Energy 111 (2016) 956–970

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Context scenarios and their usage for the construction of socio-technical energy scenarios

Wolfgang Weimer-Jehle [a,*], Jens Buchgeister [b], Wolfgang Hauser [a], Hannah Kosow [a], Tobias Naegler [c], Witold-Roger Poganietz [b], Thomas Pregger [c], Sigrid Prehofer [a], Andreas von Recklinghausen [b], Jens Schippl [b], Stefan Vögele [d]

[a] *ZIRIUS, University of Stuttgart, Seidenstr. 36, 70174 Stuttgart, Germany*
[b] *ITAS, Karlsruhe Institute of Technology, Karlstrasse 11, 76133 Karlsruhe, Germany*
[c] *ITT-STB, German Aerospace Center (DLR), Pfaffenwaldring 38-40, 70569 Stuttgart, Germany*
[d] *IEK-STE, Research Center Jülich (FZJ), Wilhelm-Johnen-Straße, 52428 Jülich, Germany*

ARTICLE INFO

Article history:
Received 18 March 2015
Received in revised form
15 May 2016
Accepted 20 May 2016

Keywords:
Energy scenario
Energy modeling
Cross-impact balance analysis
Socio-technical scenario
Context scenarios

ABSTRACT

Model-based energy scenarios are a widely used tool for supporting economic and political decision makers. The results of energy modeling and the conclusions deduced therefrom, however, depend on the model input data derived from framework assumptions about future developments in the embedding society, which are deeply uncertain in the long term. The challenge to deal with this 'context uncertainty' in a systematic and comprehensive manner has only recently started to attract intensified attention in energy research; the search for appropriate methods is ongoing. This paper proposes a new concept for the construction of socio-technical energy scenarios, which combines familiar environmental modeling approaches with new developments in qualitative scenario methodology, and demonstrates the possible application of the concept in model-based energy scenario construction.

1. Introduction

These days, model-based energy scenarios are a well-established practical tool informing public debates, corporate decision makers and policy advisors about possible futures, options, and policy effects [1]. Traditional energy scenarios achieve this by focusing on the technical and energy-economic dimensions of the future describing the deployment of techniques, changes in energy demand and supply, in emissions, in supply costs and the like. Determinants of the energy future located outside the immediate energy system, such as demographic and economic developments, innovation dynamics, changes in public attitudes, social values and consumer behavior are, despite their deep uncertainty in the long term, mostly treated as fixed framework assumptions. On the other hand, the pronounced influence of the framework assumption on model results is well known to energy modelers [2]. This begs the question how much reliability can be expected from results and the conclusions derived therefrom, bearing in mind that they critically depend on deeply uncertain assumptions – if these uncertainties are not adequately dealt with.

Adequately dealing with the 'context uncertainty' in energy modeling, however, is not an easy task. It requires an uncertainty assessment for each relevant framework assumption, while taking into account the interdependences between the various context developments. All this needs to be done in a broad field of research questions, which transcends disciplinary boundaries, at the same time also including qualitative forms of knowledge. Basically this means beginning the exercise of constructing *energy* scenarios with an effort, aimed at providing a better understanding of the range of

* Corresponding author.
E-mail addresses: wolfgang.weimer-jehle@zirius.uni-stuttgart.de (W. Weimer-Jehle), jens.buchgeister@kit.edu (J. Buchgeister), wolfgang.hauser@zirius.uni-stuttgart.de (W. Hauser), hannah.kosow@zirius.uni-stuttgart.de (H. Kosow), tobias.naegler@dlr.de (T. Naegler), poganietz@kit.edu (W.-R. Poganietz), thomas.pregger@dlr.de (T. Pregger), sigrid.prehofer@zirius.uni-stuttgart.de (S. Prehofer), andreas.von.recklinghausen@mailbox.org (A. von Recklinghausen), jens.schippl@kit.edu (J. Schippl), s.voegele@fz-juelich.de (S. Vögele).

http://dx.doi.org/10.1016/j.energy.2016.05.073
0360-5442/

possible futures of the *society* into which the energy system is embedded. Furthermore, to do justice to the scientific character of the subsequent energy systems analysis, this preparatory step should be systematic and meet minimum standards of transparency, traceability, and intersubjectivity (if objectivity cannot be achieved) – criteria that are not easily fulfilled in the construction of qualitative societal scenarios.

This article describes an approach to better address the uncertainty of societal framework assumptions in energy modeling and the socio-technical character of energy transitions. The ‘context scenario’ approach was developed in the years 2011–2014 as part of the research alliance ENERGY-TRANS, a platform for interdisciplinary research activities dealing with the socio-technical aspects of the German energy transition (‘Energiewende’) [3].

Scenarios, including energy scenarios, can assume different roles in foresight exercises and this diversity has its impacts on the role and usefulness of the proposed context scenario approach. Börjeson et al. differentiate between ‘predictive’ (e.g. what-if), ‘explorative’ and ‘normative’ scenarios [4]. The most pronounced effect of the proposed approach can be expected in the case of explorative energy scenarios which deal with the question ‘*what may happen?*’ because, obviously, a comprehensive answer to this question must exceed the closer energy system and put the same question also to the major drivers of the energy system. Hence, this case is the focus of this article. This does not mean, however, that the context scenario approach is not relevant for other types of energy scenarios: In ‘*what-if* scenarios’ (*if-then* scenarios) the ‘if’ condition usually is restricted to a small part of the model's input data set (for instance, a specific economic development or a specific political action), excluding the wide range of all other drivers. This means that the *if-then* answer constructed by the model may well critically depend on the assumptions about the excluded drivers, a fact challenging the robustness of the *if-then* analysis, when done in a traditional model-only style. Normative (‘*what should happen*’) scenarios, on the other hand, are bound to a desired final state and not open to variations in this respect. Nevertheless, they may be open to the question which pathways to the final state might be advisable or simply feasible under different framework conditions. Hence, the context scenario approach should be, to varying degree, relevant for all types of energy scenarios.

The relevance of the context scenario approach depends also on the type of energy model employed in the scenario exercise. In energy systems analysis a bunch of different types of models exist. The most common are techno-economic models, like TIMES PanEU [5]. Furthermore, economic models, like computable or applied equilibrium models (e.g. GTAP-E, see Ref. [6]), agent-based models and systems dynamics could be named. Generally spoken, the proposed approach should be useful for all model types in which the model is driven by a non-trivial set of uncertain and interrelated exogenous assumptions. This is typical for techno-economic and economic energy models. To which extent this applies also to agent-based models and system-dynamic energy models depends on the set-up of the model exercise.

The following chapters describe the motifs and the inspiration the authors took from climate change research and other research fields. The concept of context scenarios is outlined and its usage for the construction of socio-technical energy scenarios is shown using a demonstration exercise. Finally, strengths and limitations of the concept are discussed.

2. Motivation

To generate future energy system pathways, a great number of assumptions have to be defined, which are ex- and implicitly taken into account in the model, e.g. concerning demographic development, gross domestic product (GDP) growth, increases of energy efficiencies and many others (see e.g. Ref. [2] and appendix Table A1). All of these assumptions are associated with considerable uncertainty when it comes to long-term scenarios, and they imply an assessment and interpretation of current knowledge. This interpretation – which is always a part of the scenario generation process and usually not fully transparent – leads to a selection of exogenous techno-economic, political, and societal factors, together building a certain story about the future of the embedding society on the one hand and to the neglect of other possible assumptions and underlying stories on the other hand. One example are the assumptions on population growth included in International Energy Agency (IEA) studies: the IEA energy scenarios [7] are based on data published by United Nations Population Division (UNPD) [8]. UNPD analyzed different scenarios on population growth based on different societal development pathways. However, IEA – following a very common procedure – only used the data for the medium case, ignoring that this case reflects only one possible option. As a result, the scenarios published by the IEA might only reflect a very restricted spectrum of possible developments. Other examples often cited are GDP development and the derived assumptions about energy demand, and sensitive assumptions relating to fossil fuel prices, technology costs and CO_2 emission costs. This focus on *one* set of assumptions and *one* underlying story as a starting point for the model analysis may cause an unwise **limitation of the bandwidth/variety of derived energy scenarios** that is considered as possible even if sensitivity analysis is applied to test the influence of some of the assumptions.

Furthermore, a sound choice of assumptions in different fields (demography, economy, technological progress and others) requires careful consideration of the complex interdependencies between developments in all these fields, or as IEA put it “Key drivers of energy markets are hard to predict, in part because they interact with each other” [9]. This cross-disciplinary effort frequently lacks documentation in the scenario studies (if done at all) and a **lack of internal consistency** cannot be ruled out in such cases.

Internal consistency among (mathematically related) numerical assumptions can be managed more easily using quantitative approaches than qualitative approaches. However, quantitative approaches – usually used for energy scenarios – have the disadvantage that those factors that cannot be expressed in numbers are either more or less ignored, or set implicitly as constant. This may limit the suitability of existing scenarios and scenario studies for a broader range of research questions (see e.g. Ref. [10]). All of the exogenous factors employed as drivers in the model analysis, not to mention any endogenous factors (often calculated by cost optimizing objective functions) are based on various societal assumptions such as behavior patterns, attitude to technical changes, or public acceptance. Usually these are either only included implicitly, or are simply ignored in energy scenarios (cf. appendix Table A1). The results are **conclusions that risk being of limited robustness** and consistency.

One striking example of how far energy models can mislead when the stability of the societal and political environment is overrated, was highlighted by Mai et al. They described the repeated and pronounced underestimation of U.S. wind turbine deployment by energy models in the period 2001–2009, explained partly by static policy assumptions in a dynamic socio-political context [11].

Compared to common practice, a methodology that combines a quantitative approach, where possible, with a more explicit appraisal and a deeper analysis of societal assumptions should result in a far better understanding of transition processes, as well as the risks and robustness concerning possible developments in