A REVIEW OF LESSONS FROM COMBINED MODELLING APPROACHES IN ASSESSING ENERGY AND CLIMATE POLICIES

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Overview

A sustainable transition from the current system, based on dispatchable sources, to a system with a high penetration of intermittent resources (e.g. wind, solar, and biofuels) requires a better understanding of the trade-offs and benefits of different policy options. In addition, the interaction of the energy system with the other human and natural systems (such as land, food, water, human wellbeing, and natural security) should be explored in the larger adaptation and mitigation policy context. Systems modelling can play a significant role to address these complexities and trade-offs but, to date, most modelling work has been focussed on two opposing paradigms: power sector planning where the economic and social interactions are not considered, or energy economics, where the operational constraints of the power sector may not be effectively represented. Recently, efforts have been made to link these two worlds by either combining (soft or hard-linking) different models together or incorporating more parameters within the structure of a single model. The benefits and drawbacks of such approaches are not always directly evident and there is a need to investigate the effectiveness and accuracy of the different approaches. This paper provides an overview of the existing combined modelling techniques and their capability in evaluating and simulating a more realistic projection of the social, techno-economic, political, and ecological aspects of the future energy and power system. We identify the main co-benefits, important interlinkages, and the challenges of combining capacity expansion and power sector and energy-economy models of different types in assessing future energy and climate-related policies.

Methods

We begin with a literature review to identify the different combined modelling approaches currently published and describe the trade-offs and benefits of these approaches. We compare combined modelling approaches based on the policy questions they can address, their ability to explore uncertainty posed by variable renewable energy sources into the decision-making process, the cross-disciplinary ability of the model in addressing social, techno-economic, political, and ecological (nexus of water, food, land, and energy) aspects, as well as the transparency of their analysis and accessibility to other modellers. Through this review, we provide a more in-depth understanding of the existing combined modelling techniques and determine the specific interactions and challenges that combined models can address.

To date, there are three major types of models working in the energy system analysis domain. The first is energy-economy models such as CIMS [1] and GCAM [2], focussed on models that include the interaction of individuals' behaviour with climate policy (carbon pricing, flexible fuel standards, carbon trading). The assumption often is that the agents are price takers, and the market equilibrium can be achieved. Then, there are capacity expansion models that optimize the investment of new energy capacity and technologies in a given energy system to meet loads. They do the analysis based on the prediction of demand growth, fuel prices trend, technology costs, and policies. Examples of such models are MARKAL [1], and OSeMOSYS [4]. The last group is the power system models such as PLEXOS and GTMax [5], which optimize the operation of a given energy system. More recently published combined modelling techniques are mostly focused on linking either capacity expansion models and power system models or the energy economy and the capacity expansion models. Due to the diverse natures of these models in terms of structure, function, purposes, and temporal resolutions, the careful evaluation of the combing technique is required to ensure that the linkages will not lead to counterproductive policy measures.

Results

Due to recent computational and data science advances, energy models have been integrating additional parameters to enhance their representation of the domain dynamics. Though this increasing complexity enhances system representation there is a drawback of increasing the model complexity that can increase uncertainties. The main advantage of combined modelling approaches is enabling the different strengths and capabilities of the separate models while reducing the complexities introduced. The ultimate goal is to create a feedback loops to test the accuracy of assumptions and simulations. A review of the existing literature on combined modelling approaches shows that such robust interaction and reciprocal feedback loop has been already developed between capacity expansion and power system models. Feeding the capacity expansion models with the reliability, flexibility, and grid security constraints by the power system models have proven to be useful in informing decisions on power planning, policy, and new capacity expansion investments [6]. The example of this approach is the work by Diakov et al. [6] in linking the capacity expansion models and the production-cost models in 2015. The result shows that the combined model is better equipped to investigate the effect of various aspects of choosing between renewable energy options in a case of high levels of renewables in the system [7]. PLEXOS software is an example of this approach. However, the private ownership of some of these models makes the examination of the interactions difficult.

The missing feedback in the existing literature is the interlinkages between energy-economy models and capacity expansion models. Integrating these models is challenging due to the diverse temporal and technical complexity needed to make such models manageable [5]. Although increasing the level of temporal and operational detail in the simulations of energy-economy models is suggested as effective for systems with larger shares of variable renewable energy sources [7], [8], these types of models are not able to capture the full scale of flexibility and other operational constraints required within the power system. Overlooking the operational considerations affects the resulting costs or energy used by energy-economy models to determine factors such as increasing the generation capacity or determining the timing of investment in new technologies. There has been recent work combining energy-economy and capacity expansion models, such as the work by Deane et al. [8] in connecting an Irish energy system (using TIMES) and capacity expansion/ power system models (using PLEXOS). Their work showed that in the absence of the detailed technical constraints of the power system model, the energy system model tends to underrate the importance of system flexibility (namely storage), underestimate the curtailment of the renewable energy sources (in this case wind power), as well as underestimating the amount of CO_2 emissions, however, this work does not incorporate feedbacks between the different model layers.

Our findings indicate that while intersectoral interaction between energy economy, capacity expansion, and power system models are getting more attention, the cross-disciplinary interactions of energy domain with factors such as water, food, and natural securities remain relatively underrepresented in existing models.

Conclusions

Decarbonisation of our economy and its impact on the energy system requires analysis that goes beyond the current boundaries of most established modelling paradigms. Existing energy-economy models are not well equipped to project the long-term energy visions while considering the complex hourly dynamic of power supply and demand poses by renewable energies. Lack of a holistic approach causes inaccuracies in determining the timing of investment in new technologies, generation capacity, exploring trade-offs, projecting the actual CO_2 emissions, estimating needed capacity and storage. The combined modelling approaches allow for a more in-depth analysis of the interactions of different policies. Our work shows that the soft-linking of the energy economy model with the techno-economic capacity expansion model can create a feedback loop in the system that are not accounted for in the separate modelling structures or any existing combined modelling approaches. Although there are some trade-offs when combining models, and some uncertainty as to which policies a specific combined modelling approach can inform, in general, combined modelling approaches with effective feedback between the models will be able to address more holistic policy questions than the separate models will be able to address. Furthermore, though there are significant strengths in linking models, one must be careful to ensure that the linkages mutually enhance the different models being incorporated and do not exacerbate existing model weaknesses.

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