Market Mechanisms in Energy Systems Models: A Comparative Study

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Abstract

The objective of this thesis is to review and evaluate recent energy systems models (ESM) with regard to the specific modelling issues arising in conjunction with the upcoming energy transition. Accordingly, the main challenge for a sustainable energy generation in the future is the integration of a high percentage share in renewable energies within the present energy system. As the UK energy system faces the goal to attain an energy system with a renewable energy share of overall 15% until 2020, the ESM Calliope and EnergyPlan are used to implement future scenarios for the UK energy system. This case study leads to the results, that an expansion of photovoltaic (PV) and tidal energy yield to a possible solution approach in achieving this target. However, to attain a sustainable energy generation, energy systems have to constantly increase the renewable share to a large extent. Since the energy generation with renewables comes along with an increase in the variation in energy supply, further requirements on balancing these fluctuations arise. Within this thesis current ESM are set against each other with accordance to their inclusion of renewable energies. As a result, further potential for improvement on ESM arises with regard to the inclusion of determining optimal options in balancing the energy supply. Hence, this thesis evaluates several methods of compensation, such as energy storages, demand-side management, wind-hydrogen-electricity networks as well as the expansion of renewable energies. To conclude, energy planners have to consider these innovative methods of balancing energy supply particularly with regard to the future goal of a sustainable energy generation.

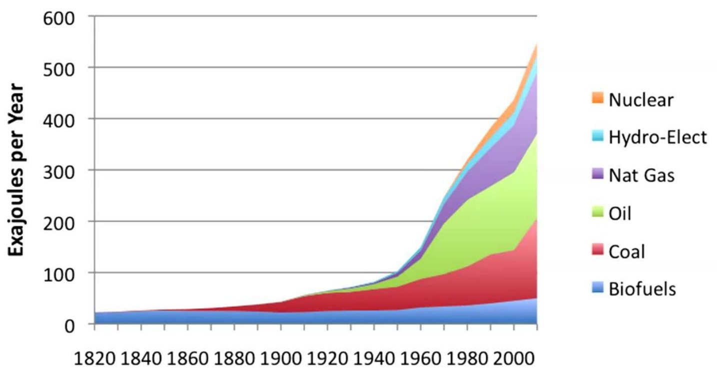
Keywords: Energy Systems, Energy Systems Models, Unit Commitment,
Renewable Energies, Energy Transition, Sustainable Energy

Contents

1 Introduction

Since the beginning of the 20th century the global energy consumption has increased significantly due to the ongoing technological development as well as the growth in population (Cf. Heitmann et al., 2005: 15). Moreover, the necessity for a sustainable energy generation arises as a fundamental precondition for economic growth within a highly industrialised economy (Cf. Berg, 2015: 6). The world energy consumption in 2014 was covered by fossil fuels with a share of 31%. According to Heitmann et al. (2005: 2) it can be assumed that in the coming decades the world population will increase to ten billion people. As a consequence, the energy consumption will increase by around three times.

Figure 1.1: World Energy Consumption.



Source: Diagram according to Statista.com (2016).

The economics of energy use and the cost of environmental control have turned into major political issues. Thereby, these matters are subject of extensive national and international debates and regulations. With this impact, a greater competition for energy supplies comes along and thus leads to tighter global energy markets (Cf. Zonooz et al., 2009: 352 ff.). With energy being a key element in the social and economic development of a nation, the generation of energy affects regional as well as global issues. Hence, generation of energy is part of today's political matters as well. Consequently, policy makers discuss the regulation of energy at a national and international level, as the importance of energy generation increases along with the growing demand of energy (Cf. Zonooz et al., 2009: 352 ff.).

1.1 Relevance

Not only to cover future primary energy consumption, but also to meet the continually growing demand in the interest of economic efficiency and environmental aspects, the share of renewable energy has been increasing constantly since the year 2000 (Cf. Heitmann et al., 2005: 2; Umweltbundesamt.de, 2016: 1). In particular, this can be traced back to the Kyoto Protocol, which was adopted in December 1997. Accordingly, all participating countries have committed themselves to contribute towards the reduction of CO_2 emissions. Throughout the climate agreement, the EU sets a binding target of 20% final energy consumption from renewable sources by 2020 over all member states (Cf. European Commission: 2017). These environmental measures can be faced in the context of sustainability through a reduction in CO_2 emissions. As a consequence, a reorganisation of conventional energy systems can be achieved by subsidisation of low-emission technologies. Primary, this reorganisation should yield to an increase in energy generation of renewable energy systems (RES), since most of the CO_2 emissions result from the energy generation with fossil fuels (Cf. Heitmann et al., 2005: 1).

1.2 Motivation

The main challenge for future energy generation is the conversion from an energy system primary depending on fossil fuels to an energy system that is composed of a high percentage share of RES. Hence, the integration of renewables plays a significant role when facing the issue of an environmentally compatible energy generation. The major challenge of future energy planning is to determine the potential of RES. According to that, detailed technical analyses are required in order to simulate energy systems such as RES. A further point to emphasise is the effect of RES on the other parts of the entire energy system. To capture these issues, the importance of computer tools arises to model an energy system as a whole (Cf. Connolly et al. 2010: 1060 ff.). Recent literature supplies a broad variety of so called energy systems models (ESM). Since the identification of the most suitable model is challenging, this work provides a comparison of current well-known ESM. Moreover, the primary focus is to emphasise possible solutions to achieve a 20% renewable energy share within the EU by 2020. Thereof, the UK faces the goal of achieving a 15% renewable share until 2020 (Cf. European Commission: 2017). Based on this example, the implementation of RES is examined in this work. Thereby, the ESM Calliope and EnergyPlan are used to simulate future options for an increase in renewable energy generation. Consequently, the focus of this work was centred on the following research question:

How are renewable energies considered by energy systems models and what potential for improvement arises?

1.3 Structure

The second chapter first describes the procedure of research design and analysis. After giving a brief definition of ESM, a literature review is made according to surveys of ESM as well as to a variety of recent ESM. Thereby, overall 18 ESM are compared regarding a variety of aspects such as their model structure, specific focus, mathematical description and resolution in time and space. The third chapter then provides a categorisation of ESM in general. The ESM reviewed in the second chapter are then classified according to overall three categories which represent different purposes of modelling. In the further analysis a selection of certain ESM is examined for each category separately. Afterwards, the fourth chapter examines three energy system models in closer detail. First of all, the ESM MARKAL as the possibly most widely used general purpose ESM is examined (Cf. Pfenninger et al., 2014: 76 ff.). In addition to MARKAL, the ESM Calliope as well as the ESM EnergyPlan will be presented in detail. These two open source models are then used in the fourth chapter to simulate the energy system of the United Kingdom (UK). The main goal of the case study is to provide future scenarios of the UK energy system which ensure a sustainable energy generation. Hence, the ESM Calliope and EnergyPlan are used to generate a high renewable share in energy generation. The effects on total costs as well as CO_2 emissions are then examined. Chapter 6.1 then provides a discussion of all ESM in general. Hereby, the following four challenges are discussed against each other: Data resolution and tractability, uncertainty and transparency, behavioural and social factors as well as complexity and optimisation across the scales. Out of these challenges, limitations as well as action recommendations for future ESM become apparent. The second part of the discussion then focuses on the case study. The simulation results of both models are compared to the actual UK energy system. Furthermore, both models are compared against each other. Finally, this work completes with a critical appraisal as well as a conclusion along with an outlook for potential in future improvements on ESM.

7 Conclusion and Outlook

In order to meet the worldwide increasing energy demand with an efficient and especially sustainable energy generation, optimisation models are required to simulate future options for energy systems. Hence, this study provides a review of recent ESM in order to compare and discuss them in the further analysis. As current energy systems face the goal of a sustainable energy generation in the future, the importance of RES increases. Since the generation profile of RES highly varies over time, the requirements on ESM change with regard to the future challenge to attain a sustainable energy future. Thus, ESM are discussed according to their inclusion of renewable energies.

On this occasion a case study was provided to apply certain ESM and to determine the inclusion of a high renewable share. The basis of the case study is the UK energy system, which pursues the target to achieve a renewable share of 15% in 2020. To implement future scenarios of the UK energy system the open source models Calliope and EnergyPlan were applied. Thereby, the impact of an increase in tidal and PV energy was determined in each of the model throughout several case scenarios. To sum up, the simulation with the EnergyPlan Tidal Scenario achieved a renewable share of 11%, whereas the Calliope Tidal Scenario determines 32% renewable share. Accordingly, both of the models provide possible solutions of how to get closer to the target of a 15% renewable share. The main statement of the case study is that the current energy system in the UK can be improved with an increase in PV energy. Moreover, it is recommended to continue research on the tidal energy generation as the inclusion of this technology provides potential to derive a sustainable energy generation.

The discussion examined several advantages and disadvantages of both, Calliope and EnergyPlan. In order to decide which model is more suitable depends on the specific modelling purpose. On the one hand, Calliope is an ESOM, which provides a more detailed simulation according to the resolution in space. Whereas on the other hand EnergyPlan provides high computational tractability. When comparing recent ESM according to the inclusion of renewables, further challenges in modelling energy systems arise. As the future energy generation will be based on a high renewable share an increased variation of energy supply has to be balanced. On this occasion further improvement on ESM arises with regard to derive best options in balancing these upcoming issues. Thus, ESM have to model energy storages more realistically. A further option to balance the variation on renewables is given by the demand-side management. Hence, this method is a further aspect to be taken into account for improvement on ESM. Beside these issue other methods such as wind-hydrogen-electricity networks and the compensation of variation in energy generation through expansion were discussed. All of these approaches build potential ways to compensate the variation in future energy generation with a high renewable share. Accordingly, future ESM have to be extended by these options in order to calculate the optimal interplay of these methods to balance the energy supply. As a consequence of the upcoming energy revolution, the modelling of energy systems represents one of the major challenges of the 21st century. Also with regard to an increasing importance of sustainability and the growth in the worldwide energy demand, energy planners have to adjust the current energy system to innovative approaches of energy generation.