Chapter 7
Multi-Scale, Multi-Dimensional Modelling of Future Energy Systems

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ABSTRACT

This chapter provides a discussion of current multi-scale energy systems expressed by a multitude of data and simulation models, and how these modelling approaches can be (re)designed or combined to improve the representation of such system. It aims to address the knowledge gap in energy system modelling in order to better understand its existing and future challenges. The frontiers between operational algorithms embedded in hardware and modelling control strategies are becoming fuzzier: therefore the paradigm of modelling intelligent urban energy systems for the future has to be constantly evolving. The chapter concludes on the need to build a holistic, multi-dimensional and multi-scale framework in order to address tomorrow's urban energy challenges. Advances in multi-scale methods applied to material science, chemistry, fluid dynamics, and biology have not been transferred to the full extend to power system engineering. New tools are therefore necessary to describe dynamics of coupled energy systems with optimal control.

BACKGROUND

Many countries around the world still rely heavily on conventional fossil and nuclear energy. Targets are now being set around the world to reduce greenhouse gas emissions (European Commission, 2014). Most carbon reduction scenarios rely on a combination of decarbonised supply and demand reduction to achieve the medium to long-term targets (GEA, 2012). In recent years, significant efforts worldwide at multiple layers, from individual energy systems to whole energy systems,

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and at different levels, from research to policy analysis, have been undertaken to analyse the integration of renewables into the system. Furthermore, inter-governmental and non-governmental institutions have proposed various scenarios to support energy policy makers. Table 1 provides a list with worldwide scenario studies carried out by a number of institutions covering a broad range of stakeholder groups and published recently in 2012-2013. Each scenario has diverse results in terms of energy use, technological efficiency and the energy resources mix, all having as a main goal to succeed global energy access, especially for developing countries, to reduce air pollution and tackle climate change while improving energy security worldwide.

To generate scenarios, energy models have been used. Since the early 1970s, a wide range of models to analyse energy systems and sub-systems have become available worldwide. Various approaches and tools are used: agent-based models; Geographic Information Systems (GIS) or system dynamics to name just a few. However, today, many energy system models are still based on linear approaches while system interaction is known to be the key. In addition, many engineering tools do not allow a thorough spatial definition of the systems. Granular 3D GIS data and GIS technology can add significant value to the modelling of energy systems. This is important because the multiple interacting systems in the urban context are not only connected through their spatial proximity but also through functional units (called virtual power plants).

By coupling dynamic models with GIS which allow for spatial analysis, data interpretation makes it possible to develop more coherent models that are both dynamic and spatially explicit. These advantages are widely discussed in literature. Jebaraj and Iniyan (2006) provide a detailed overview of a large range of energy models: supply-demand models, forecasting models, optimization models, neural-network models and emissions models covering 252 publications. Keirstead et al. (2012) provide an overview of urban energy system models covering 219 publications.

The different existing modelling techniques have various strengths, weaknesses, capabilities and applicability. By quantifying and predicting consumption patterns due to retrofits or technology evolution, they can act as technology incentives (Huang & Broderick, 2000; Aydinalp et al., 2002; Kadian et. al., 2007).

Energy models are applied to specific scales – a building, a district, a city or even a state. The detail needed for the interface is a combination of data availability, model purpose and assumptions. A detailed model allows for deeper analysis of end-use consumers and particulars. Accurate assumptions can make the modelling process easier and still provide reliable results. However, the accuracy of the results relies on input data and on the availability of information.

Some models have attempted to predict how energy flows might change over time (Summerfield et al., 2010). Significant advances have been seen in energy demand predictions for buildings (residential, commercial, industrial) as distinct categories and to estimate energy demand. In addition, significant efforts have looked at the energy supply side, where various models can be used to interrogate the evolution of renewables with GIS technologies.

Recently, the major trend has been to develop integrated and holistic models of the systems. Models can be classified in different ways, on different temporal and spatial dimensions, by application focus and simulation approach.

There are data-driven models such as MARKAL family models (Faraji-Zonooz et al., 2009) which represent the evolution over a period of usually 40-50 years of a specific energy system at national, regional or community level.

In addition to the aforementioned models, other types of energy models exist: econometric models which combine economic theory and statistical