Optimal Sizing of a Nuclear Reactor for Embedded Grid Systems

Preliminary Work

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Outline

1. Motivation
    - Illinois Climate Action Plan (iCAP)
    - Need for Nuclear
    - Framing the Question
2. Methods
    - Overview
    - Methods for `RAVEN`
    - Methods for `Temoa`
    - Modeling-to-Generate-Alternatives (MGA)
3. Results
    - RAVEN results
    - `Temoa`: Business As Usual
    - `Temoa`: Nuclear Scenarios
    - Scenario 1: Zero Capital Costs
    - Scenario 2: No Capacity Limit
    - Scenario 3: Small Modular Reactor
4. Conclusion

iCAP Goal and Obstacles

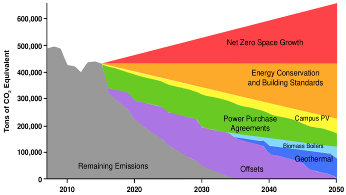

Figure: Shows projected CO_2 emissions for UIUC [9]. Offsets include shutdown of the Blue Waters Supercomputer.

Goal:
Carbon neutrality by 2050 or sooner.

Obstacles:

1. Requires *zero net space growth*.
2. Campus depends on a system of steam tunnels for heating.
3. and more...

The Nuclear Option

Nuclear energy...

1. ...produces almost no carbon emissions [8].
2. ...can produce high-temperature steam.
3. ...requires little physical space*.

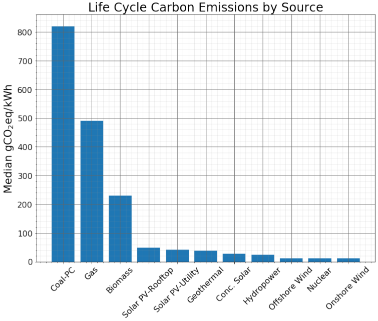

Figure: Lifetime carbon-equivalent emissions by energy source from IPCC findings [8].

*compared to solar and wind.

What is the optimal size for a nuclear reactor on the UIUC grid?

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To answer this question we considered two modeling approaches:

1. `RAVEN` (INL) - Risk Analysis and Virtual Environment [1][6]
2. `TEMOA` (NCSU) - Tools for Energy Model Optimization and Analysis [3][4][7]

Both modeling tools are open source and use publicly available version control software, `Git`, to track changes.

The analysis in `RAVEN` requires some external modules that are not currently available to the public.

Workflow in RAVEN

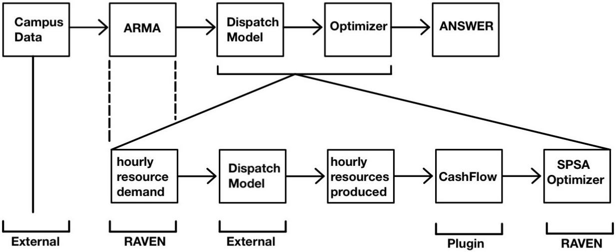

Figure: A general optimization workflow in RAVEN

Temoa Implementation

Temoa uses linear optimization to search decision space [7].

1. Objective Function (minimizes system cost)
2. Constraints
    1. Demand must be satisfied at each time step (always).
    2. Carbon limits must be satisfied at each time step (optionally).
3. Variables
    1. Cost
    2. Generation
    3. Capacity

Modeling-to-Generate-Alternatives (MGA)

`Temoa` uses the Hop-Skip-Jump formulation of MGA [2].

1. Identify an optimal solution by any method.
2. Relax the original objective function by adding a slack variable.
3. Find another sub-optimal solution that still satisifies constraints.

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Step 1: Generate Synthetic Histories

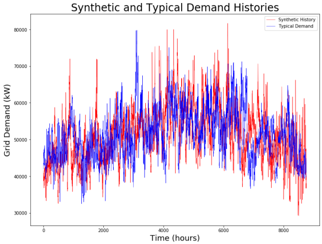


Figure: Shows the synthetic (red) vs typical (blue) hourly electricity demand at UIUC.

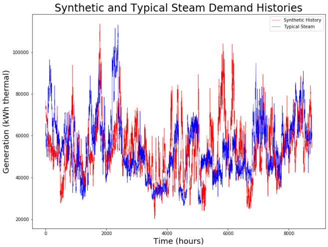


Figure: Shows the synthetic (red) vs typical (blue) hourly steam demand at UIUC.

BAU: Grid Model

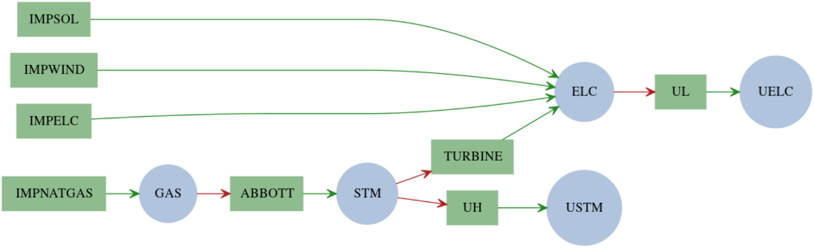


Figure: Graph representation of the UIUC embedded grid.

BAU: Generation

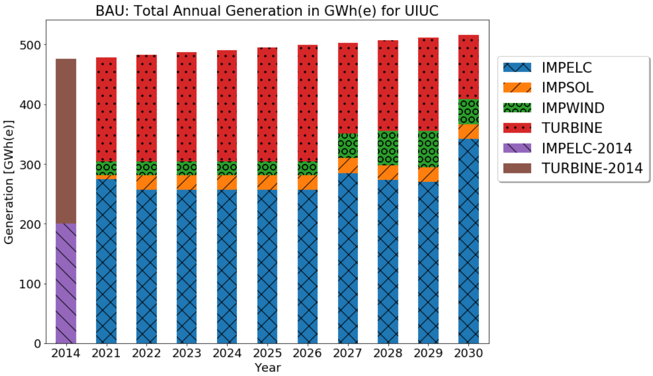
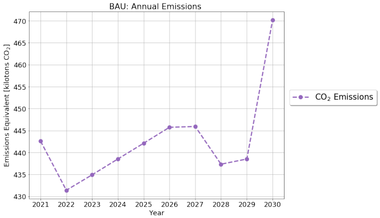


Figure: The change in activity from each energy source from 2020-2030. Assuming 1% demand growth each year

BAU: Emissions



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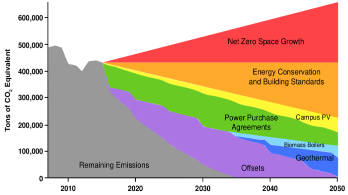


Figure: Predicted growth in emissions from iCAP [9].

Nuclear Scenarios

1. Scenario 1: Zero Capital Costs
2. Scenario 2: No Capacity Limit
3. Scenario 3: Limited to Small Modular Reactor (100MWth)

Table: Summary of Nuclear Scenarios. Costs from EIA and NEI reports [5][10].

Scenario	Operation Costs [$/MWh(th)]	Capital Costs [M$/MWth]	Maximum Capacity [MWth]
1	8.91	-	-
2	8.91	1.982	-
3	8.91	1.982	100

Nuclear Scenarios: Grid Model

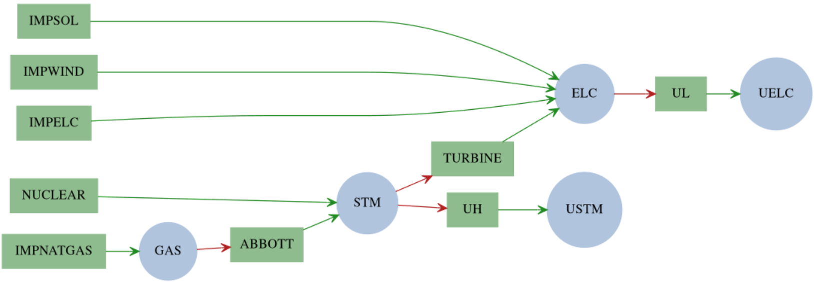


Figure: Graph representation of the UIUC grid with nuclear reactor.

Scenario 1: Generation

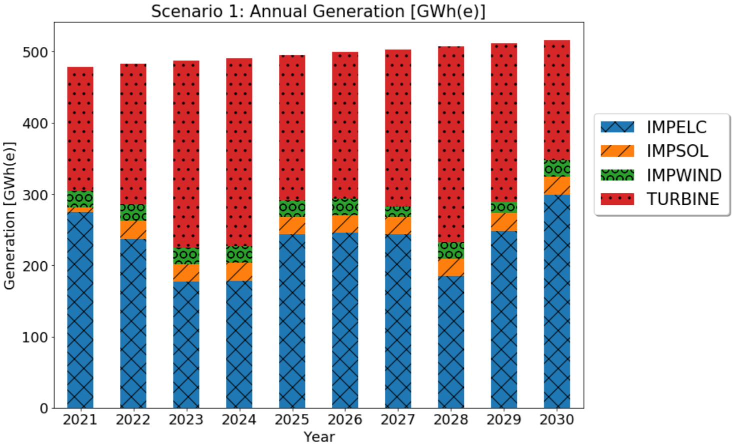


Figure: The electric generation without a cost constraint on nuclear

Scenario 1: Emissions

Figure: The carbon equivalent emissions without a cost constraint on nuclear

Scenario 2: Generation

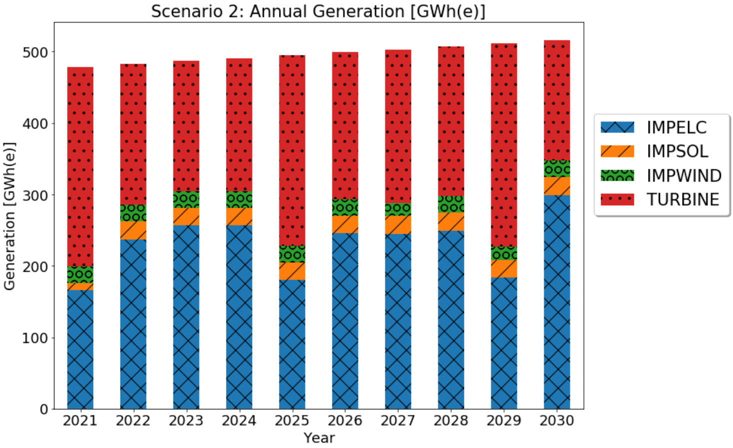


Figure: The electric generation without a size constraint on nuclear

Scenario 2: Emissions

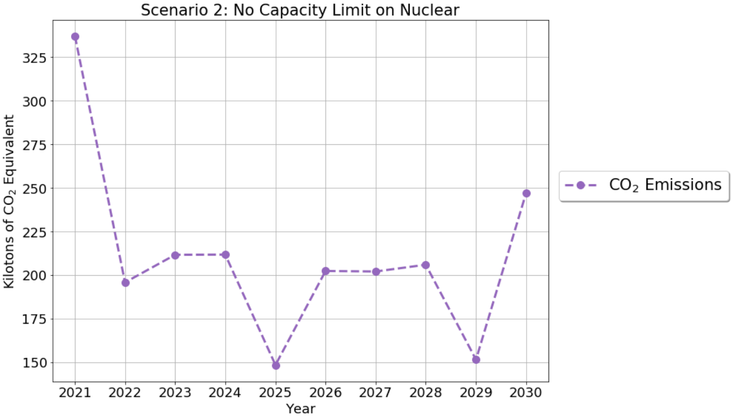


Figure: The carbon equivalent emissions without a size constraint on nuclear

Scenario 3: Generation

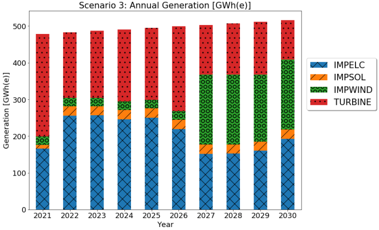


Figure: The electric generation with constrained nuclear.

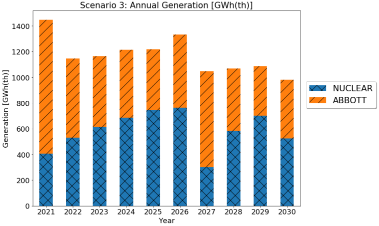
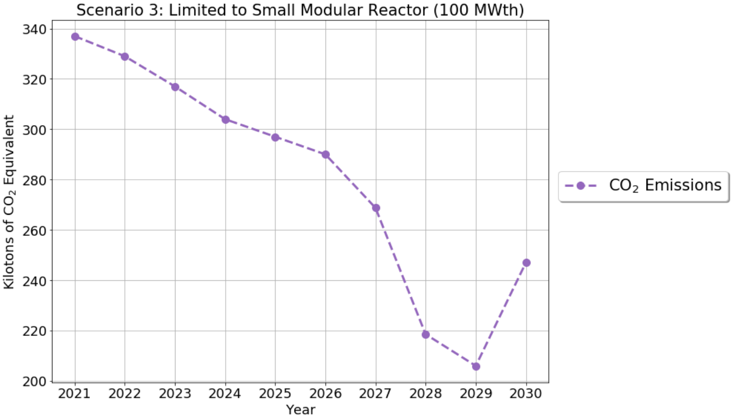


Figure: The steam generation with constrained nuclear

Scenario 3: Emissions



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Conclusion

1. Replacing "ABBOTT" with nuclear would resolve all of the Universities carbon goals, *regardless of other offsets and building growth.*
2. Adding a small modular reactor will cost effectively meet carbon goals until mid-decade when renewable resources must be expanded.

Acknowledgement

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