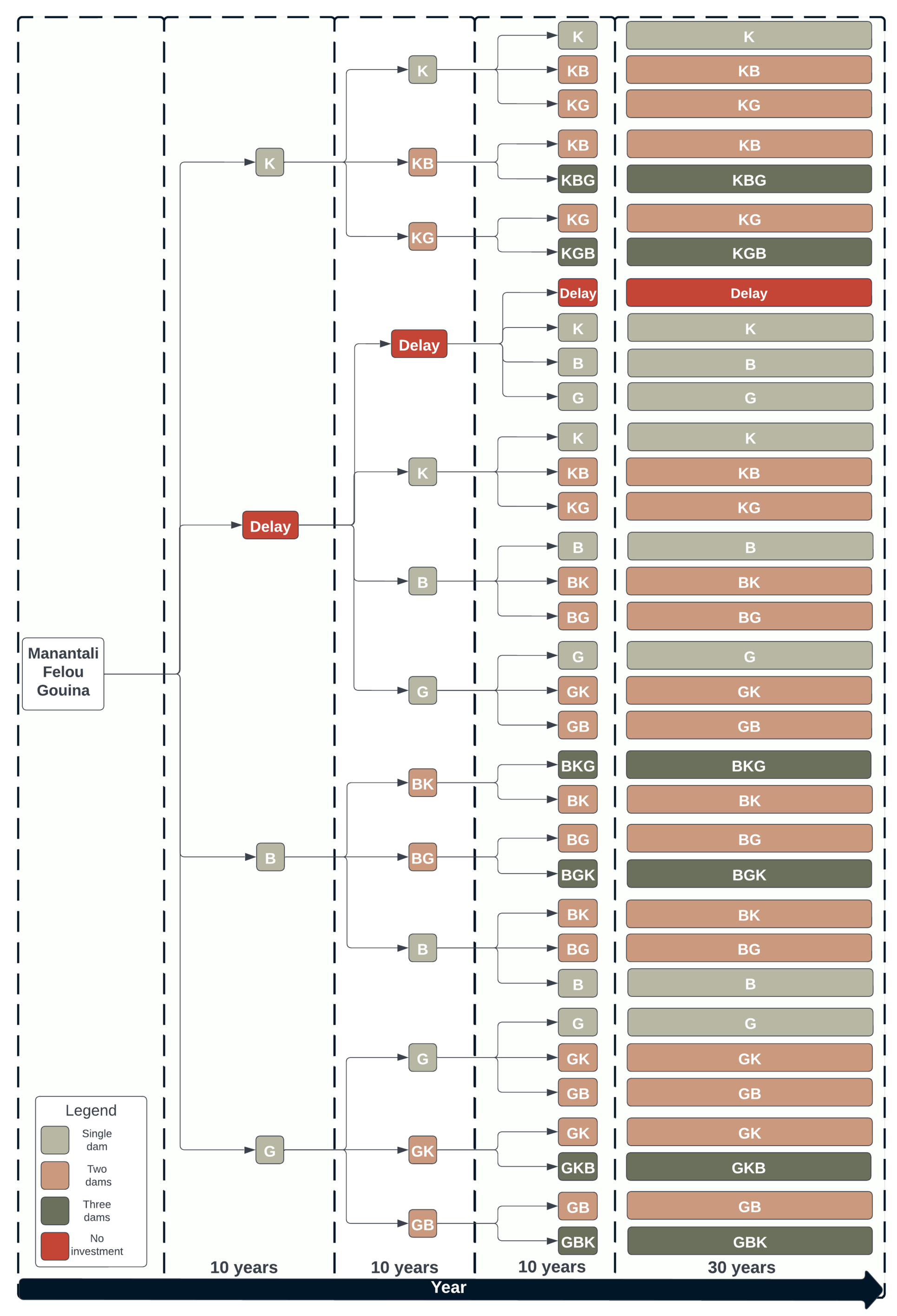
Schematic of water resources system in SRB

III. Alternatives' evaluation

Temporal multicriteria analysis (TMCA)	Hydropower	Total annual hydropower production (GWh/year)
	Flood recession	Floodplain cultivated area at downstream (Bakel) (ha/year)
	Fisheries	The amount of fishing in the reservoirs + downstream river (Ton/year)
	Irrigated area	Irrigated area in the basin (ha/year)
	Navigation	Navigation reliability (%)
Net present Value (NPV)	The present value of all future cash flows of the projects, subtracting the initial investments (MUSD)	

- **Temporal multicriteria analysis (TMCA)**

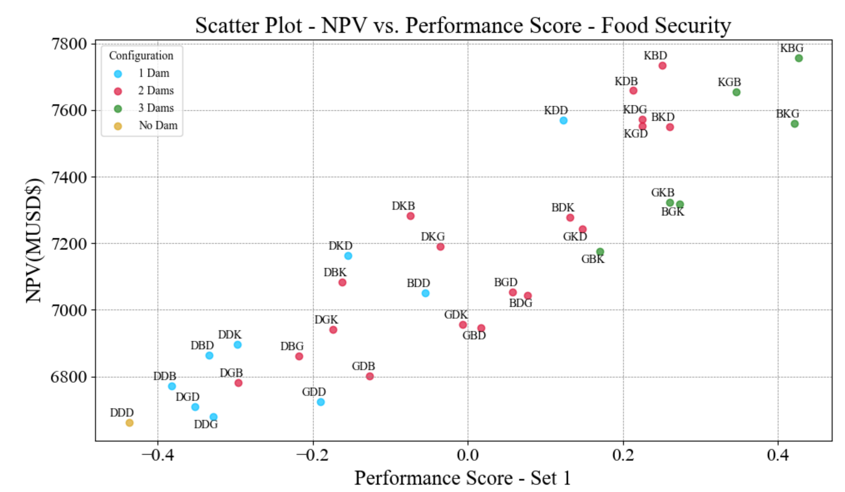
  To rank order alternative investment decisions according to multiple criteria over multiple periods of time

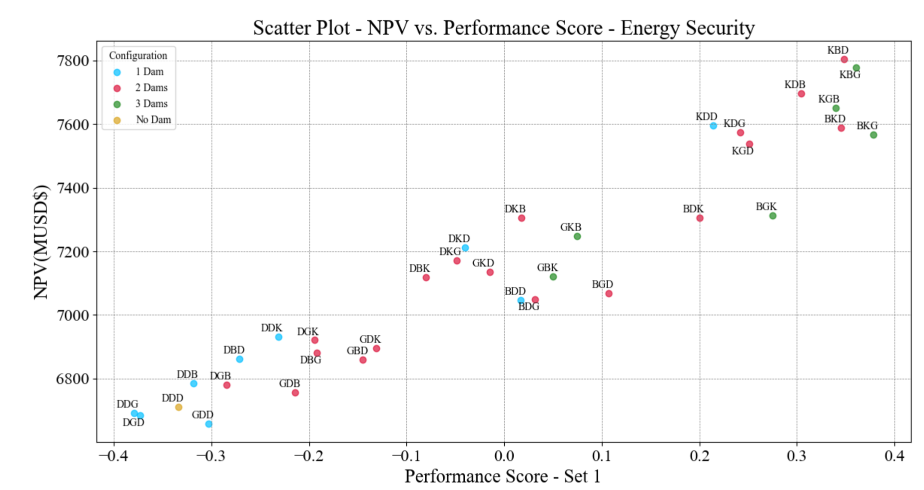


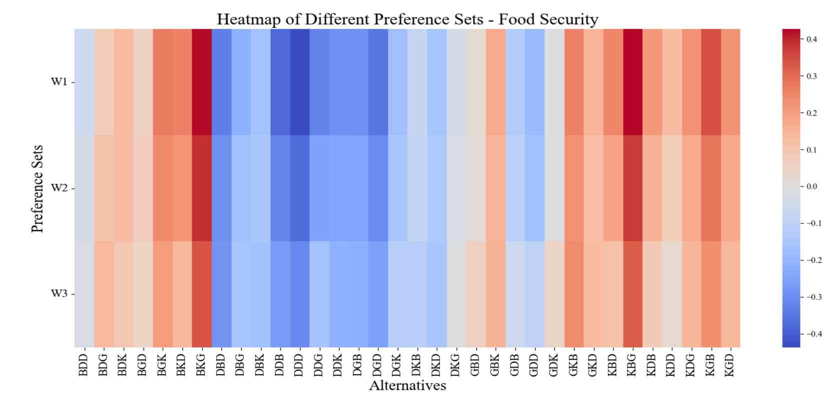
The decision tree represents different investment pathways.

4 Results

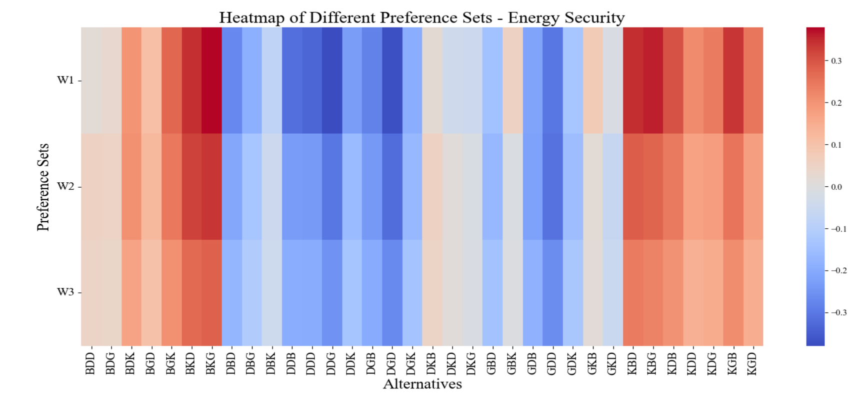
I. Performance scores & NPV





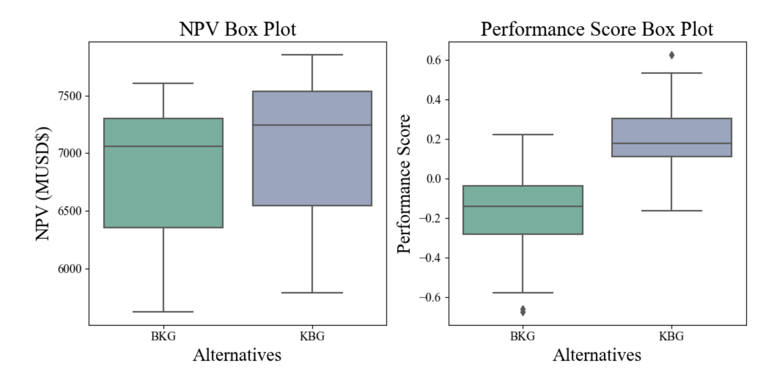


Performance Scores for different sets- Food security scenario

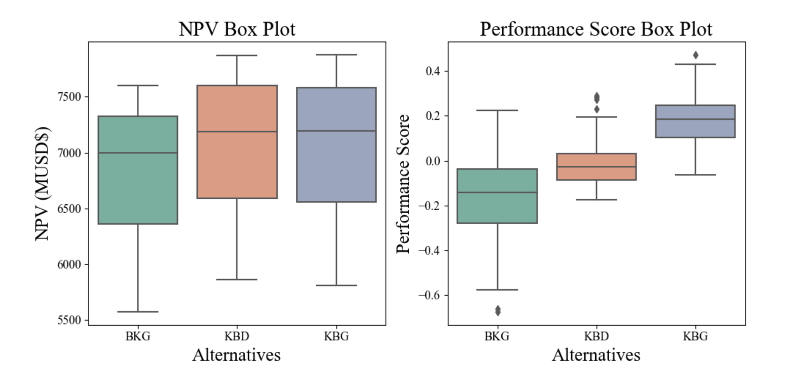


Performance Scores for different sets- Energy security scenario

II. Sensitivity analysis on Hydrological flows



NPV & performance score box plots - Food security scenario



NPV & performance score box plots – Energy security scenario

Conclusion

The main objective of this research is to develop a decision-making framework for hydraulic infrastructure investments under deep uncertainty. For the first step toward achieving this, the presented methodology is developed and examined on the historical flows in the Senegal River Basin. The results of this analysis show that:

- The 'No Dam' alternative, marked in yellow, is among the least favorable alternatives, emphasizing the necessity of development in the SRB.
- Analyzing different development pathways based on performance scores and NPV has important implications for sequencing and configurations. Adding Koukoutamba to the system in the first decision stage would generally lead to better performance, regardless of future decisions. Moreover, a single dam configuration (i.e., KDD) performs better than development pathways, where the initial decision was not to construct Koukoutamba.
- Pareto optimal pathways have stable performance across variations in TMCA preference weights, indicating their robustness to the evaluation criteria.
- The sensitivity analysis of the pareto optimal pathways on hydrological flows shows that KBG preforms better than KBD or BKG. Furthermore, the KBD pathway shows the least sensitivity to fluctuations in hydrological flows, suggesting greater stability under varying conditions.