Energy Models

Energy models characterize the energy system, its evolution, and its interactions with the broader economy. The energy system consists of primary resources, including both fossil fuels and renewable sources; electric power plants, refineries, and other technologies to process and convert these resources into secondary energy carriers such as electricity and gasoline; technologies such as furnaces and light-duty vehicles that use these energy carriers to meet demands for energy services; and end-use demands for services such as indoor space heating and personal transportation.

Attention to energy has increased with growing concern over global imbalances between the demand and supply of petroleum resources, as well as the need to mitigate global climate change and other environmental impacts related to energy use. Understanding the role energy plays in these concerns requires an awareness of how energy is produced and consumed, the price dynamics that mediate this relationship, and the physical systems that transform primary energy into secondary energy carriers and ultimately the services energy provides. Modeling frameworks from both economics and operations research provide analytical tools for characterizing the energy system and its evolution and find wide use in design, forecasting, scenario analysis, and similar applications. As the energy system is driven by region-specific patterns of resource availability, land use, technology deployment, and demand, energy modeling necessarily requires a geographic perspective. Likewise, spatially referenced energy models are useful for studying emissions related to climate change, infrastructure needs, land use, transportation, and other areas of interest in contemporary geography. This entry provides an introduction to energy models, first reviewing common analytical frameworks before discussing the importance of a spatial perspective.

Energy Modeling Frameworks

Unlike geologic models of petroleum reservoirs, assessments of single technologies, or statistical forecasts of demand, energy models characterize interdependencies between parts of a system or relationships between the energy system and the broader economy. The most commonly used energy models are dynamic, built around a mathematical optimization framework, and incorporate either classical economic theory or systems engineering principles. Outputs include technology choices, energy consumption, pollutant emissions, and marginal costs for energy resources, over time and by region.

Individual energy models differ in their representation of behavior (i.e., what is determined within the model endogenously rather than assumed exogenously), mathematical framework, economic focus, level of technological detail, and sectoral coverage, as well as in their geographic and temporal resolution and horizon. An important modeling distinction captures differences in the representation of economic feedbacks and technology detail. “Top-down” models adopt a macroeconomic perspective and balance the demand for and supply of resources, including energy, across sectors of the economy. The representation of technology in these models, however, tends to be very aggregate. The Second Generation Model provides an example of a top-down model with a substantial energy system focus. “Bottom-up” models, in contrast, downplay key economic feedbacks, such as the responsiveness of demand to changes in energy prices, in favor of a detailed representation of individual technologies. Partial equilibrium models such as MARKAL, for instance, focus primarily on the physical energy system and determine the least-cost mix of technologies needed to meet specified demands across sectors of the economy. In practice, advances in computational power are blurring the top-down, bottom-up distinction.

Energy models also differ in the interpretation of their results. Models such as MARKAL are optimization based and are therefore prescriptive in orientation. Results reflect what a rational, cost-minimizing decision maker should do, subject to constraints that capture how the energy system functions, as well as policies such as emissions caps that influence the use of resources and technologies. More descriptive frameworks include regional econometric and input-output (IO) models, as well as simulation models. System dynamics models such as the U.S. Department of Energy's FOSSIL2 and its successor IDEAS (Integrated Dynamic Energy Analysis Simulation), as well as LEAP (Long Range Energy Alternatives Planning System), provide examples of the latter.

Importance of a Spatial Perspective in Energy Modeling

Many energy models are capable of capturing regional differences in resources, transport costs, technology suitability, end-use demand patterns, policies, trading patterns, and other factors that drive energy production and use. Common geographic representations include administrative units such as national or state boundaries and census districts, or energy-system entities such as the North American Electric Reliability Corporation regions and Petroleum Administration for Defense Districts in the United States. Like the representation of time and technology, greater geographic resolution increases model run time, assumes that data are available at finer spatial scales, and compounds the assumptions needed for model calibration.

A spatial perspective, however, remains important for energy modeling. Input parameters, for instance, are often the product of detailed geographic information system (GIS) spatial analyses, even when aggregated up to a broader regional representation for model use. Likewise, GIS modeling provides a means to downscale and visualize results. Surrogates such as human populations, to give an example, may be used to disaggregate air pollutant emissions from model regions to a finer raster grid. Such applications involve soft coupling of GIS and energy system models. While GIS modeling provides a valuable tool for energy-related analyses, few examples exist of tightly linked GIS energy system models. The AIDAIR modeling framework, which has been used for integrated energy-environmental analyses of Geneva, approaches this ideal.

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Further Readings

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