Towards a Holistic Integration of Energy Justice and Energy System Engineering

Preliminary Exam

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Outline I

Presentation Goals

I have the following goals for this presentation:

1. **Motivate** why social science and quantitative modeling *must* be more strongly integrated (based on the relations among three types of uncertainty).
2. **Demonstrate** how `Osier` currently accomplishes this goal.
3. **Propose** future work to enhance `Osier`'s capabilities and validate its usage.

and I hope to show the **layered novelty** of this work as a corrolary of the above.

Proposal Overview

I propose to:

1. **Deepen** the theoretical foundations of this work.
2. **Develop** an optimization tool (`Osier`) that
   - addresses three related uncertainties,
   - closes the gap between technical expertise and public preferences,
   - enhances justice outcomes related to energy planning.
3. **Validate** this tool by conducting a case study of energy planning processes in the Champaign-Urbana region.

Outline I

Climate change exists and *we're causing it*!

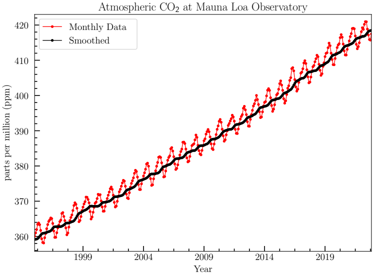


Figure 1: Observed increase in CO_2 levels at Mauna Loa Observatory [11].

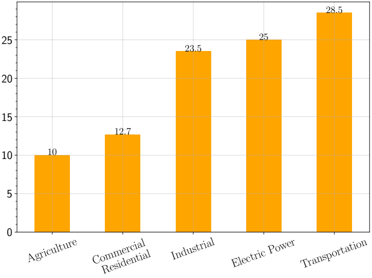


Figure 2: Carbon emissions by economic sector [5]

We have the technology to stop using fossil fuels

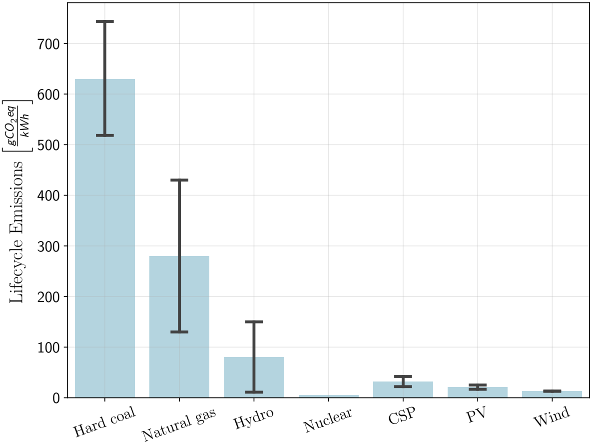


Figure 3: Lifecycle carbon emissions by energy source [24].

… and yet

1. Most climate change mitigation policies will overshoot U.N. emissions targets [19]
2. and there is still local public opposition to clean energy projects [1, 7, 22]

Motivating Questions

Question 1

What drives public opposition to clean energy projects?

Question 2

How does energy modeling contribute to this problem?

What drives opposition? It's not NIMBY

Question #1

What drives public opposition to clean energy projects?

1. NIMBY is popularly understood to drive opposition.
2. However, several case studies and larger surveys have demonstrated that this is not the case [12, 1].
3. Instead, perceptions of legitimacy in decision-making processes motivates this opposition [8, 22, 1, 27, 13].
4. Public testimony may be dismissed for being nontechnical casting doubt on legitimacy [10].

title

Existing energy planning processes and new energy projects (even "clean energy" projects) reproduce existing sociopolitical structures that violate principles of justice.

Three tenets of justice

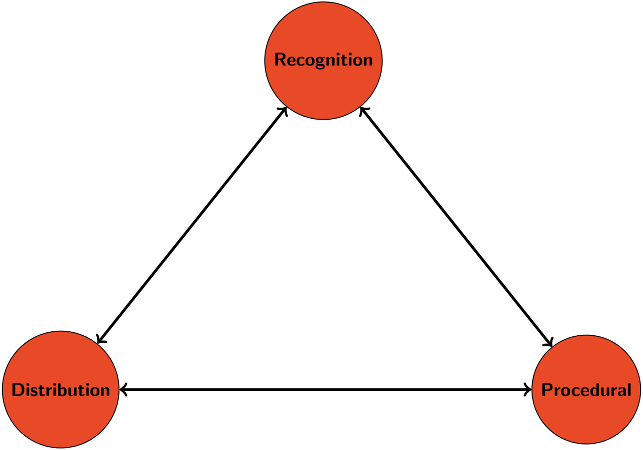
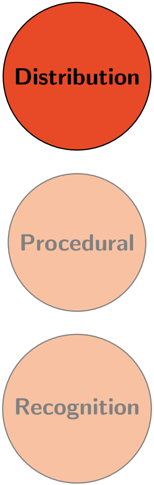


Figure 4: Three aspects of justice [20].

Distributional



Distributional Justice

Related to the distribution of burdens and benefits.

Normative Question

What is the fairest way to distribute benefits and burdens?

Examples of injustice

- Dispossession of land and benefits [28, 21].
- Poorer air quality around fossil fuel plants — primarily located in poorer communities [14].
- Solar panel subsidies and installations benefitting wealthier communities [18].

Procedural

Distribution

Procedural

Recognition

Procedural Justice

Related to decision-making processes — method and inclusion.

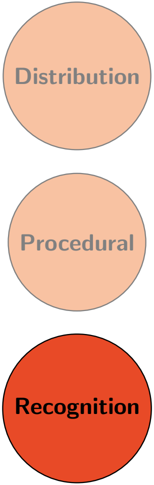
Normative Question

What is the fairest way to make decisions affecting specific groups of people?

Examples of injustice

- Dismissal of testimony for its lack of technical expertise [10].
- Lack of transparency in decision making (do energy system models make this more transparent or less?).

Recognitional



Recognitional Justice

Related to social value of people or groups derived from relationships, laws, and cultural standing.

Normative Question

How much and in what ways should a person or group of people be valued?

Examples of injustice

- Energy policies that interfere with loving relationships (e.g., stress from energy insecurity).[26]
- Lack of labor protections for workers.[26]
- Exclusion from a policy process (how inclusive is energy modeling?).[26]

How does modeling contribute to justice issues?

Question 2

How does energy modeling contribute to this problem [of public opposition to energy projects]?

How does modeling contribute to justice issues?

Question 2

How does energy modeling contribute to ~~this problem [of public opposition to energy projects]~~? violations of procedural/recognition justice?

Energy System Optimization Models (ESOMs)

Formulation

ESOMs consist of:

- A set of decision variables
- "An economic objective" [9]
- A set of constraints

Solution method

Linear programming (LP) / mixed-integer linear programming (MILP)

Simple Example Linear Program

Decision variables

Determine the mix of energy sources...

$$\mathbf{X} = x_1, x_2 \mid x \in \mathbf{R}+ \qquad (1)$$

Objective

...that minimizes total cost...

$$\min\left(c_1x_1 + c_2x_2\right) \qquad (2)$$

Constraint

...such that energy demand is always met.

$$x_1 + x_2 = 1 \qquad (3)$$

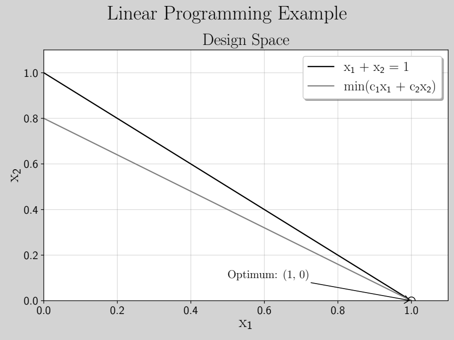
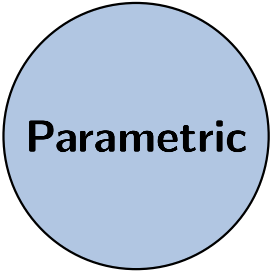


Figure 5: Solving a simple linear program by inspection.

Parametric Uncertainty



Parametric Uncertainty

Related to uncertainty in model inputs (empirical values). The most commonly addressed type of uncertainty in science and engineering [29, 3, 15].

Examples of Parametric Uncertainty

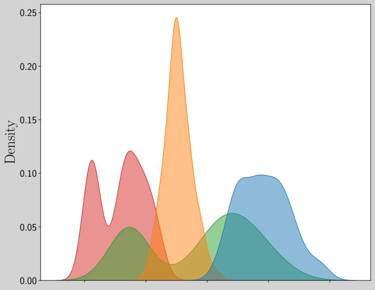


Figure 6: Possible distributions of several parameters.

- Rates (e.g., interest, learning, growth),
- costs (e.g., fuel, capital, O&M),
- aggregated energy demand,
- spent fuel burnup [6],
- nuclear cross-section data [4, 17],
- likelihood and magnitude of consequences (i.e., probabilistic risk assessment).

Considering Parametric Uncertainty in a Linear Program

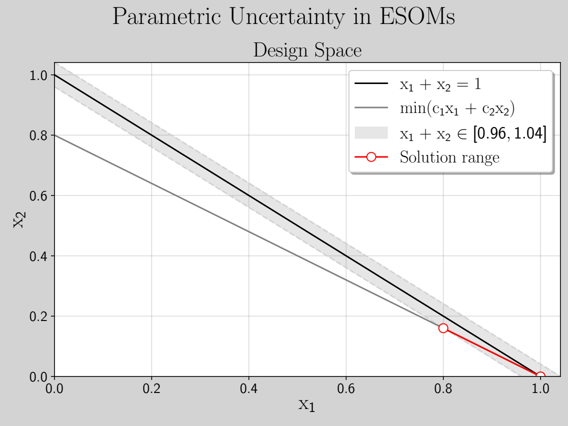
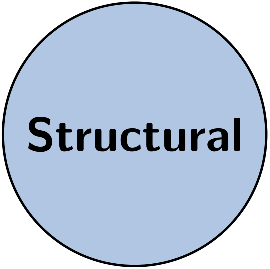


Figure 7: Solving a simple linear program by inspection.

Structural Uncertainty



Structural Uncertainty

[R]efers to the imperfect and incomplete nature of the equations describing the system [3].

This type of uncertainty will *always* persist.

Examples Sources of Structural Uncertainty

Unmodeled or unmodelable aspects of the model related to:

1. Objective functions
2. Physics fidelity, for example
   - optimal power flow,
   - turbulence (air flow, water flow, etc.),
   - thermodynamics (e.g., weather impacting a power plant's ultimate heat sink)

Addressing Structural Uncertainty

Idea

Look for alternatives in the "near-optimal" space.

Modeling-to-generate-alternatives (MGA)

1. **Relax** the objective function.
2. **Search** for maximally different solutions in the design space.
3. **Iterate** until enough solutions have been generated.

Addressing Structural Uncertainty

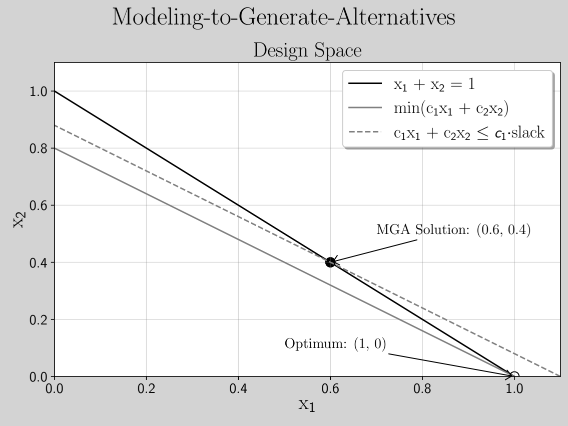


Figure 8: Illustration of the MGA algorithm.

Gap 1: Challenges with current ESOM practices

Technical Gap

1. Exclusive optimization over system cost misrecognizes the plurality of preferences and priorities. Tradeoff analysis is impossible.
2. Even with open source code and transparent data sources, energy system models remain opaque — decision making black boxes.

Proposed Work Component I: Multi-objective optimization

- Partially address procedural/recognition justice by facilitating tradeoff analysis through multi-objective optimization with evolutionary algorithms.
- Develop an MGA algorithm for high dimensional space.

Stretch Goal

Further enhance the transparency component of procedural justice by developing this tool in a way that provides the *capability* for anyone interested to verify model results. I.e., make accessibility a design priority.

Outline I

Osier

- Hybrid methods: linear programming & evolutionary algorithms
- Novel algorithm for high dimensional MGA

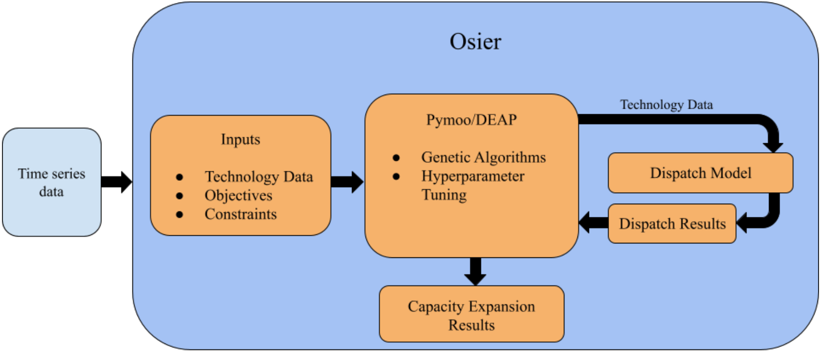


Figure 9: Flow of data through Osier.

Multi-objective Solutions

Pareto Front

Creates a **set of solutions** rather than a single optimum.

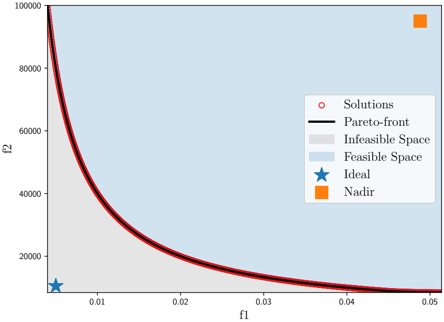


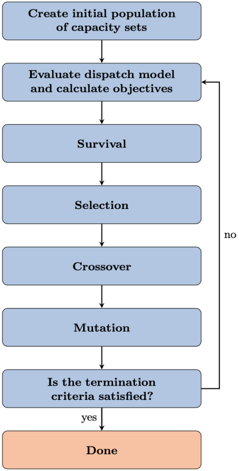
Figure 10: Pareto front example.

Evolutionary Algorithms

Evolutionary Algorithms for Energy System Optimization

- Inspired by natural selection
- Parallelizable
- Superior to pure linear programming methods for
    - independence from problem convexity
    - good sampling/spacing of points along solution set.

Right: Evolutionary algorithm flow [2].



How Osier handles structural uncertainty

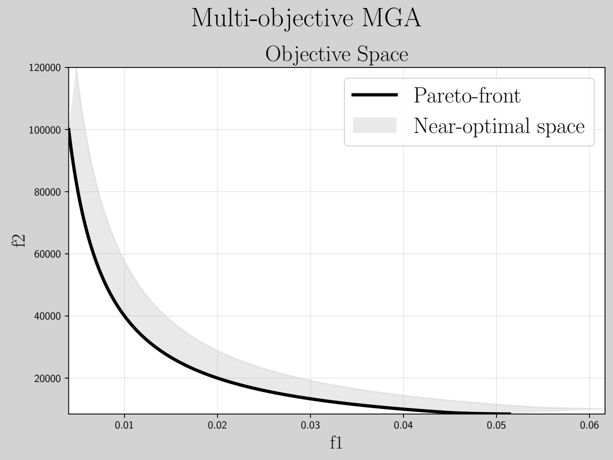


Figure 11: Near optimal space for a multi-objective problem.

How Osier handles structural uncertainty

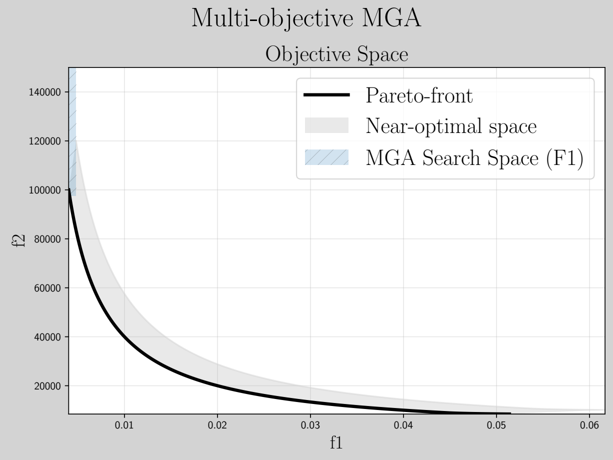


Figure 12: Near optimal space for mono- and multi-objective problems. The light blue area shows a vertically truncated near-optimal space around the f1 objective.

How Osier handles structural uncertainty

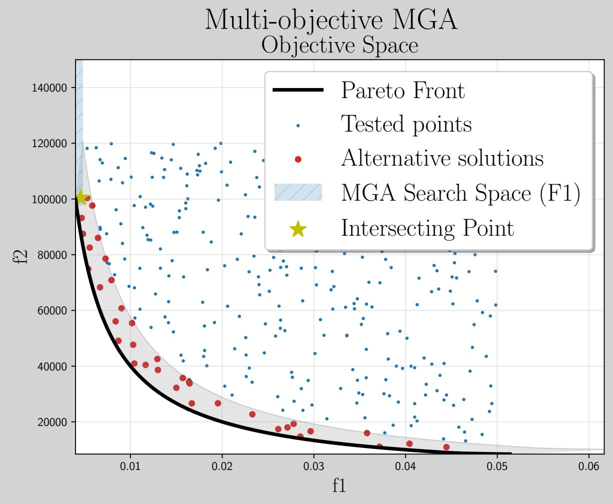


Figure 13: Alternative solutions identified in the near optimal space

Validating `Osier`

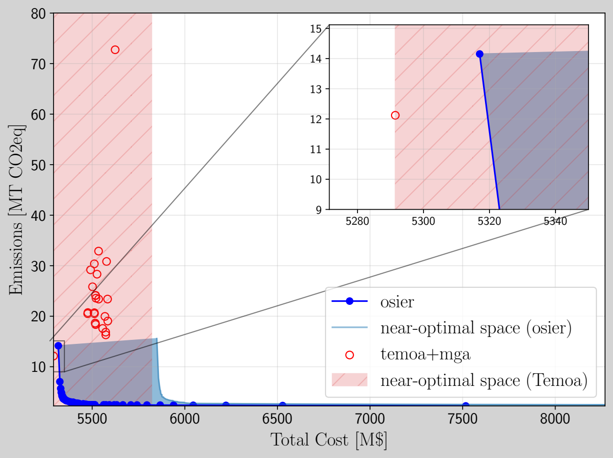


Figure 14: Comparing the results from `Osier` with another ESOM, `Temoa`.

Near-optimal Space for Cost and Carbon Emissions

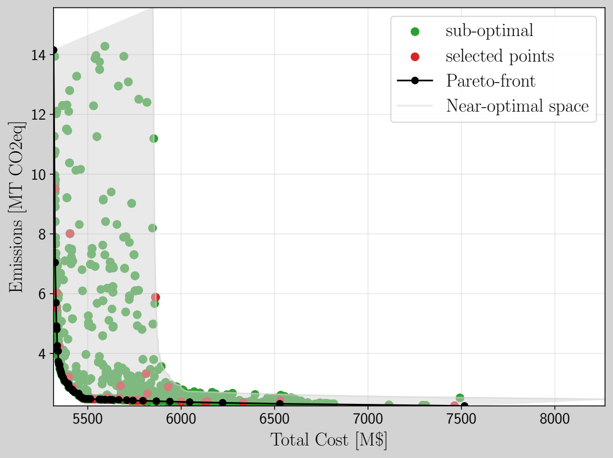


Figure 15: Sampling the near-optimal space for Osier's Pareto front.

Optimizing four objectives

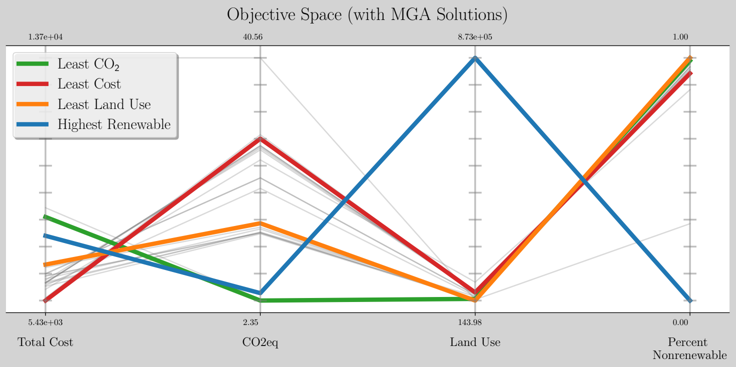


Figure 16: Pareto front and near-optimal solutions for the same problem with 4 objectives.

Optimizing four objectives

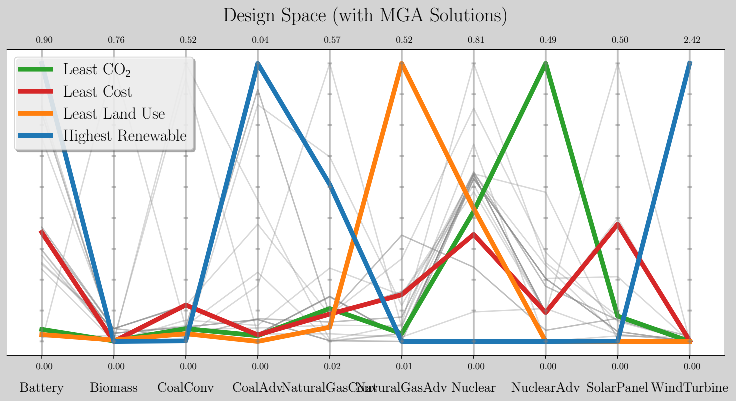


Figure 17: Design space for the 4-objective problem with near-optimal solutions.

Optimizing four objectives

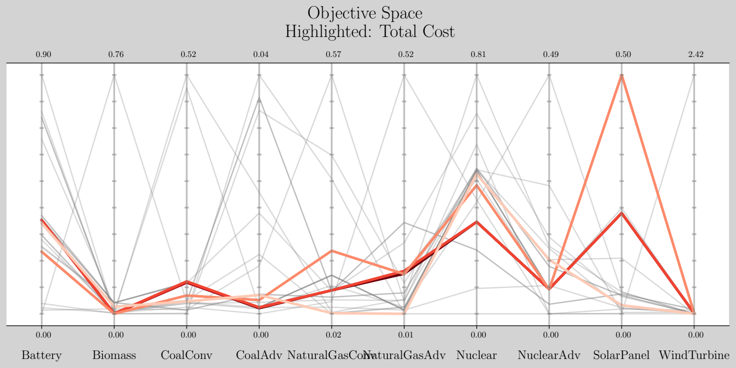


Figure 18: The five lowest cost solutions. Darker shade corresponds to lower cost.

Outline I

New Questions

Question 3

If structural uncertainty is addressed by presenting mutliple solutions, how should society choose among those alternatives?

Question 4

How can members of the lay public adequately deliberate on issues perceived by experts as highly technical?

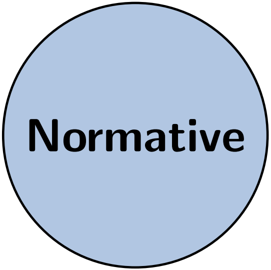
What's still missing?

Despite awareness of structural and parametric uncertainties modelers still don't address

- How parameter distributions are chosen?
- Why are certain objectives chosen (why should an economic objective be *assumed*)?
- What motivated the specified set of decision variables (why are technologies included/excluded)?
- Why is the recommended solution preferred to nearby alternatives?

This alludes to another kind of uncertainty...

Normative Uncertainty



Normative Uncertainty

Arises from the plurality of morally defensible, but incompatible, choices; and a plurality of moral theories justifying those choices [23, 25].

Addressing Normative Uncertainty

There are no formal methods to address normative uncertainty... *in engineering.*

Gap 2: Normative Uncertainty & Deliberative Processes

Technical Gap

1. Deciding among alternative solutions is challenging without a normative premise.
2. Without direct consultation of stakeholders, it's impossible know how they would understand tradeoffs.
3. Capturing the "human dimension" requires incorporating formal methods from social science: case studies, interviews, focus groups, surveys, etc. The ESOM literature struggles to do this [16].

Proposed Work Component II: Integrative theory of uncertainties

Further develop the unifying theory of model development through the lens of addressing triple uncertainties.

Proposed Work Component III: Case study of Champaign-Urbana

Case study of energy planning processes in the Champaign-Urbana region to validate the usefulness of `Osier` and test the salience of various uncertainties in these planning processes.

Outline I

How energy modeling can incorporate energy justice

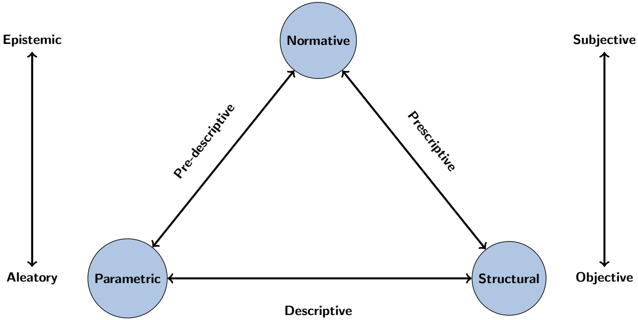


Figure 19: A summary of three uncertainties and their interactions.

Regional Case Study

Someday, details will go here!

Acknowledgement

Acknowledgements should include both people who helped and funding streams. If you are funded by an NEUP grant, that number usually goes here. .

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