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A review of energy systems models in the UK: Prevalent usage and categorisation

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HIGHLIGHTS

- We review UK academic and policy literature since 2008 on energy systems modelling.
- We find that nearly 100 models are referenced within academic literature.
- We propose a classification schema and define its suggested usage.
- The UK model landscape is considered and 22 models are classified within the schema.

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ABSTRACT

In this paper, a systematic review of academic literature and policy papers since 2008 is undertaken with an aim of identifying the prevalent energy systems models and tools in the UK. A list of all referenced models is presented and the literature is analysed with regards sectoral coverage and technological inclusion, as well as mathematical structure of models.

The paper compares available models using an appropriate classification schema, the introduction of which is aimed at making the model landscape more accessible and perspicuous, thereby enhancing the diversity of models within use. The distinct classification presented in this paper comprises three sections, which specify the model purpose and structure, technological detail and mathematical approach. The schema is not designed to be comprehensive, but rather to be a broad classification with pertinent level of information required to differentiate between models.

As an example, the UK model landscape is considered and 22 models are classified in three tables, as per the proposed schema.

1. Introduction

The problem of sustainable energy is naturally unique to each decision maker depending on their circumstances, which include geographical location, the sectoral coverage and available resources. Whilst the World Energy Council coined the phrase *energy trilemma* to describe the core challenges of sustainable energy, an on-going debate focusses around the United Nation's set 17 Sustainable Development Goals (SDGs), which replace the previous Millennium Development Goals and cover a broad range of sustainable development issues. Specifically, Goal 7 states "Ensure access to affordable, reliable, sustainable, and modern energy for all". This issue concerns the world as a global unit, though it tends to define the political debate of energy supply in individual countries or continents. With the growing concern of Climate Change [1], energy supply and demand has become an increasingly important issue.

Due to the increasing global demand for energy, as well as the strict emissions targets, actors within the energy system have to make complex decisions based on risk-based assessments about the future. Since the specific objectives vary amongst actors, there is a direct need for support tools which aid the decision making process around energy systems.

Owing to the complexity of the problem, scenario exercises have been developed in recent years, which can inform about possible future pathways, as well as defining and testing energy policy [2]. To aid quantification of scenario detail, especially in relation to trends and technological influence, energy systems models are often utilised. Such models simulate or explore the evolutionary response to disparate policies, which may be technological, economical or social. Accordingly, energy systems modelling is

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inherently inter-disciplined, involving social and geographical research as well as scientific and engineering disciplines.

The existing landscape of energy models is varied [3–5] and each model has its own unique blend of paradigms, techniques and solutions. There are several prominent models, which have been developed over many decades and which span wide topical areas. These include MARKAL (the MARKet ALlocation model) [6] and MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental impact model) [7], both of which have several variants aimed at increasing their functionality and applicability.

However, the total range of choices and variables in systems modelling is so vast (and sometimes disparate) that it is unlikely that one single model could (or perhaps should) incorporate them all at once. Taylor et al. acknowledge that "UK energy modelling has been described as in need of a broader range of analytical tools" and state that the predominant tool, MARKAL, might be replaced only "by a number of tools suited for related by different purposes" [8]. Indeed, a recent approach is to develop a "storyline" and incorporate several models with varying focii to achieve different objectives within one framework [9]. With such approaches emerging in the decision making process in energy systems, the choice of models or tools becomes pivotal.

This paper focusses on the prevalence of energy systems models within literature in the UK. In addition, models are compared side-by-side using a classification schema developed here. This schema is designed to be used as a decision support tool, for example to aid researchers identify gaps within the modelling field or to assist the wider range of actors in selecting models to investigate specific issues or questions. The overall objective of this work is to highlight the wide diversity of models already available and support decisions.

In Section 2, we perform a literature review and identify the predominant models utilised and topics of interest within the field. In Section 3, the introduction of a classification schema is proposed, which aims to categorise existing models and a broad, but detailed, classification schema is suggested in Section 4. A subset of models used within the UK are categorised in Section 5 with information valid as of May 2015.

2. The model landscape

Energy systems models were first designed after the 1970s oil crisis, with an objective of maintaining energy stability. At that time, there was a negligible variable generation component and limited option for storage technologies (which existed in the form of fuel supply). Instantaneous stability of the grid came through grid inertia of synchronous plants and spinning reserve capacity.

However, with the realisation of global climate change, the emphasis of models has moved towards environmental issues, including CO_{2e} emissions. From a modelling perspective, this has notable consequences: the addition of variable generation (solar PV and wind sources) has cost implications (new infrastructure, demand balancing, etc.) and there are longer-term issues related to technological change within the system. These modifications to the energy system are not necessarily easily reflected in existing algorithms, which may not have been designed to cope with variable generation sources.

The rapid changes in the energy market (with emerging technologies) have not always been mirrored in somewhat bulky energy models and the models which have been adapted can seem disjointed. Added to the fact that many comprehensive models have a tendency to be opaque (sometimes referred to as in-transparent) and inaccessible, the choice of models to use for specific scenarios is complex.

The full landscape of energy models accounts for the full range of actors (producers, generators, suppliers and end users), which in turn implies the inclusion of all energy sectors (electricity generation, heating, industrial usage, residential demand, transportation), economical aspects (costs, tariffs) and social aspects (policy, planning, risk, social practices/behaviours).

In addition to the broad purpose of models, there is a large set of mathematical approaches in the landscape. Models using optimisation and simulation techniques are plentiful, but are being joined by those utilising neural networks, agent-based modelling, complexity science and fuzzy theory [3,10,11].

2.1. Academic literature review

In order to identify the full and complex landscape of existing models and their uses within literature, the ScienceDirect search facility was utilised to select all papers since 2008 mentioning "energy systems model UK" (as four distinct words, not a phrase). The result of this search was over 1600 papers, though papers neither concerning the UK nor originating from the UK were removed. The product was 423 publications though the majority of these focus on energy efficiency measures (typically related to energy saving strategies within industrial buildings). The results shown in this section only relate to a subset of 110 papers, specifically related to energy systems modelling in the UK. It can be noted, however, that the main conclusions are broadly valid between both sets of publications.

The subset of 110 papers are disparate in their content and range from implementation of a single technology within the wider system context to the impact of policy decisions. Compelling reviews of the subject can be found in Allan et al. [12], Connolly et al. [13], Pfenninger et al. [4], Pilvachi et al. [14], and Strachan [15]. A review of the MARKAL model over the past 35 years is given by Taylor et al. [8] and a classification of techno-economic energy models is given in [16].

Reviews of the application or use of particular models or tools include: UK MARKAL with reference to bioenergy [17], hybrid modelling approaches (MARKAL-MACRO) [18], Marginal Abatement Cost (MAC) curves [19] and multi-criteria analysis for renewable energy technologies [20].

A whole energy systems approach has been taken by [21–23], whilst infrastructure networks are discussed in [24]. There is a plethora of literature around necessary infrastructure for hydrogen energy: a review of hydrogen studies is found in [25], the SHIPMod model is introduced in [26], spatial development studies are detailed in [27,28], hydrogen transitions are discussed in [29–31], the Scottish market is modelled in [32], potential benefits are promoted in [33] and an investment-led approach is developed in [34].

In contrast, some authors choose to focus on one or two single sectors, rather than a whole systems approach. Papers can be found which cover the oil and gas sectors [35–38], data centres [39], the transport sector [40–45] and domestic sector [46–52].

Smaller scale systems analysis is undertaken for micro-grids [53,54] and for urban or district scales [55–59]. The models used within these latter papers include VantagePoint, TURN and land-use transport models.

A range of long-term UK energy scenarios are presented in [60]. A review of UK and international scenarios is given in [2], whilst [61] discusses the predictive ability of existing scenarios against actual data. The impact of scenarios on policy have been discussed in [62]. Specific pathway development is discussed in [63–67]. An approach for linking storylines with multiple models is proposed in [9]. Direct uncertainties are discussed in [68,69] in relation to energy decarbonisation targets.