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Optimal Sizing of a Nuclear Reactor for Microgrid Decarbonization

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Abstract

The abstract goes here. As a general guide, you should provide a concise (150-250 words) summary of your article - introduction, methodology, results, and conclusion. Avoid using abbreviations and acronyms unless the abbreviation/acronym is used repeatedly in the abstract. There should be no references in the abstract.

Keywords: FIXME, key words, go here, like:, simulation, spent nuclear fuel

1. Introduction

In this work we use an Energy system optimization model (ESOM) called Tools for Energy Model Optimization and Analysis (Temoa) to determine the optimal size of a nuclear reactor for a micro-grid system. The optimal reactor capacity satisfies carbon emissions limits and minimizes system cost.

The looming threat of irreversible damage to global ecosystems due to anthropogenic climate change has motivated many countries to adopt goals to curb damaging carbon emissions, underscored by the 196 signatories of the 2015 Paris Agreement [1]. In 2019, the United States made plans to formally withdraw from the agreement, the only country to do so [2]. In spite of this, individual states and institutions have created their own climate goals conistent with the aims of the Paris Agreement. The University of Illinois at Urbana-Champaign (UIUC) is one such institution. In 2015 UIUC published the Illinois Climate Action Plan (iCAP) with the goal to become carbon neutral by 2050 or sooner [3]. Emissions projections shown in Figure **??** illustrate the needed policy changes to meet climate goals.

[iCAP river plot here]

UIUC poses an interesting opportunity to explore options for rapid decarbonization because it: (1) is a mostly self-contained micro-grid (2) has a diverse mix of energy production and (3) relies on steam for district heating which challenges decarbonization efforts.

The iCAP goals for UIUC include several categories [3]:

1. Energy conservation and building standards
2. Energy generation, purchasing, and distribution
3. Transportation
4. Water
5. Waste and recycling
6. Agriculture and land use

Energy conservation, generation, and purchasing objectives are of primary interest because these items account for 88% of UIUC's emissions, shown in Figure **??**. iCAP 2015 showed that UIUC made progress towards its emissions goals. Further, in 2016 UIUC entered a power purchase agreement with Railsplitter Wind Farm [4] and completed Solar Farm 1.0 [5]. Though these investments indicate UIUC's dedication to emissions goals, they have not been enough to curb emissions as shown in Figure 1.

The struggle to meet these climate goals demonstrates the challenge decision makers face in balancing stakeholder interests, cost, and sustainability goals. The 2015 Facilities and Services Master Plan, used to define the needs of the UIUC campus, outlined 13 scenarios informed by iCAP [7]. This report found that no combination of existing technologies can achieve the emissions goals developed by iCAP. One of its recommendations was to "investigate additional renewable power purchase agreements or purchasing renewable energy credits."

In order for UIUC to become carbon neutral, it must continue to meet the electricity and steam demand while producing this energy without emissions.

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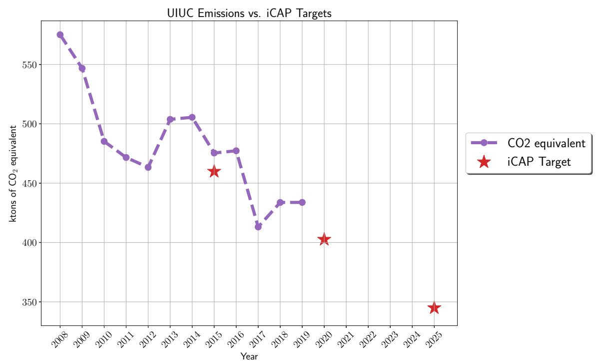

Figure 1: UIUC's actual net emissions compared with iCAP's stated goals. Data taken from the iCAP Sustainability Portal [6].

Investments in renewable energy through power purchase agreements and solar farm construction will enable carbon free electricity production, but more than half of UIUC's energy demand comes from steam [3] . Renewable energy cannot efficiently produce heat in a manner that is simultaneosly cost effective and friendly to the environment.

Nuclear energy was conspicuously absent from the Master Plan's analysis. Yet the life cycle carbon emissions of a nuclear power plant is rivaled only by on- shore wind power, shown in Figure **??** and is capable of producing the high temperature steam required for district heating at UIUC [8]. These two facts alone make nuclear power an ideal candidate for replacing the coal and natural gas boilers in the campus power plant. Additionally, criticisms about nuclear's lack of profitability would not apply to nuclear power at UIUC because the campus operates a micro-grid and is thus uninfluenced by the deregulated energy market in Illinois [9, 10]. The University has already demonstrated its willingness to pay a premium to adopt clean energy for wind and solar [4, 5, 11] which indicates that other premiums might be overlooked in favor of lasting decisions on energy production.

ESOMs are useful for exploring different policy scenarios and energy mixes when faced with future uncertainty [12, 13, 14, 15]. In this work, we use an ESOM called Temoa to analyze future energy mixes that will allow UIUC to meet the iCAP goals [16]. This study is unique because we do not consider all possible technologies that could replace natural gas and coal capacity, which have a range of maturity and readiness. Rather, we consider UIUC's existing energy mix and use Temoa to find the minimum capacity of a nuclear power plant that will enable UIUC to satisfy its emissions goals.

We first examine a business-as-usual model to verify that Temoa agrees with the findings in the Master Plan [7]. Then we consider three scenarios that introduce a nuclear power plant to the energy mix. Finally we employ an uncertainty analysis method known as Modeling-to-Generate-Alternatives (MGA) to evaluate futures that also meet the emissions limits for UIUC but where system cost is not perfectly minimized.

2. Model and Data

1. Describe Temoa
2. Explain the time horizon
   - 2020 is considered a historical year and reflects the current energy mix of the university.
   - The model optimizes years 2021-2030 in single year increments.
   - In this study, one year is divided 6 time slices. 3 seasons, and 2 times of day. Future work will refine this temporal detail.
3. Typical demand for winter, summer, and the spring/fall "inter" season are determined by averaging historical data from 2015-2018.
4. The natural gas plant, "ABBOTT" as a cogeneration plant that produces all of the steam on campus and much of the electricity. In order to capture the cogeneration, we introduced a "TURBINE" technology that produces electricity from steam. The proposed nuclear reactor will also produce steam that "TURBINE" can use to produce electricity. Thus the model assumes that the nuclear reactor will serve as a direct replacement of "ABBOTT" or function alongside "ABBOTT" in an identical way.
5. Natural gas prices.
   The price of natural gas is one of main factors driving the choice of energy production at UIUC. Since 2014, natural gas prices have somewhat steadily declined.
6. Carbon Emissions
   Carbon emissions in the model are captured by using a carbon emission equivalent that matches the strategy adopted by iCAP.
7. Capacity caps
   Solar and wind capacities are both capped by Temoa and reflect the reality of the UIUC energy mix.

- The cap on solar energy is due to the maximum capacity of the solar farms on campus. Currently, the solar farm is rated to produce 4.68 MWe, but will be quadrupled in 2022 when the university finishes the planned Solar Farm 2.0.

- The cap on wind energy is due to the 10-year power purchase agreement between UIUC and Rail-splitter Wind Farm. This contract ends in 2026, at which point the university can elect to purchase more or not.

8. Offsets, Growth, and Building Standards
   This model assumes an energy demand growth of 1% per year. Thus, offsets like shutting down the Blue Waters Supercomputer and improving building standards, which serve to reduce demand, are not accounted for and assumes the university will carry on with business as usual in every regard except its energy mix.

9. Scenarios
   Describe the modeled scenarios - BAU, 1, 2, 3. Uncertainty analysis is only performed on scenario 3 because scenarios 1 and 2 will be pushed along the same technology trajectory because not limiting the size of the nuclear reactor means demand and emissions constraints can be satisfied arbitrarily. The business as usual scenario is not analyzed for uncertainty because it served as a sanity check to verify that Temoa was giving appropriate results.

3. Methodology

This is the methodology section.

3.1. Subsection

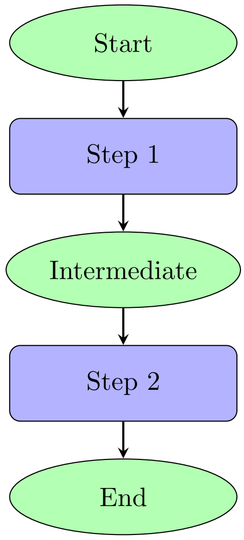

Figure 2: A caption for the flowchart.

4. Results

The results section should be based on the following graphs.

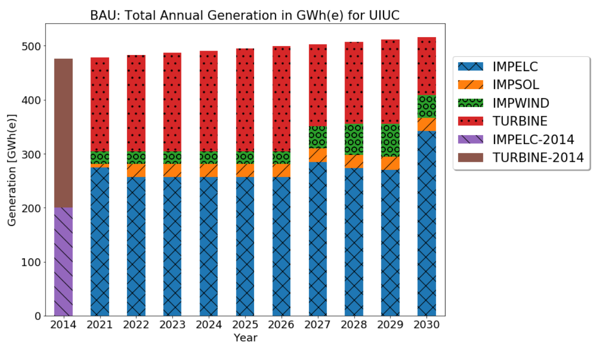

Figure 3: Business as usual electricity generation.

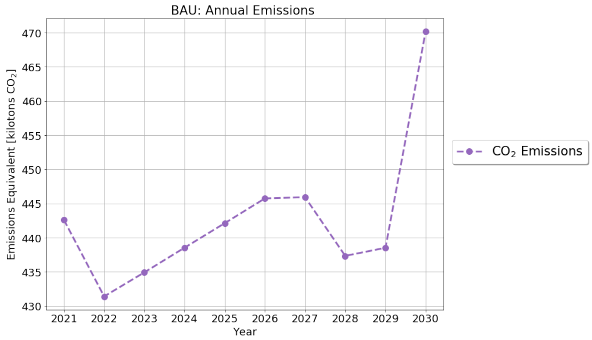

Figure 4: Business as usual carbon emissions.

4.1. Scenario 1

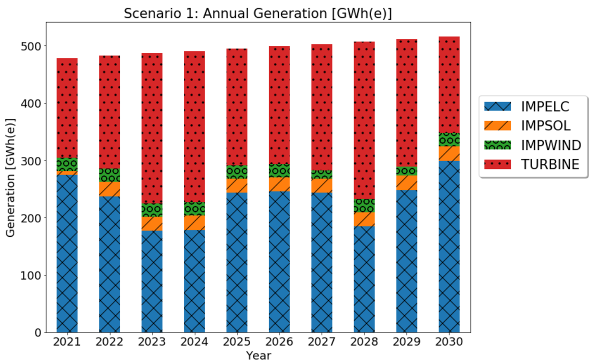

Figure 5: Business as usual electricity generation.

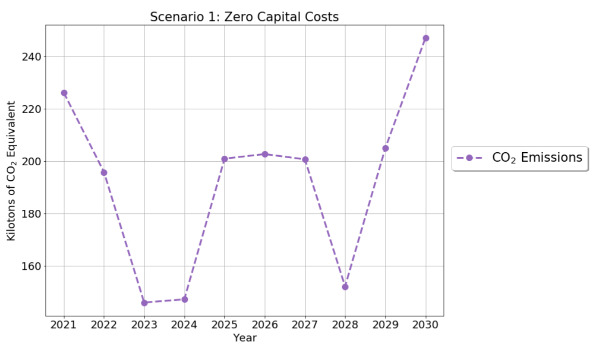

Figure 6: Business as usual electricity generation.

4.2. Scenario 2

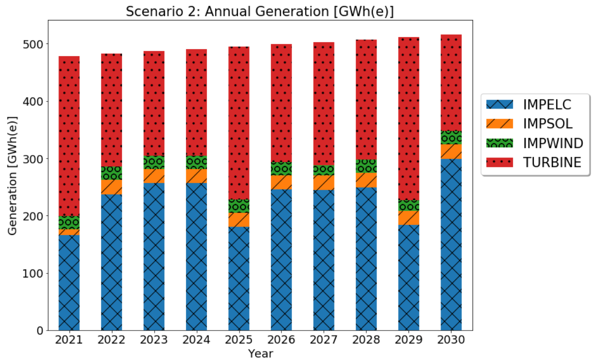

Figure 7: Business as usual electricity generation.

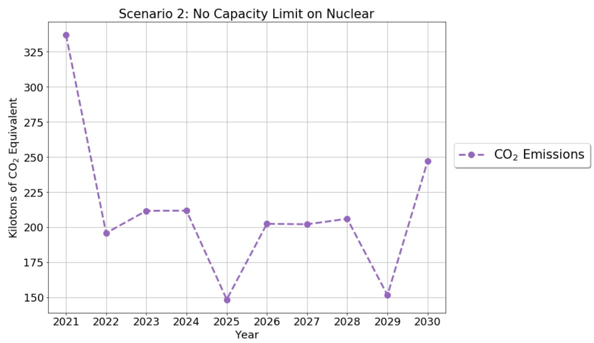

Figure 8: Business as usual electricity generation.

4.3. Scenario 3

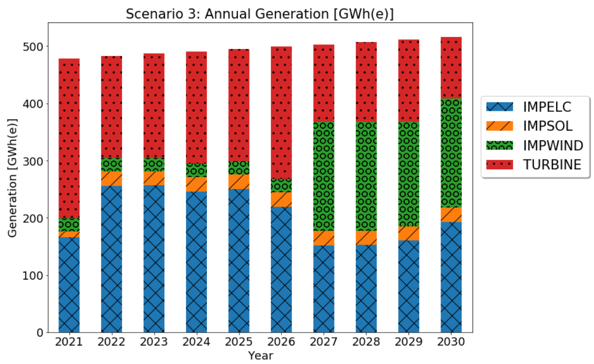

Figure 9: Business as usual electricity generation.

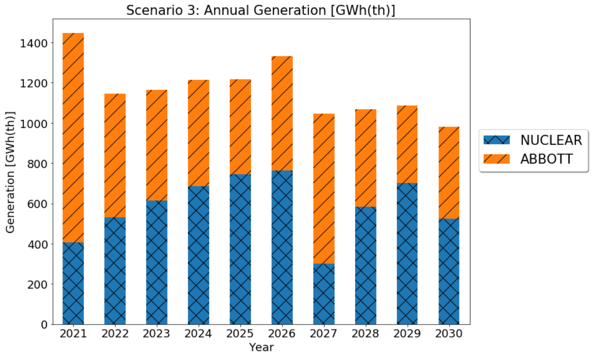

Figure 10: Business as usual electricity generation.

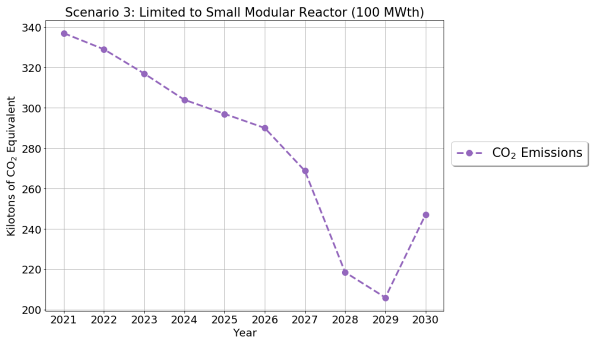

Figure 11: Business as usual electricity generation.

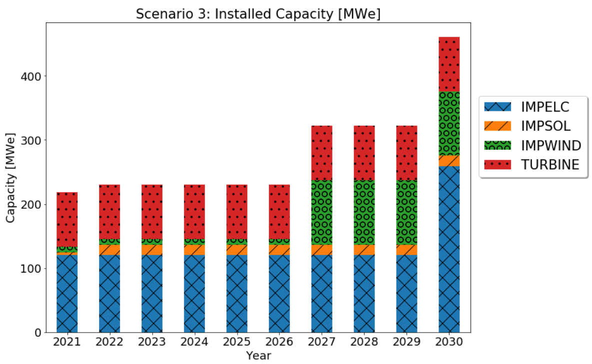

Figure 12: Business as usual electricity generation.

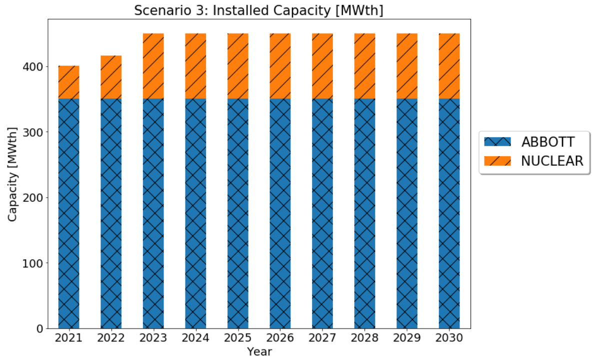

Figure 13: Business as usual electricity generation.

5. Conclusion

This is the conclusion section.

6. Acknowledgments

This is the acknowledgements section. Include acknowledgements for relevant funding sources and contributors for this work. Review the how-to-acknowledge document for the appropriate text, which changes frequently as grants and people come and go.

References

[1] The paris agreement | UNFCCC.
URL `https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement`

[2] H. Eshraghi, A. R. de Queiroz, J. F. DeCarolis, US energy-related greenhouse gas emissions in the absence of federal climate policy 52 (17) 9595–9604, publisher: American Chemical Society. `doi:10.1021/acs.est.8b01586`.
URL `https://doi.org/10.1021/acs.est.8b01586`

[3] iSEE, Illinois climate action plan (iCAP).
URL `https://sustainability.illinois.edu/campus-sustainability/icap/`

[4] S. Breitweiser, Wind power: University of illinois at urbana-champaign.
URL `https://www.fs.illinois.edu/docs/default-source/news-docs/newsrelease_windppa___factsheet.pdf?sfvrsn=43aaffea_0`

[5] M. White, Solar farm fact sheet.

[6] Metric: Total campus GHG emissions | iCAP portal | university of illinois.
URL `https://icap.sustainability.illinois.edu/metric/total-campus-ghg-emissions`

[7] Affiliated Engineers, Inc, Utilities production and distribution master plan.
URL `https://www.fs.illinois.edu/docs/default-source/utilities-energy/utilities-master-plan_.pdf?sfvrsn=16bbfbea_0`

[8] M. Allen, O. P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, K. Zickfeld, Framing and context, in: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, p. 46.
URL https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter1_Low_Res.pdf

[9] S. Clemmer, J. Richardson, S. Sattler, D. Lochbaum, The nuclear power dilemma.

[10] V. Nian, S. Zhong, Economic feasibility of flexible energy productions by small modular reactors from the perspective of integrated planning 118 103106. doi:10.1016/j.pnucene.2019.103106.
URL http://www.sciencedirect.com/science/article/pii/S0149197019302070

[11] Solar farm 2.0 (in progress) | iCAP portal | university of illinois.
URL https://icap.sustainability.illinois.edu/project/solar-farm-20

[12] J. DeCarolis, S. Babaee, B. Li, S. Kanungo, Modelling to generate alternatives with an energy system optimization model 79 300–310. doi:10.1016/j.envsoft.2015.11.019.
URL https://linkinghub.elsevier.com/retrieve/pii/S1364815215301080

[13] K. Hunter, S. Sreepathi, J. F. DeCarolis, Modeling for insight using tools for energy model optimization and analysis (temoa) 40 339–349. doi:10.1016/j.eneco.2013.07.014.
URL http://www.sciencedirect.com/science/article/pii/S014098831300159X

[14] B. Li, J. Thomas, A. R. de Queiroz, J. F. DeCarolis, Open source energy system modeling using break-even costs to inform state-level policy: A north carolina case study 54 (2) 665–676. doi:10.1021/acs.est.9b04184.
URL https://pubs.acs.org/doi/10.1021/acs.est.9b04184

[15] J. DeCarolis, K. Hunter, S. Sreepathi, Multi-stage stochastic optimization of a simple energy system 14.

[16] J. DeCarolis, K. Hunter, Tools for energy model optimization and analysis (temoa).