[*WHY RAPID AND DEEP DECARBONIZATION ISN'T SIMPLE: LINKING BOTTOM-UP SOCIO-TECHNICAL DECISION-MAKING INSIGHTS WITH TOP-DOWN MACROECONOMIC ANALYSES*]

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Overview

Energy-economy-emissions modeling has commonly projected that the rapid and significant reductions in greenhouse gas emissions (GHGs) required to avoid the most significant consequences of climate change are, in theory, attainable with the implementation of emissions policies, existing technologies, and moderate investment costs [1]. However, the assumptions of rates of change embodied in the technological deployments and retirements of these projections may not be consistent with constraints imposed by socio-technical factors that influence transition processes. A rapid socio-technical transition to a low-carbon future will require the development and deployment of technical projects and infrastructure coupled with their effective integration within society [2], [3]. Addressing the coevolution of social and technical elements in a low-carbon transition will thus require decision-making models that extend beyond techno-economic analysis and incorporate behavioral, social, political, and institutional dynamics.

Although numerical (e.g. CGE) models offer analytical strengths and a formal structure for evaluating low-carbon transitions, they rely on a mathematical representation of the world distilled to a level of simplification. Socio-technical dimensions have long been analyzed externally to formal models because they are difficult to represent with mathematical equations, yet these dimensions play a critical role in describing realistic influences on the rate of transition to new energy-economic systems and are, therefore, major drivers of model uncertainty. This paper proposes to evaluate the top-down projections of a Computable General Equilibrium (CGE) model—one of a number of energy-economy-emissions modeling approaches commonly used for assessing the impacts of decarbonization—with a bottom-up framework representing the aggregated effect of project planning and approval processes. Illustrative scenarios of nuclear power generation in the U.S. are presented to extend and improve our current understanding of CGE model predictions of technical feasibility, as well as the manner in which alternative parameterization for socioeconomic and political impediments can modify simulated pathways. A key finding is that the deployment of nuclear power technologies as a low-carbon generation resource in the U.S. may need to be constrained below economic projections due to influences from political, regulatory, industrial, and social drivers.

Methodology

BAEGEM, a recursively dynamic CGE model of the world economy written in GEMPACK and developed by BAEconomics Propriety Limited [4], is used to simulate technological projections subject to economic growth assumptions and climate change policy constraints. BAEGEM provides a high degree of technological, sectoral, and regional detail to support an analysis of rate impacts in a low-carbon transition. This CGE model is, however, subject to limits largely imposed by its neoclassical nature. Alternative approaches to overcoming these limitations fall into two categories: (a) make the model more complicated, or (b) minimize changes and complications to the model but deploy complementary approaches outside the model. Our choice to pursue the latter option is supported by the development of a bottom-up evaluation framework.

The Socio-technical Decision-making Model (SDM) will be used to construct an upper-bound achievability limit for project developments, given timelines and constraints for regulatory approval, capital investment cycles, public acceptance, and other socio-technical considerations. For any given technical project of considerable scale, there exists a set of established steps and checkpoints, some more explicitly defined than others, that the project must satisfy before it can be commissioned and begin providing services for the economy. These socio-technical factors, which are not adequately captured by a CGE modeling framework, represent decision-making realities that can influence the project's deployment. Then, when aggregated to an economy-wide level, they have leverage to either constrain or accelerate the deployment trajectory of an entire technology. The SDM seeks to characterize these processes and their project- and economy-level impacts.

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Results

The long-term electricity generation portfolio of each of the presented scenarios varies depending on the existence of carbon taxing and socio-technical factors. The introduction of the carbon tax in the policy scenario shifted the bulk of the generation mix to renewable resources. In addition to impacting the system generation mix, the various inputs and shocks of each of the scenarios have implications for national GHG emissions.

In the base case, the implementation of the model's exogenous inputs aligned with constraining socio-technical factors results in an approximately 3.3% increase in CO_2 emissions (i.e. additional 1.35 GtC) from 2007 – 2060 in the Modified Base scenario compared to the original base scenario; these additional emissions could be explained by substitution by cheap coal and gas for nuclear generation. In the policy case, the Modified Policy scenario results in an approximately 1.4% increase in CO_2 emissions from 2018 – 2060 than the original Policy scenario because of an increased share of generation by solar power and other renewable energy technologies. Therefore, implementing a carbon tax at a global or multi-regional scale as well as incentivizing key energy technologies (e.g. nuclear power) with emissions policies or other mechanisms has the potential to deliver significant GHG emissions reductions.

Conclusions

Taken independently, the two approaches may fail to consider some of the critical dynamics in an analysis of a rapid and deep decarbonization. However, the combination of the two approaches is able to more fully address key political, economic, social, technical, regulatory, and environmental factors. The approach of top-down macroeconomic modeling coupled with bottom-up realistic, process-driven insights provides a testbed for exploring how low-carbon transitions could evolve. Insights obtained from this modeling interaction could be used to apply exogenous inputs to the CGE model, refine or calibrate the CGE parameters, identify key socio-technical "pinch points," and quantify emission reduction opportunities. Furthermore, results can be used to develop energy and climate change policy targets more cognizant of the sensitivity of predictions to highly uncertain social, economic, and technical outcomes and adaptations. Future research efforts will focus on employing expert elicitation techniques in order to characterize the current scientific range of beliefs regarding the SDM's parameters for targeted technological, sectoral, and regional evaluations.

References

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