Illinois Energy System Models & the Potential for Proactive Nuclear Activism

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Introduction

In 2020, the primary energy source for Illinois' electricity generation was the state's nuclear fleet [1]. In 2021, two of the six facilities that comprise this fleet, Byron and Dresden Generating Stations, were at high risk of closure [2].

In an effort to demonstrate the economic and climate effects of these closures and Illinois' energy usage overall, Dotson et al. created a predictive model of Illinois' energy grid using North Carolina State University's Tools for Economic Modeling and Optimization Analysis (Temoa) software. The model sought to minimize two major factors, CO_2 and other greenhouse gas (GHG) emissions and overall system costs [3]. The results of the model and a preliminary interpretation of the results in relation to state energy policy proposals were compiled by Dotson et al. in the 2021 report, "Economic and Carbon Impacts of Potential Illinois Nuclear Plant Closures" [3].

Dotson et al.'s findings serve as a data-based underpinning of the need to demonstrate the importance of clean and safe nuclear energy outside of a time-sensitive closure preventing rhetoric. Ultimately, this project uses the recent history of Illinois' energy policy and predicative energy grid models to promote proactive nuclear activism on a global scale.

Objectives

- Review several modeled Illinois energy-grid scenarios, including three variations of each business-as-usual (BAU), constrained carbon (CC), expensive nuclear (XN), and zero advanced nuclear (ZN), with a range of renewable energy growth rates to reach a zero carbon target.
- Summarize computational models in a policy-oriented manner to demonstrate the difference in potential impact between *proactive* and *reactive* nuclear activism.

Theory

The structure of Temoa is an intentionally flexible linear programming tool; creating an energy system based on user inputted technologies that generate commodities that fill a certain demand [4].

The Illinois energy model referenced in this project had an end demand of electricity, with technologies such as nuclear power plants, solar farms, wind farms, coal plants, natural gas, etc.

Temoa's objective function minimizes the total system cost of the Illinois energy system for Dotson et al.'s model and imposes a variety of constraints on the system, such as land use, carbon emissions, and specified renewable energy and energy deployment speeds [3]. The objective function is to minimize:

$$\sum_{g=1}^{G} = \int_{t=2020}^{t=2050} c_g(t) \tag{1}$$

where

- G = number of generation technologies
- $x_g(t)$ = capacity of technology g in year t $[TW]$
- $c_g(t)$ = total cost of technology g in year t $[\frac{\$}{TW}]$

[3].

The main objective function of the Temoa model of the Illinois energy grid minimizes total system costs, which is a high priority for policymakers and taxpayers alike. The costs of each energy technology comes in three parts:

1. Investment costs: a one-time payment of the technology.
2. Fixed costs: an annual payment for the technology.
3. Variable costs: an annual payment for the technology that varies directly with the amount it operates and produces.

By creating a model and forecasting the total system costs and carbon emissions of a variety of energy scenarios, policymakers can make quantitative data-based decisions on how to move forwards in an economically and environmentally sustainable way. By varying the contributions nuclear energy has to such a modeled grid, this work highlights the often under-appreciated role nuclear plays in producing large quantities of carbon-free electricity across the state.

Results & Analysis

Scenarios

There are four scenarios for deployment with three cases: 1) premature closure of Byron and Dresden; 2) scheduled closure; 3) license extension outside 2050.

Table: Nuclear deployment scenarios, and their model hyperparameters [3]

ID	Name	Zero Carbon Target [yr]	Renewable Growth Rate
BAU	Business as Usual	none	limited
CC	Constrained Carbon	2030	optimistic
XN	Expensive Nuclear	2030	optimistic
ZN	Zero Advanced Nuclear	2030	unlimited

The limited growth rate is based off of current developments in renewables, whereas the optimistic rate is defined by the bold proposals in the Illinois Clean Energy Jobs Act (allowing utility solar to grow to 10 GWe by 2030, wind turbine deployments to grow to 13.8 GWe by 2030, and capping a steady increase in residential solar at 75% [5])

Costs

When these plants continued to operate, they did so with relatively low fixed and variable costs, since the majority of the expense of nuclear power is paid upfront via the investment cost. Without GHG restrictions imposed on the model, the cost of using other sources wasn't significant. With restrictions imposed, the model showed increased costs in the land-use required by renewable technologies.

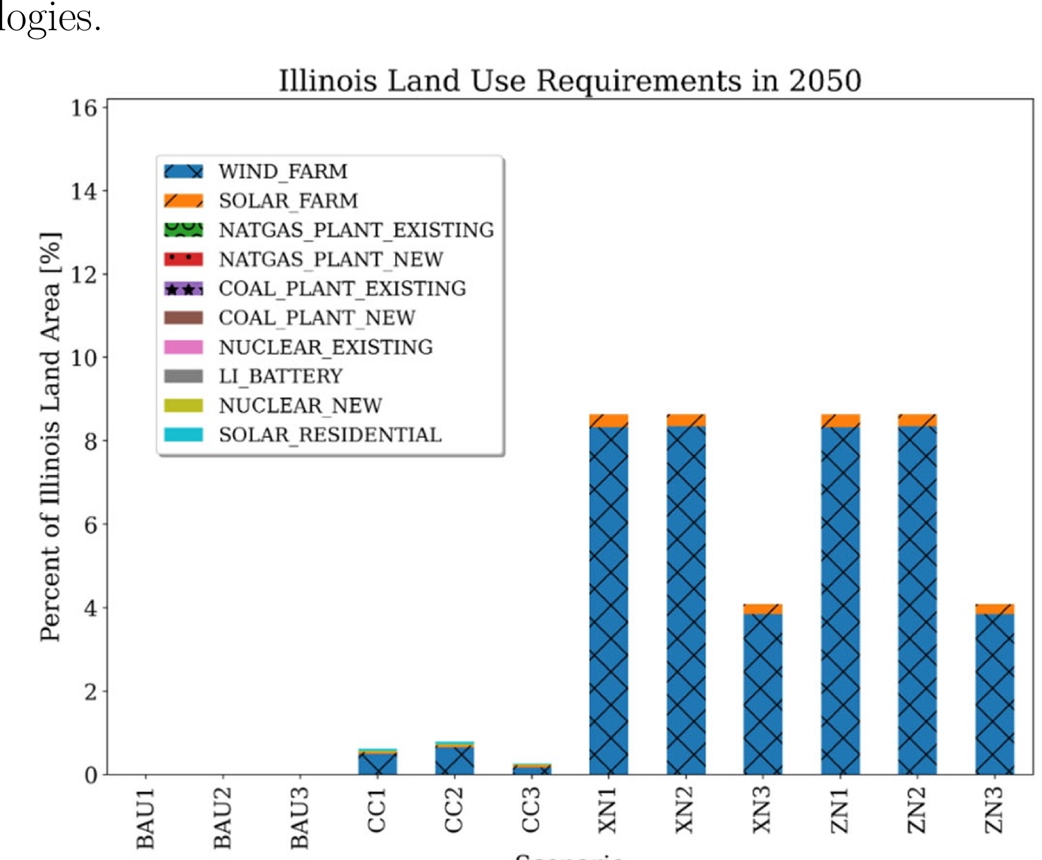

Figure: Percentage of land use required for each scenario in the Dotson et al. model [3].

Figure 1 shows the massive increase in Illinois' land area that would be required to produce adequate levels of clean energy in the zero nuclear situation. Further, the land most suitable for such renewable implementation (specifically, solar-PV), happens to coincide with the regions used for 15% and 14% of corn and soybean production, respectively [6].

Emissions

The Clean Air Task Force report [7] on the health impacts of these closures predicted that the decline in air quality would lead to 500 to 1,100 premature deaths using the EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)—costing a little over half of a billion dollars per year.

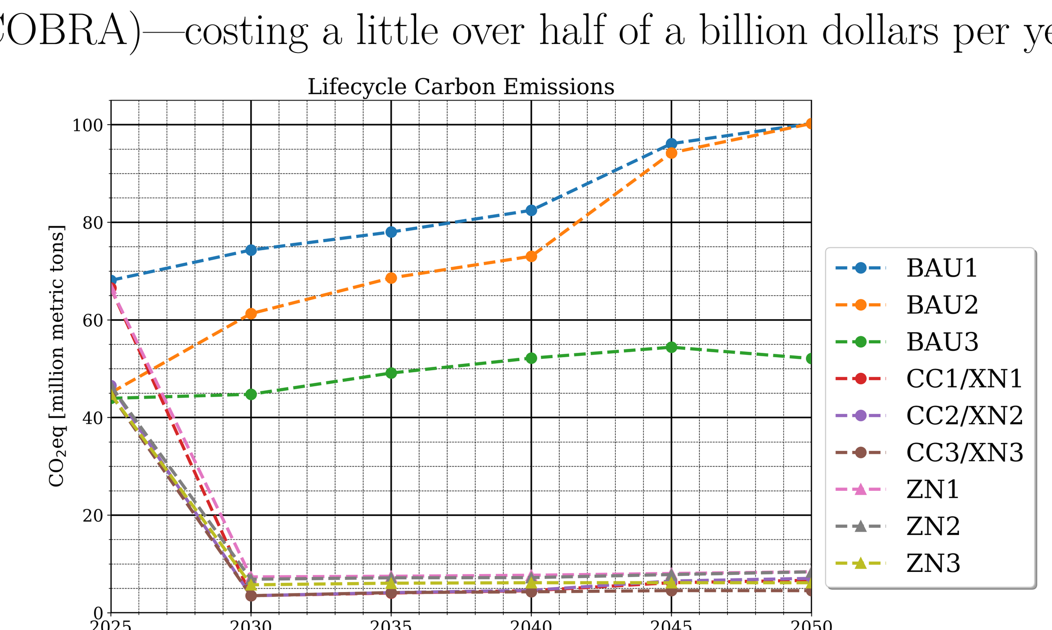

Figure: CO2 equivalent of lifecycle emissions for each scenario over time in the Dotson et al. model [3].

Illinois recently joined the US Climate Alliance, committing the state to reducing their emissions to at least 26% below 2005 levels (among other promises) to track progress and accelerate technological development [8].

Conclusion

The key takeaways of this research are less focused on the specific outcomes and projections of ESOMs but rather on the pertinence that they exist. Neuroscience indicates that despite our best efforts, humans have a particularly challenging time imagining "future developments that deviate significantly from current and historic trends" [9]. The scenario we now face, a critical need to completely re-envision our energy generation schemes in order to avoid the effects of climate change, has a major risk of failure due to this psychological impairment. ESOM research, like the Illinois energy model described here, provide an antidote to this barrier by eliminating the need for human brains to "imagine" the new scenario. Instead, tools like Temoa create the new, prospective scenarios for us.

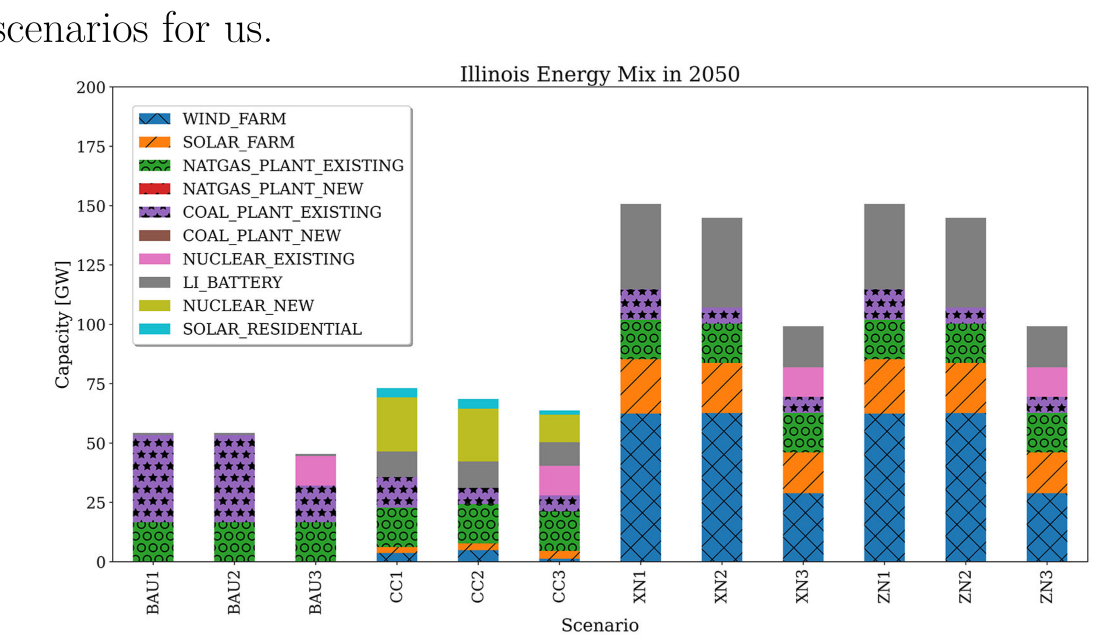

Figure: 12 energy generation combinations for Illinois in 2050 [3]

For the example of Illinois, we can draw conclusions on relative expenses for transition scenarios or emissions related costs for a variety of potential energy grid outlooks. Figure 1 shows 12 possible combinations of energy generation sources for Illinois in 2050 shown as GW capacity for each source. Clearly, the results shown here are not expected to be completely accurate to a future scenario, but they provide policymakers and citizens alike the capacity to envision a solution that may otherwise seem impractical, even impossible. Using quantitative, predictive, optimization models like the one demonstrated in this work highlight the potential of nuclear among a variety of sources and underline the need to portray this potential to the general public and community leaders.

Future Work

Future iterations could extend this work to take into account the effects of the recent commitments by the state to supply all of the electricity to Illinoisans from renewable sources by 2050. This project could also be extended to other states like Michigan, which is facing a similar premature closure scenario with their Palisades facility—it was licensed through 2031.

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