University of Sheffield

Decision-making under a changing climate

Deep uncertainty and application to small hydropower design

Dr Charles Rougé

24 October 2024

Contents

1. Decision-making under deep uncertainty (DMDU): key concepts and methods

2. Illustration: small hydropower design

3. Key conclusions

Contents

1. Decision-making under deep uncertainty (DMDU): key concepts and methods

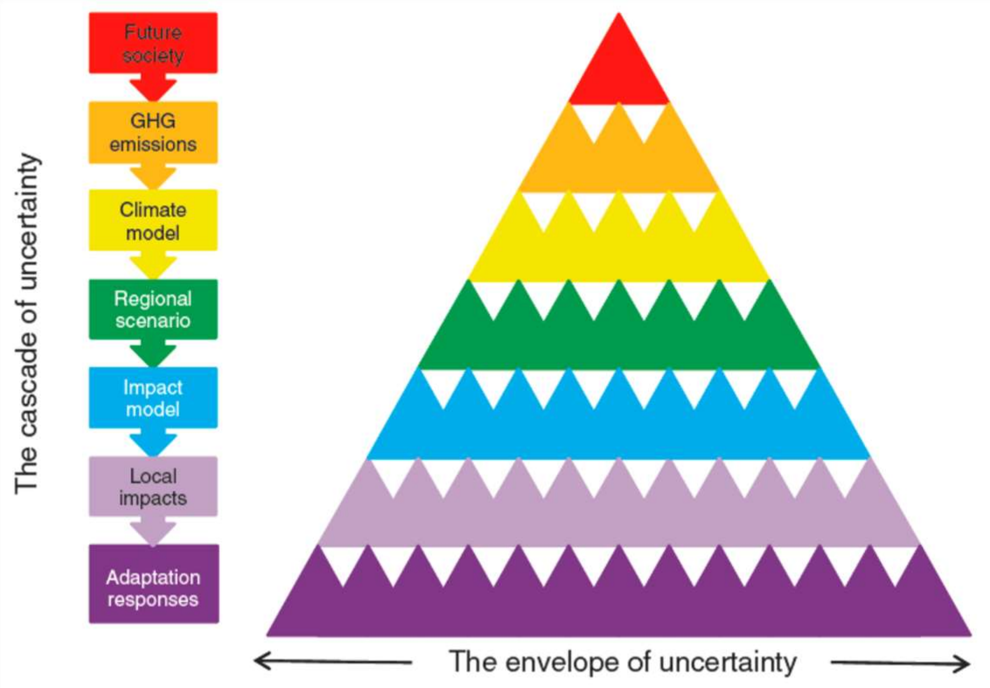
2. Illustration: small hydropower design

3. Key conclusions

University of Sheffield

Hard-to-quantify uncertainties

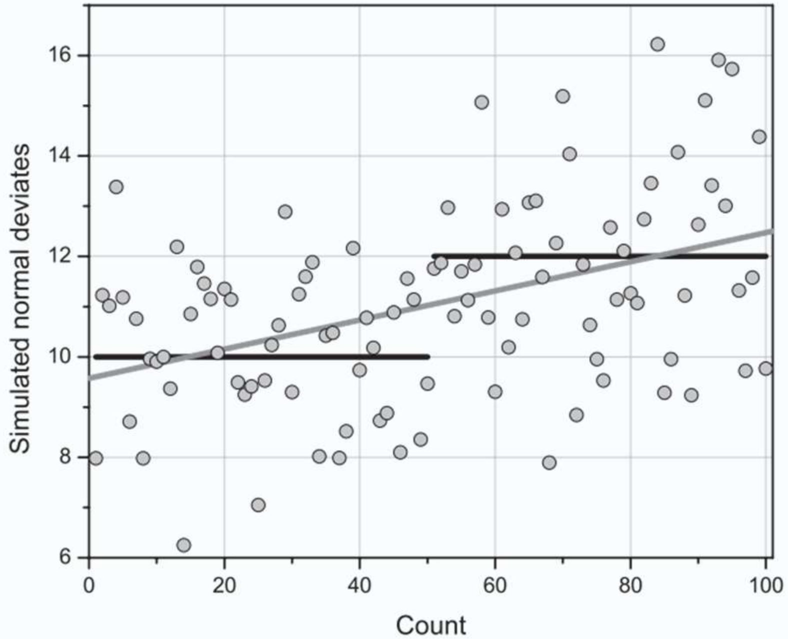
In the future...



Source: Wilby and Dessai, 2010

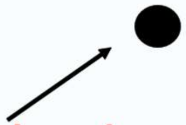
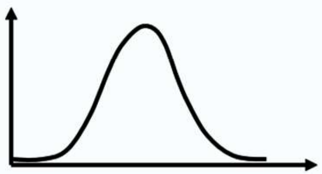
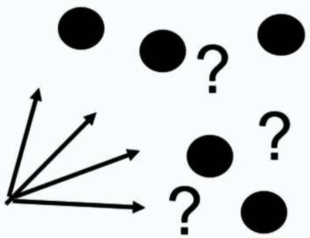
… and in the past

Trend or step change?



Source: Villarini et al., 2009

Well-characterised vs. deep uncertainty

	Model	Dynamics & outcomes
Minimal		Known dynamics and finite number of scenarios One outcome for each scenario
Probabilistic		Known dynamics and finite range of scenarios A range of outcomes for each scenario
Deep		No consensus on the dynamics or the range of possible scenarios No consensus on the range of outcomes (or the tools to assess them)

Well-characterised

University of Sheffield

Planning problems are wicked

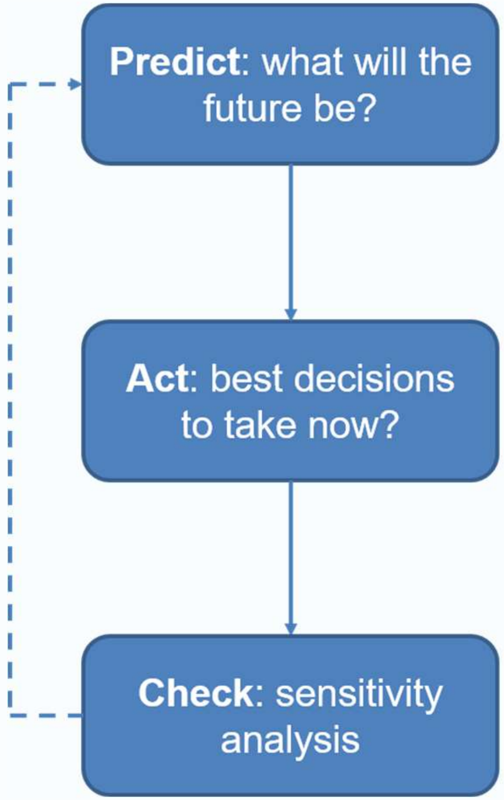
1. No definitive formulation
2. No stopping rule (or “final” solution)
3. Solutions are not true or false but good or bad
4. No immediate / ultimate test of a solution
5. Irreversibility of implementing a solution
6. No exhaustive set of solutions
7. Every problem is essentially unique
8. The planner has no right to be wrong

Separation between problem formulation and solution breaks down (Kwakkel et al., 2016)

Characteristics of a “wicked” problem (Rittel and Webber, 1973)

What concepts / methods are needed?

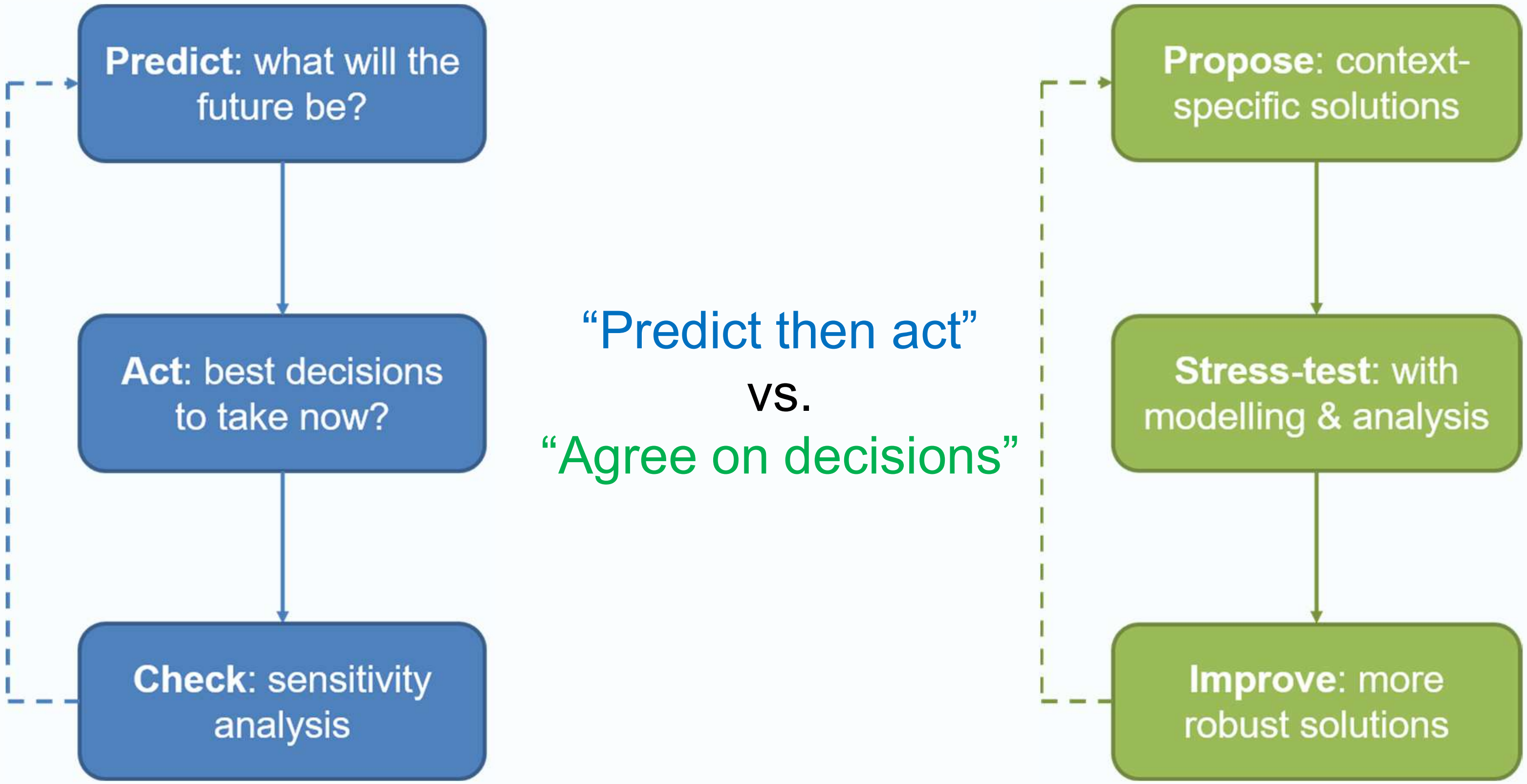
Traditional optimisation / risk management



For policy design, optimisation

- Fit for well-characterised uncertainties
- Not fit for deep uncertainties or surprise
- Values (what is best) often implicit: competing science-based analyses lead to gridlock

DMDU: Backward analysis



University of Sheffield

Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, S. Gill and A. Shah (2014). Agreeing on Robust Decisions: A New Process for Decision Making Under Deep Uncertainty. WPS-6906, World Bank.

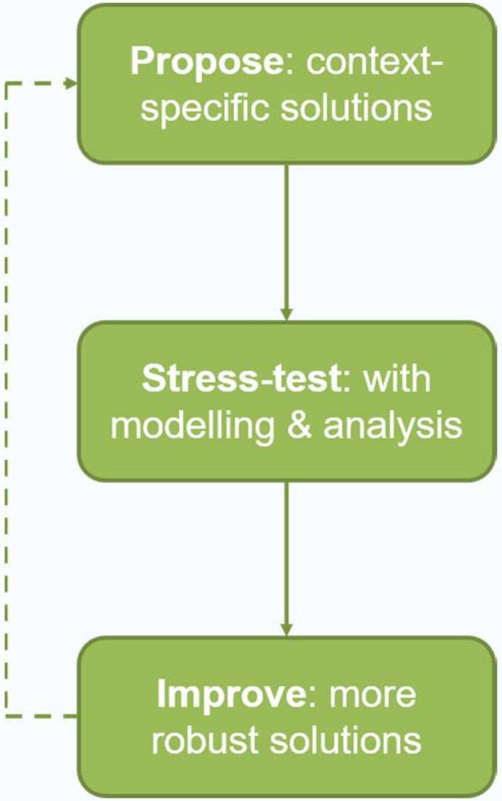
DMDU: Key principles

1) Plan under multiple futures NOT single best guess

2) Select plans that perform well under these futures NOT optimal plan under single future

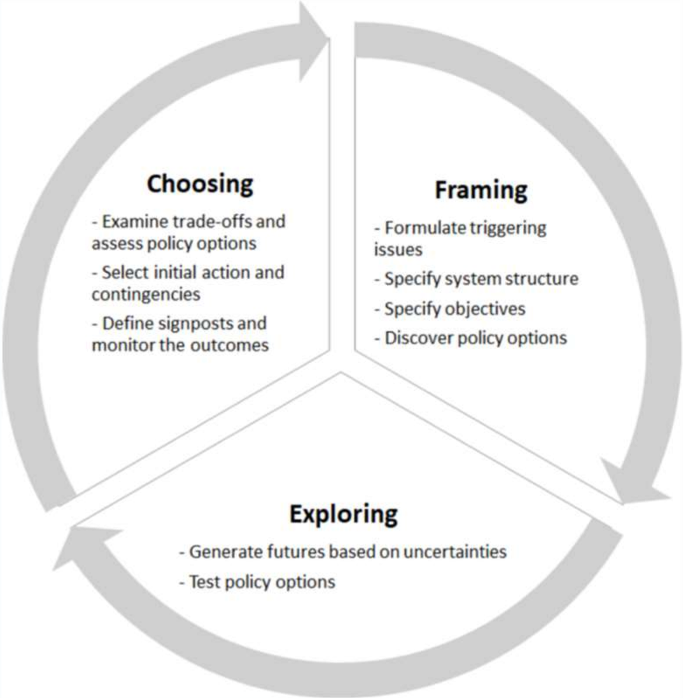
3) Make plans flexible and adaptive NOT predefined sequence of actions

4) Use models and tools to explore actions and futures NOT “science will tell us what to do”



University of Sheffield

DMDU in practice: various models

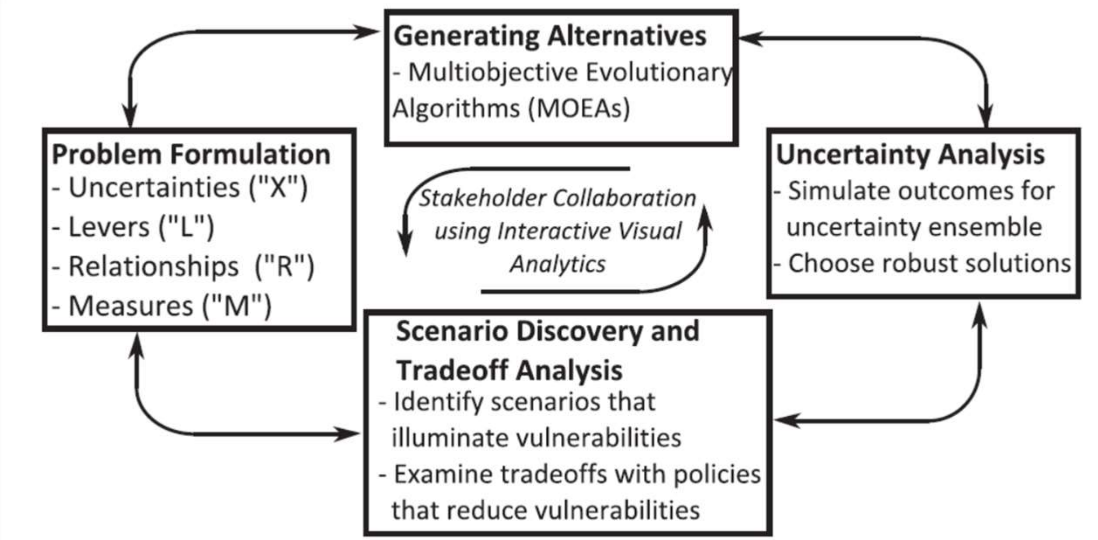


Decision making under deep uncertainty for pandemic policy planning

Sophie Hadjisotiriou[a,#], Vincent Marchau[b,#,*], Warren Walker[c], Marcel Olde Rikkert[a]

Many objective robust decision making for complex environmental systems undergoing change

Joseph R. Kasprzyk[a,*], Shanthi Nataraj[b], Patrick M. Reed[a], Robert J. Lempert[b]



University of Sheffield

Contents

1. Decision-making under deep uncertainty (DMDU): key concepts and methods

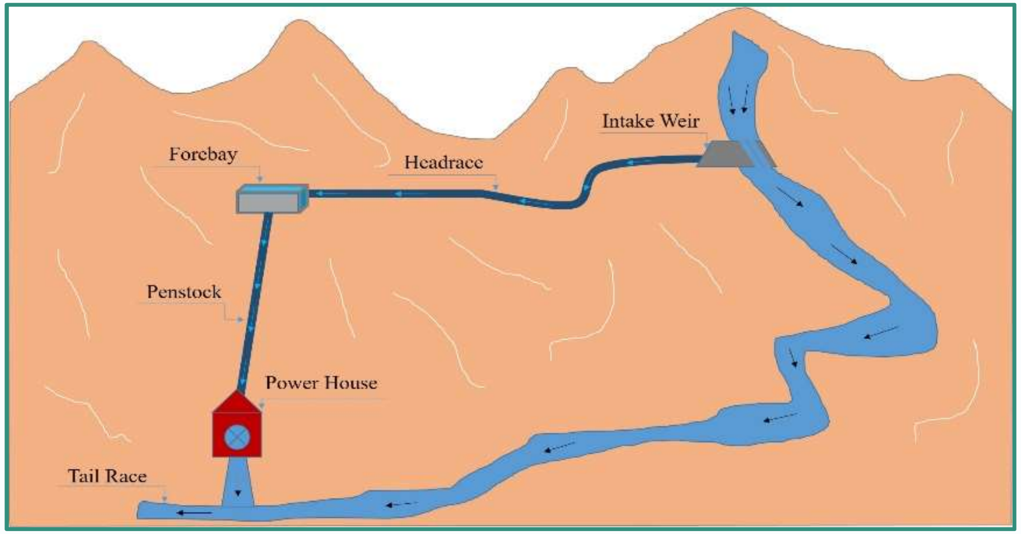
2. Illustration: small hydropower design

3. Key conclusions

Dr Veysel Yildiz

Hydropower: construction boom & issues

Run-of-river (RoR) hydropower



Currently 3,000+ planned or in construction worldwide with RoRs accounting for more than 75% of that total.

36 % of the global potential of small hydropower (<10MW) is currently exploited:
140 GW untapped capacity .

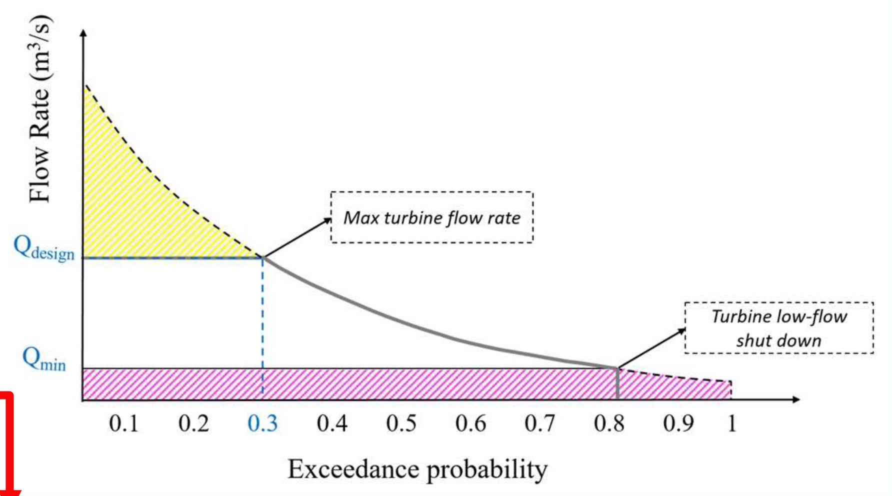
RoRs designed today will operate in a world of changing climate and uncertain economic conditions.

University of Sheffield

Interrogating traditional plant design…

Usually:

- Sequential approach (e.g. hydrologist communicates Q_{design} to turbine engineer)
- Operations not considered at design stage.

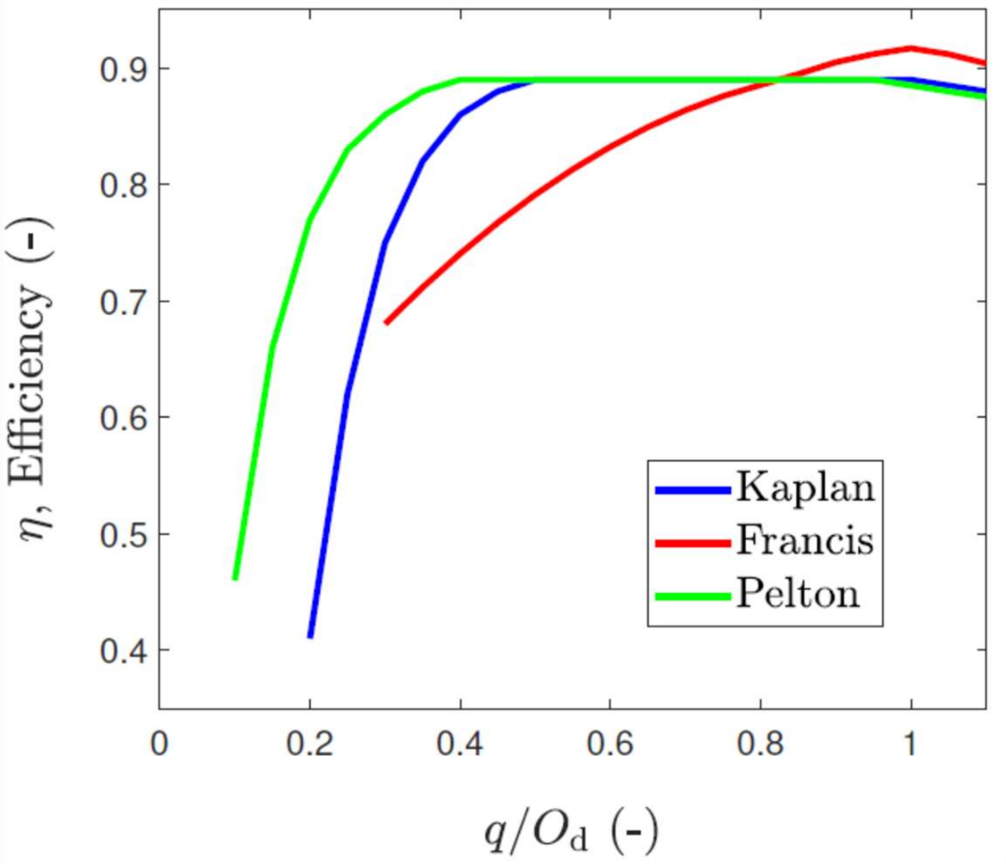


A few consequences:

- Climate change excluded from design
- Turbines often identical
- Turbine designed with fixed flows, fixed efficiency…

University of Sheffield

Importance of turbine design



Design dependent on net head and flow

- More variable with climate change!

If flow (or head) lower than design:

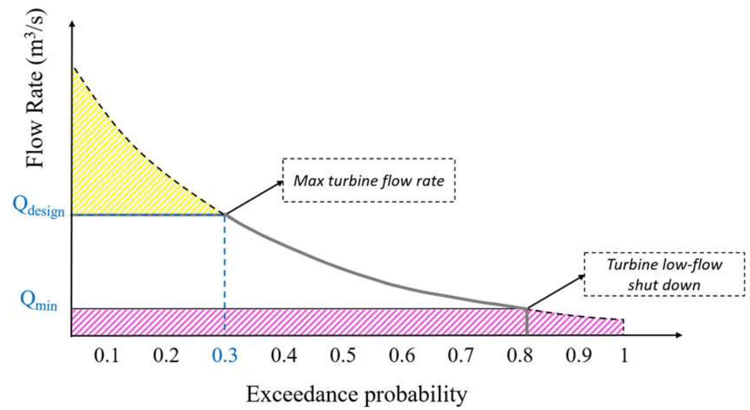
- Performance decreases
- Turbines may have to stop

Research questions

1 How do we **model plausible climate change** for robust plant design?

How do **design assumptions** affect outcomes under a changing climate?

What **metrics** should we use for hydropower plant design?



University of Sheffield

Generating plausible climatic futures

Hydrol. Earth Syst. Sci., 27, 2499–2507, 2023
https://doi.org/10.5194/hess-27-2499-2023

Hydrology and Earth System Sciences
Open Access
EGU

Technical note: Statistical generation of climate-perturbed flow duration curves

Veysel Yildiz[1], Robert Milton[2], Solomon Brown[2], and Charles Rougé[1]

[1]Department of Civil and Structural Engineering, The University of Sheffield, Sheffield, United Kingdom
[2]Department of Chemical and Biological Engineering, The University of Sheffield, Sheffield, United Kingdom

Correspondence: Veysel Yildiz (vyildiz1@sheffield.ac.uk)

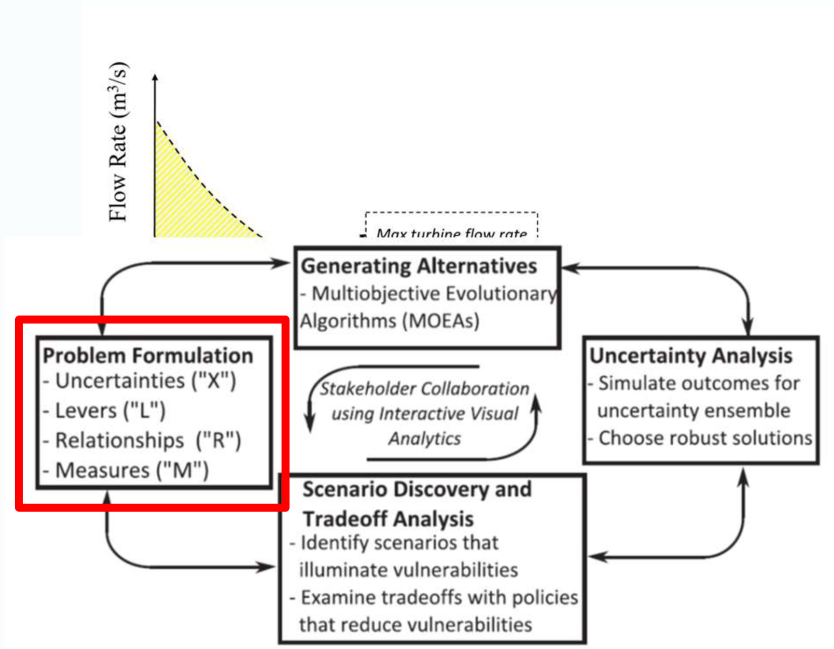
Received: 19 December 2022 – Discussion started: 16 February 2023
Revised: 30 May 2023 – Accepted: 11 June 2023 – Published: 10 July 2023

Research questions

1. How do we **model plausible climate change** for robust plant design?

2. How do **design assumptions** affect outcomes under a changing climate?

3. What **metrics** should we use for hydropower plant design?



University of Sheffield

Framing for small hydropower design

Uncertain factors (X)

Climate uncertainty
Economics: interest rates, cost overruns, power prices
500 sampled futures

Levers (L)

Design variables, including turbine size and number

Relationships (R)

X, L → *M*

Optimal design toolbox with flexible turbine settings (HYPER)

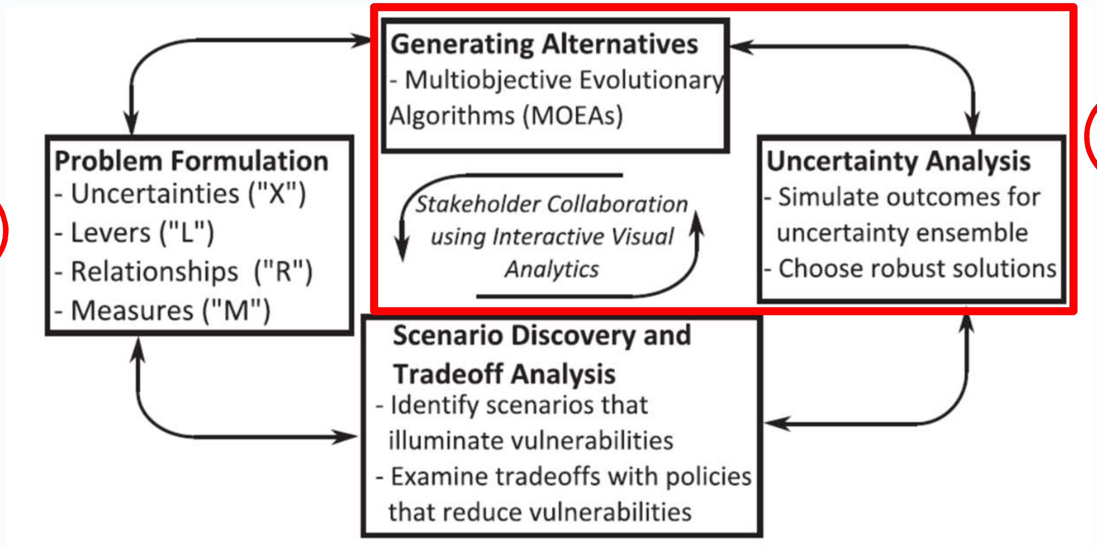
Performance Metrics (M)

Annual benefits and costs
Design objectives: NPV, Benefit cost ratio (BC)
A future is financially robust if NPV > 0 or payback within 15 years.

DMDU approach to small hydropower

2 Design under historical flows

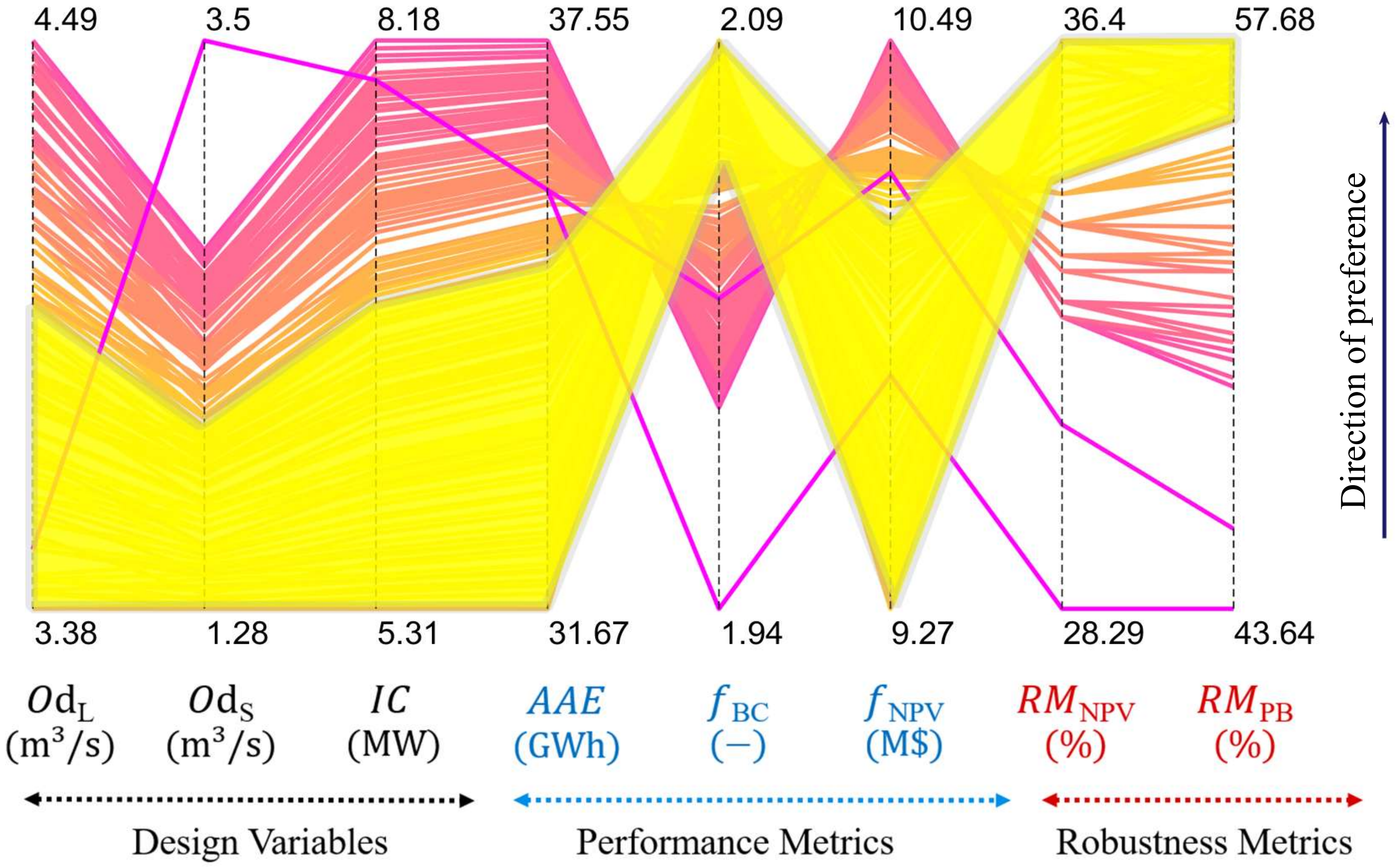
1



3 Tested under range of futures

University of Sheffield

Alternative designs and their financial robustness

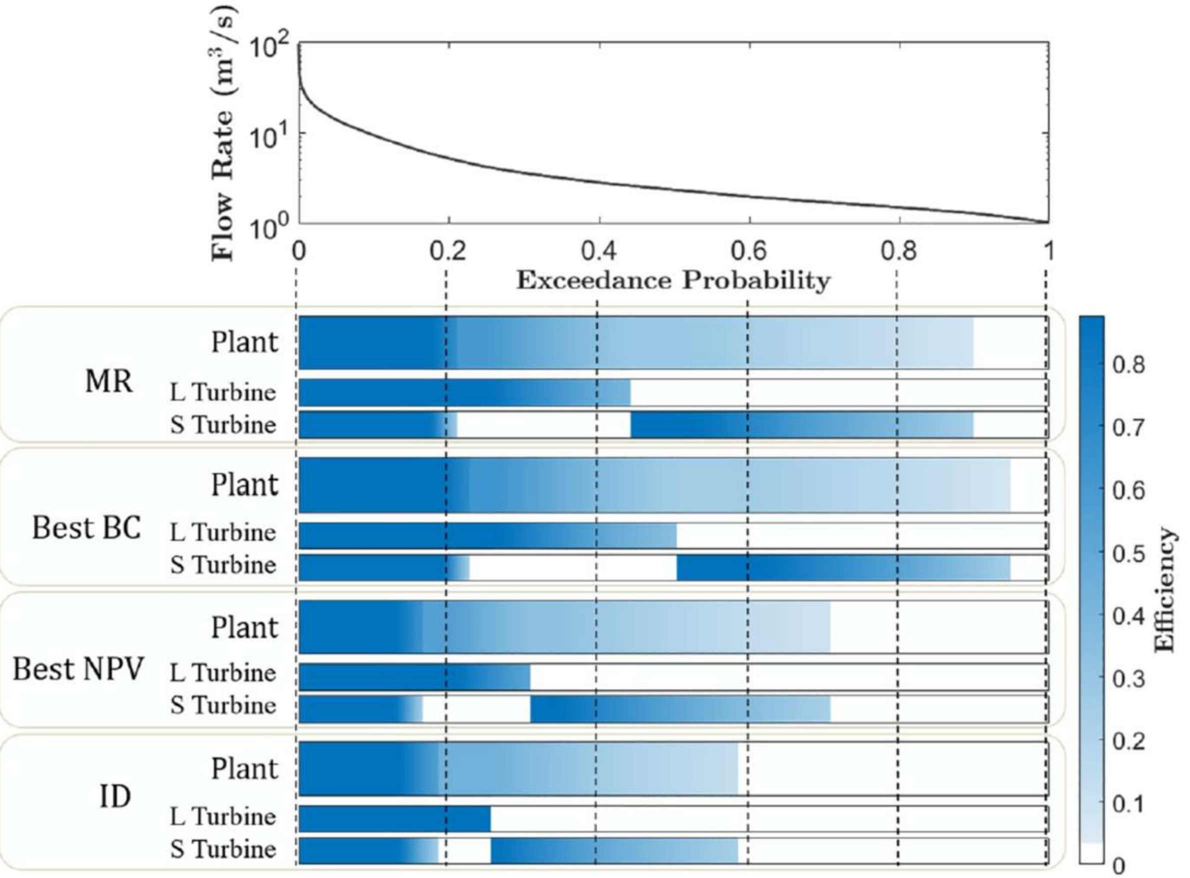


Plant efficiencies under a drier future

Flexible, smaller designs
Efficient use of flows

Larger design
Less adapted to drying

Least flexible

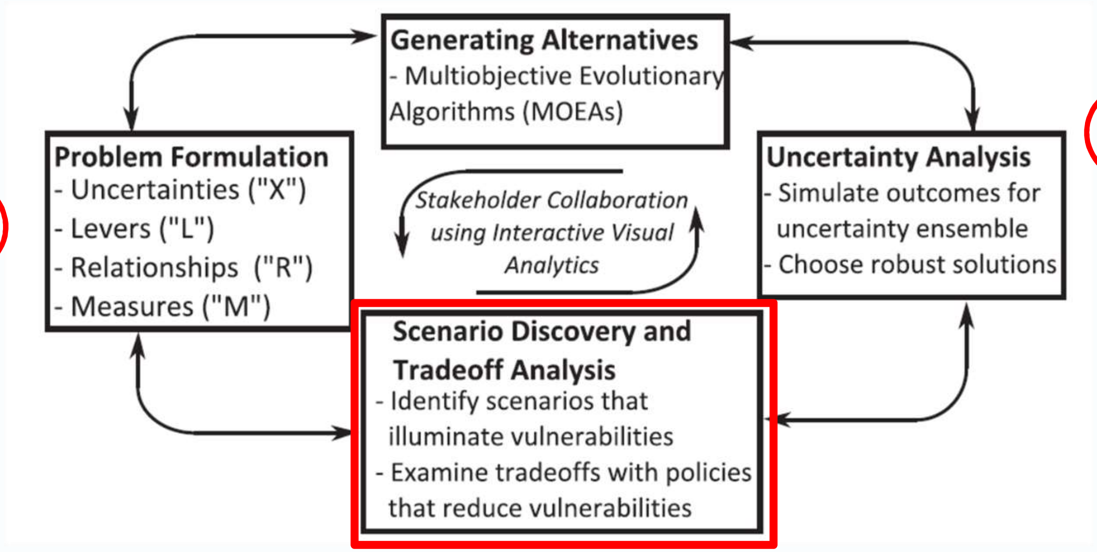


University of Sheffield

DMDU approach to small hydropower

2 Design under historical flows

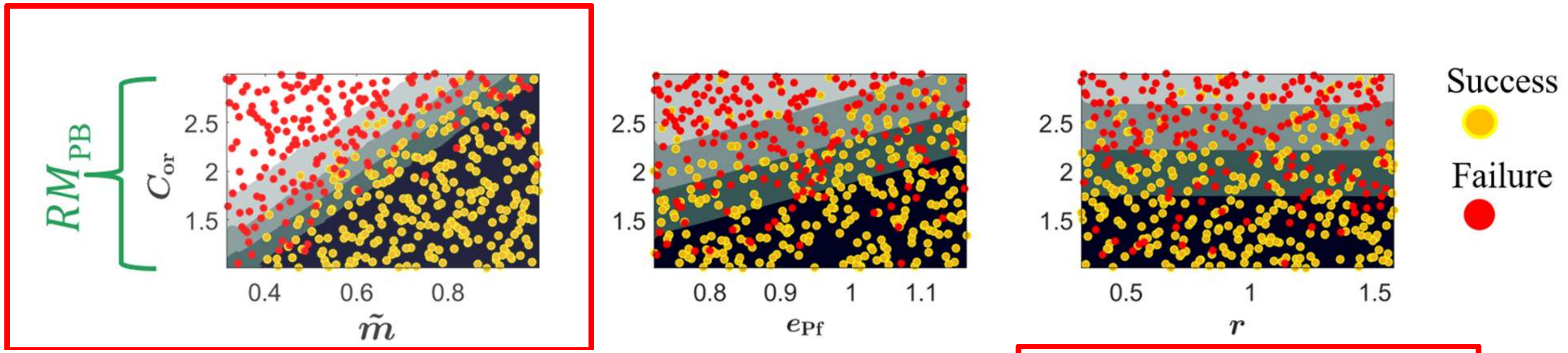
1



3 Tested under range of futures

4 Dig deeper for further insights

Vulnerability Analysis



Water Resources Research

RESEARCH ARTICLE

10.1029/2023WR035713

Importance of Variable Turbine Efficiency in Run-Of-River Hydropower Design Under Deep Uncertainty

Veysel Yildiz[1], Solomon Brown[2], and Charles Rougé[1]

[1]Department of Civil and Structural Engineering, The University of Sheffield, Sheffield, UK, [2]Department of Chemical and Biological Engineering, The University of Sheffield, Sheffield, UK

Key Points:

- Traditional approaches to hydropower planning need to be revisited to account for the impact of a variable climate on turbine efficiency

Contents

1. Decision-making under deep uncertainty (DMDU): key concepts and methods
2. Illustration: small hydropower design
3. Key conclusions

Some key takeaways

- Single economic objective leads to unique solution (e.g., best NPV), may miss solutions more robust to uncertainty.
    - ➢ Multi-objective optimization leads to many solutions to choose from (& quantifies trade-offs).

- More generally, DMDU concepts and tools aim to explore future scenarios, outcomes and decisions to discover the most relevant.
    - ➢ Differentiated turbines and small designs are more robust can be more financially robust to climate change.
    - ➢ Cost overruns (e.g., unfavourable geology) risk that can make investments not worthwhile (at least from private actors)

DMDU methods

- Varied methods for robustness and adaptation.
- Increasingly used in variety of “wicked” problems.
  - ✓ Key users: World Bank, RAND, Deltares,UK water utilities…
  - ✓ Applications: sea level protection in the Netherlands, reservoir planning (England, Nepal, US), water allocation (Colorado)
- Growing community! E.g., session at EGU 2025 in Vienna

University of Sheffield