Improving the Epistemological Basis for Energy Policy Modeling and Analysis

Danny Cullenward

One of most crucial analytical needs for addressing climate policy is the ability to model and compare various future scenarios for the energy sector. Because global energy use constitutes the largest source of greenhouse gas emissions, the trajectory of energy supplies, consumer demand, and conversion technologies has direct and important implications for climate change. Gaining some sort of policy traction on the sector will be necessary to avoid dangerous levels of global warming.

However, due to the time frame of analysis–decades or longer–and the complexity of the energy system, energy forecasting presents a set of challenges that reflect a generalized problem in the field of sustainability science. Namely, the need for systematic modeling of behavioral and technological change outpaces our understanding of the physical, economic, and social systems governing the energy sector.

If one looks at the issue of climate change, stark contrasts emerge between physical climate models and the energy-economic models used to forecast and analyze policy options. Perhaps most importantly, physical climate models “compete” against one another in ranked metrics, assessed by the Intergovernmental Panel on Climate Change (IPCC) according to their ability to reproduce the observed historical record. In contrast, there are no systematic efforts to validate energy-economic models’ performance in recreating the historical record.

There are some ontological reasons why it may be difficult to assess physical climate models and energy-economic models using the same framework. Physical climate scientists place confidence in their models’ predictions because they know that the models accurately reflect known conditions. This is no small part a product of the fact that physical systems do not exhibit choice or other human dynamics, though they may be complicated and our understanding of them may be imperfect. Extending the same physical systems into the future, with different inputs (in the form of greenhouse gases), gives scientists confidence in their ability to project likely futures (given emissions trajectories). Although there is enormous uncertainty left in the physical system– particularly with complicated feedbacks from the atmosphere, oceans, and cryosphere– the basic physical laws of the climate are understood to a reasonable degree. A good scientist knows to place a physical climate model forecast in the context of these uncertainties.

Energy-economic models are less certain by nature. They rely primarily on economic theory, which lacks fixed, immutable laws, owing to the more elusive reality of the human experience. Most energy-economic models that investigate energy futures use optimization functions as the primary determinant of change over time. In turn, optimization conceptually requires information about the costs and benefits of various alternatives, and a structure in which alternatives compete. This means that most energy-economic models require projections of technology costs, regulatory environments, and social behavior; adding these elements increasing the complexity of forecasting.

Fundamentally, technological and behavioral change parameters are uncertain, as they are assertions about the future of complex systems for which we often lack the most basic predictive intuitions. One example is learning curves for technology, which model the relationship between production experience and costs. Several technologies (including some in the energy sector) have been shown to display regular cost declines as output doubles, leading many energy-economic modeling teams to apply this technique. Because climate/energy futures require long time horizons, we know that today's technology options and costs are extremely unlikely to be constant over the next century. However, even among the technologies for which historical learning curves have been determined, we have no theoretical basis for which to predict the future extent of learning, nor the rate of learning (which varies significantly from technology to technology). Perhaps more troubling, the literature on learning curves may exhibit a deep selection bias, as the vast majority of studies examine technologies that were successfully adopted on a wide scale. Many more technologies fail than succeed, casting doubt on the ability of modelers to predict a priori at what rate a technology will experience learning, let alone whether the technology will experience any learning at all.

A second complexity not captured in today's models is a framework by which to assess the rates of technological change. Optimization models determine technology "winners" through levelized costs, typically without consideration of growth constraints; logit models use statistical inference to allocate market shares to technologies on the basis of disaggregated variables such operating costs, capital costs, or other consumer preferences. But no modeling technique directly accounts for the feasibility of technological change; rates of change result from the optimization or logit calculations, and are not directly justifiable one way or the other. We currently have no established theory on the governing forces of innovation, and we have only an emerging theory on the rate of technological diffusion. And yet, the rate and scale technological change is one of the most important aspects of long-term energy policy.

A third complexity not resolved in energy-economic models is the overall role of consumer demand. Almost all models assume some sort of economic growth pattern and a fixed relationship between income and energy demand. More sophisticated models project energy services demand (e.g. lighting, mobility) rather than simple energy demand (e.g. kWh of electricity, barrels of oil); but both are rooted in the traditional economists' convention that increasing consumer welfare requires increased consumption. Models projecting energy services are typically coupled with technological change, in order to reflect the ability for energy technologies to deliver greater efficiency (a lower ration of energy consumption to energy services delivered). Any yet, this still does not account for the many choices that face growing and mature economies with respect to their demand for energy services.

All of this is not to say, however, that energy forecasting is a useless endeavor, or that models are not appropriate tools. Rather, the above discussion calls for a more sophisticated and institutionalized approach to the business of energy forecasting and long-term policy analysis. Three specific needs stand out:

1. A standardized report of model epistemology and assumptions. In order for policymakers, non-specialist scientists, non-governmental organizations and the concerned public to be better consumers of energy forecasts and policy analysis, the energy modeling community needs to develop a standard reporting instrument documenting the assumptions and structure of any given model.

2. A standardized report of implied rates of technological change. When models forecast large roles from unproven, risky, or even hypothetical technologies, it is important for the implied requirements to be transparent. A good example may be found in carbon capture and storage, a technology not yet commercialized, but omnipresent in the energy forecasting literature. Because it is impossible to be correct about the future while in the present, modelers need to report the investments and scaling parameters implied by the model more explicitly. Technology strategy is necessarily debated under conditions of extreme uncertainty, and debates would be improved by a greater transparency of model results in this area.
3. An improved treatment of the demand side of energy. We simply do not understand what factors influence consumer demand, particularly over many decades and during periods of social change; nor do we know how changes occur and what the welfare impacts truly are. Here anthropologists, sociologists and psychologists have an enormous role to play, and energy modelers ought to engage these and other social science communities more openly. Similarly, urban planning has huge implications for energy demand from mobility and building services, yet few models treat these choices as variables. Simply assuming fixed links between economic growth and energy demand ignores the huge role social change could (and probably should) play in the coming decade; therefore, this is a crucial area for further research.