Energy and Economic Growth
Applied Research Programme

Integrated energy and economic modelling

A short summary of current practice

Strategic energy planning is an essential input for effective policy and investment decision-making. Traditionally, modelling within the energy sector has focused either on specific aspects or overall energy system effects. Modelling the interplay between energy and the economy can be achieved through different approaches. This Energy Insight paper provides a short summary of these.

July 2022

Oxford Policy Management

UKaid
from the British people

Strategic energy planning is an essential input for effective policy and investment decision-making. It involves identifying a country's or region's future energy needs, and shaping broad pathways for meeting them in ways that satisfy goals such as energy access, energy security, climate action and environmental protection. The use of effective planning models and tools allows decision-makers to assess scenarios and policy choices in a comprehensive manner. Models make visible the inter-dependencies and trade-offs within the complex energy system. Models represent a stylised version of reality, designed to capture critical dimensions while being solvable within an analytical framework. However, models are an effective tool for decision-making if and only if they are built to address the particular concerns and priorities of the intended beneficiary. This note summarises the approaches used currently to integrate energy and economic modelling, and implications for decision-makers and modellers.

Traditional energy system models

Traditionally, modelling within the energy sector has focused either on specific aspects or overall energy system effects. For example, optimisation of electricity networks and power plant utilisation is typically analysed through detailed electricity dispatch models that simulate demand-supply requirements at a high frequency, e.g. hourly intervals, to assess the potential for integration of fossil fuels, renewables, electricity storage and other technology options. Dispatch models can also include estimates of electricity import and export potential, driven by costs and assumptions around external supply and demand. Likewise, models could be built specific to other sectors such as road transport, individual industrial sectors, irrigation, etc.

Energy system models seek to assess the evolution of the entire energy system at a defined geographic level, e.g. a country, region or indeed the world. Popular energy system modelling platforms include open-source tools such as TIMES and OSeMOSYS. They are bottom-up technology-rich models, anchored around detailed assumptions on the cost and availability of individual technologies, their potential to meet demand, the ability of individual technologies to utilise different fuels (i.e. fuel switching potential at a technology level), and availability and cost of each fuel. Fuel availability can be represented in energy system models 'exogenously' via cost curves (which assume availability of individual sources of supply at pre-specified cost levels) or 'endogenously' (where the model solves for individual supply production based on e.g. the cost of oil and gas extraction, the conversion of biomass into fuels or installation of solar photovoltaic cells). Energy system models can be combined with dispatch models for a more granular description of electricity generation. Importantly, the demand side is fixed at the level of energy 'service demands', e.g. the total requirement for heating, cooking, lighting, output from individual industries, transport, etc at each point in time. The model then optimises how each 'service demand' is met based on least-cost optimisation algorithms. For example, given a pre-specified distance that individuals are assumed to travel over a period of time, an energy system model will determine whether a conventional or electric vehicle best provides this (or even switching across different modes of transport), and what this may imply for diesel, petrol, gas and electricity production. Thus, an energy system model can help assess, e.g., what impact a change in transport policy or a carbon price may have on solar power generation needs and total electricity costs. However, the need to pre-specify fixed service demands means that energy system models are 'partial equilibrium models'. They assess how energy supply and demand are most cost effectively met, but not the feedback loops of how changes in this balance (and thus implied changes in the cost of energy) in turn affect demand or economic growth.

Soft linked energy / economy models

Modelling the interplay between energy and the economy can be achieved through different approaches. One option is to 'soft link' an energy system model and macroeconomic model. In this, the macroeconomy is described via an input-output (IO) model based on granular national statistics that include detail on each sector of economic activity, international trade, population (and potentially even income levels, urban/rural splits, occupation, skills levels, etc). The models are then linked firstly by determining the future scenarios in terms of service demand growth, available energy technologies, fuel supply side, etc. Such energy system model results are then exogenously imposed to the soft-linked IO model, which returns for all the years of the modelling horizon the results as described above. This is a 'demand-driven' approach: once different scenarios have been identified, the model returns the economic and environmental consequences with high physical details related to the energy technologies and fine time and space description. However, it remains a partial equilibrium approach: the interplay between energy and economic variables is assessed, but the level of economic activity or make-up of productive sectors within an economy does not change as a result of shifts in the energy system. It will be necessary for the model user to interpret the results and their plausibility, developing alternative scenarios to show how underlying economic activity may evolve and affect 'service demands' in turn. The benefit of such partial equilibrium 'soft linked' energy and economic models is interrogability of results. Because energy and economic effects are estimated in turn, it is possible to assess at each stage the mechanisms for change as well as barriers for the effectiveness of potential policy reform. Such a modelling approach thus allows the modeler to either assess the effect of an imposed change (e.g. a mandated level of renewable energy) or to solve endogenously for the required investment to achieve a policy objective (e.g. a carbon budget, or a desired change in employment).

Computable General Equilibrium Models

Computable General Equilibrium (CGE) models provide the ability to endogenously model the entire integrated energy and economic system, including all feedback loops. They require the neo-classical macroeconomic assumption of fully quantifiable 'utility functions' with estimated demand response coefficients (elasticities) to every price and economic parameter change. In other words, rather than being built bottom-up from a technology level, CGE models operate based on statistically estimated relationships between price (or cost) of inputs and the demand for such inputs (price elasticity), demand for other inputs (cross-price elasticity), levels of income (income elasticity) and the relationship to other economic variables. Once these relationships are specified, such models can estimate how, for example, the imposition of a limit on carbon emissions may cause a shift from cement making to other industrial activities or services, the effect on commodity prices, the resulting impact on employment and the demand for energy by fuel. CGE models are widely used to help forecast turning points in energy use and in commodity prices. The challenge is that the underlying data can be difficult to generate or might have to rely on global rather than country-specific coefficients (where national statistics are less advanced or new technologies have only just been introduced), and it ignores recent behavioural economic insights. Moreover, such models can easily become 'black boxes', with every optimisation occurring within the model and little ability to interrogate the overall driving factors or levers that policymakers need to consider. Nevertheless, they have been successfully applied to developing countries, for example in a study by the Policy Studies Institute (PSI) on impacts and drivers of policies for electricity access in Ethiopia (publication of paper forthcoming) under the UK Aid-funded Applied Research Programme Energy and Economic Growth (EEG).

New modelling approaches

New modelling approaches keep emerging, underpinned by technological advances and innovation by researchers. The latest approaches focus on spatial data, nexus issues such as around land-water-health-environment-energy, transition risk factors, scale, heterogeneity of actors and the existence of multiple equilibria. They comprise integrated, agent-based, non-linear and dynamic models among others. Artificial intelligence and machine learning remove boundaries of quantity and type of data, allowing the input of any quantitative or non-numerical as well as visual (e.g. satellite imagery) data. Some models even directly include political and social factors. For now, these so-called 'soft factors' require manual assessment, but innovation keeps pushing the boundary of possibilities.

Implications for decision-makers and modellers

There is no single 'right' model, but a suite of tools exists both on an open source and proprietary basis to empower decision-makers to understand the inter-dependencies, trade-offs and critical dimensions within the evolving energy system. The choice of modelling approach thus depends first and foremost on clarity of purpose of the specific questions and energy sector challenges to be understood. These must be defined upfront, so that models can focus on the critical aspects. Second, data must exist to populate models – with recognition of underlying data quality essential in determining the degree of accuracy, especially for more complex models. Moreover, tailoring models to specific needs requires skills, which may not exist sufficiently in all countries, particularly in developing countries. As a series of EEG webinars run by Oxford Policy Management concluded, it is vital that transparency, trust and skills are created through participation of decision-makers and local stakeholders in the modelling process. National or end-user ownership of models is key for longevity. This also defines the core elements of the Roundtable Initiative on Strategic Energy Planning, which works with major development partners and technical institutions to improve the support they provide for energy planning in developing countries. The key principles include: a) national ownership; b) coherence and inclusivity; c) capacity building; d) robustness; and e) transparency and accessibility. After all, it is the process of modelling through which trade-offs and levers are identified, tested and quantified such that the process is at least as valuable as the model result end-product.

About the author: Benjamin Klooss is a Principal Consultant at Oxford Policy Management and the Head of Research and Engagement for the Energy and Economic Growth Applied Research programme

Front cover image: poco_bw, iStock