Developing a New Modeling Tool to Understand Decarbonization at the State Level

Data Methods in Integrated Assessment Models Used to Predict Climate Change Mitigation Strategies

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

2°C of climate warming will cause irreversible consequences for humans and ecosystems around the world. Remaining under this level will require widespread implementation of negative emissions technologies (NETs) (*IPCC Sixth Assessment Report*, 2022). As we rapidly approach this 2° threshold, organizations around the world are turning to more advanced modeling techniques to coordinate decarbonization efforts with the help of NETs (Fuhrman et al., 2019; Fuhrman et al., 2020). Accurately predicting the impacts of net-zero emissions plans will allow society to develop implementation strategies that properly address the climate issue and minimize unforeseen consequences. Both my technical and STS research are centered on this notion of accurate predictions: how can we develop and use these models such that they yield the best results? If we are going to rely on models to help define pathways to meet global sustainability targets, there are some crucial capabilities that must be realized: this is what connects the topics of my research.

In the field of STS research, a robust analysis of the data methods used in climate change mitigation models is missing. Whether in integrated assessment, computable general equilibrium, or other form of model, the evaluation is focused on the output, and we need to focus on the steps that come earlier. The data is what determines model outcomes, and therefore how we assess its performance. For my STS research I will evaluate the current methods of data processing and explore their abilities to create reliable and representative models. In terms of model development, there is a need for capabilities to be expanded to a regional scale. We do not possess a sufficient understanding of how net-zero emissions plans will impact regional economies or environments. This is the topic of my technical research: my group will develop a new modeling tool to understand decarbonization at the state level, building off of existing model formulations.

Technical Topic

Realization of net-zero greenhouse gas emission goals warrants quantitative tools for understanding how potential policies impact not only net emissions, but the fate of systems in place to support and produce the emissions. Computer modeling has long been used in policy decision-making, with environmental policy-specific models largely falling into two categories: integrated assessment models (IAMs) and computer generated equilibrium (CGE) models (Nikas et al., 2019). Both model families allow us to simulate human-earth system interactions, but specific to modeling what a net-zero emission future looks like, results are most comprehensive when the models are used together. In practice, the outputs of IAMs, which define what is necessary in terms of emission reductions, can be used as boundary conditions in CGE models that simulate policy impacts. National and multinational models are the natural consequence of the global scale of net-zero goals, but such high level scopes overlook the diversity of sub-national and regional economies. Only using models that overlook regional factors will cause inaccurate modeling results and thus less effective climate mitigation strategies. Regional resources will dictate the scale and capacity of the deployment of sustainable technologies needed to meet emission goals (Baik et al., 2018), and therefore the impacts of climate change mitigation strategies will be felt differently across US states and regions. Our technical research aims to fill the gap in regional modeling abilities by developing a model that will take economic factors into account when defining the impacts of decarbonization efforts at a regional scale.

We begin with an assessment of two models, the Global Change Assessment Model (GCAM), an IAM, and the China Hybrid Energy Economic Research Model (CHEER), a CGE model, to understand their mechanics and potential synergies in regional modeling. GCAM represents the interactions between energy, water, land, climate, and economic systems (*Global*

Change Analysis Model, n.d.). One recent expansion of GCAM was the development of GCAM-USA, which includes spatial detail of the 50 states and Washington D.C. (GCAM V6 Documentation, 2022). This effort to further dissect the global regions aligns with the issue our group aims to address, but is still missing macroeconomic factors outside of GDP. Inversely, the core CHEER model is constructed with a macroeconomic focus, but computes results for the Chinese economy on an exclusively national scale. There are ongoing efforts to disaggregate CHEER to obtain more granular results, but these efforts have been primarily focused on a rural-urban analysis (Huang et al., 2020). The methodology used for data disaggregation is relevant to my technical research in understanding the nuances between sub-national regions, but the urban-rural distinction may not translate to an accurate depiction of the regional United States and warrants a reevaluation of disaggregation criteria.

An important distinction between the two models is that GCAM uses a top-down approach, while CHEER uses a bottom-up approach. CHEER's bottom up structure makes it easier to incorporate more granular information in the base data, making it a good option to begin with in our efforts to create a more localized model. Our goal is to develop a CGE model that can make economic predictions at a regional level relevant to the United States by building off of the CHEER framework. Using results from GCAM simulations as inputs, our CGE model will output predictions for future impacts of policy implementations to reach net-zero goals. We will utilize existing code from open-source models to create the foundation for ours, and then focus on adjusting input parameters and constructing accurate data to feed into the model. We plan to build off the methodology outlined in by Mu et al. (2018) for our data collection and disaggregation approach; this group outlines their processes for establishing data from the census and independent research.

STS Topic

Decision makers around the world are relying on integrated assessment models (IAMs) as tools to assess pathways for achieving global goals for climate change mitigation. IAMs provide a way to "explore how human development and societal choices interact with and affect the natural world" (Evans & Hausfather, 2018). Many recognize the powerful capabilities of IAMs to provide valuable insights when it comes to the society/environment/economy interface. van Beek et al. (2020) explores the evolution of IAMs as tools in future climate action, concluding that their flexible, broad nature, coupled with the urgency of defining a climate response has given way to the prominent role they hold in society today. Though the analysis of this evolution demonstrates the clear advantages of these models, it fails to provide context regarding the higher level of scrutiny due to increased use. Critiques of IAMs are prevalent in academic literature due to the prevalence of the models themselves. I have found that within the current landscape, scholars tend to focus their critiques solely on model results. This is problematic because the results are driven by what we input (data and assumptions), and in order to obtain accurate and reliable results we must focus on the data that drives them.

The overarching criticism of IAMs centers on whether they accurately translate to the real world. Several studies reviewing IAMs cite problems with the models in terms of transparency and representation of complex systems and feedback, among several others (Gambhir et al., 2019; Keppo et al., 2021; Lamperti et al., 2019). Though realization of these weaknesses is important, these papers do not investigate the data used to construct the models. Wilson et al. (2017) explores the current evaluation techniques of IAMs, yet this exploration lacks discussion of how model inputs are or should be evaluated, despite the fact that they drive the results being critiqued. This is yet another example of how present literature and discourse is focused on the outcomes of models rather than the data inputs informing them.

In order for IAMs to serve as useful tools for analyzing long-term global climate change, their results and analyses need to be trusted. For trust to be possible, we must be able to trust the data: it is the data that play a crucial role in determining whether or not the model accurately represents the real world. This warrants a definition of what it means for data to be (un)trustworthy. For the scope of my research, I define data trustworthiness as the ability to have confidence in its representation of the real world. Data for IAMs are carefully constructed to fit the model, so this definition should be applied to both the raw data (before processing) and the aggregated data that serves as a direct input.

The lack of research on data methods in integrated assessment models and the notion of data trustworthiness form the basis of my STS research. Rather than a systematic review of all complaints cited with IAMs, I will focus specifically on the methods used to construct the input data for models used by the International Panel for Climate Change (IPCC). I will draw on Leonelli's framework of data journeys (2020) and the relational view to frame my analysis of how data are manipulated to be used in IAMs for climate change mitigation strategies. Both frameworks highlight the idea that data can not inherently provide an answer, but rather it takes work to obtain a usable form. The meticulous processing of IAM inputs speaks to Leonelli's perspective on how we should understand data. My research begins with a literature review, both of past studies criticizing IAMs and model documentation describing data methods. This will be followed by ethical analysis and autoethnography, drawing on the progress of my group's technical research to provide context and insights from those within the modeling community. Using these sources of evidence to understand the data journey in integrated assessment modeling will help shift the focus of evaluation to earlier in the model development process, and thus allow scholars to develop more effective and representative models.

Conclusion

As the global economy moves forward on a path towards net-zero emissions, predictive models will continue to be used to understand environmental, economic, and social impacts of proposed environmental policies. It is important that we recognize both the capabilities and weaknesses of integrated modeling so that we can thoughtfully move forward on a path that is best for global society. Climate change is viewed as an inherently sociotechnical problem, and as we work to address it through advanced modeling techniques we must keep this same perspective. In simultaneously working on model development and evaluating the implications of its construction through my STS research, I will be able to bridge the gap between the social and technical issues raised by the global problem of addressing climate change. This provides a unique opportunity to contribute to the discourse on both sides, playing a part in the advancements in both the model and its evaluation.

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