

# Sectoral Demand Modeling in German Long-Term Energy Scenarios

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## Abstract:

**Keywords:** energy system modeling, long term energy system scenarios, energy demand representation

## 1 Introduction

Long-term energy system scenarios play a crucial role in exploring viable transformation pathways, evaluating trade-offs between various system design options, and assessing sensitivities to cost trends or other boundary conditions. Because quantitative outcomes might be heavily influenced by specific modeling approaches and parameter choices, transformation studies typically analyze multiple scenarios to derive robust insights that extend beyond the results of individual models. However, this requires comparison of scenarios derived from different models, often applying diverging methodological decisions and parametrization choices.

Informed comparison of scenarios is made possible by the comprehensive documentation and sharing of modeling assumptions, parameter settings, and complete input and output data. However, even when such information is provided for individual studies or projects, discrepancies in the scope, format, and level of detail of the data are common and make the comparison process tedious and time consuming [1]–[3]. Initiatives such as the *Open Energy Platform* and the *NFDI4Energy* consortium, particularly through one of its use cases, aim to address these challenges [4], [5]. While it has become common standard to publish techno-economic input parameters (investment costs or fuel prices, for instance) and supply-side output data (capacity expansion values or generation mixes, for instance) as a supplement of studies, the demand side of the modeling process is often not well documented.

Recently there has been a growing body of literature emphasizing demand side options of the energy transition [6]–[8]. Although these studies address potentially reduced energy demand from various perspectives, they do not focus on the conceptual implications of the demand side models themselves. However, knowledge of the internal structure, scope and differentiation between what is an input and what is an output of models is vital to enhancing transparency and understanding the variations in results. Since the outputs of the sectoral demand models are coupled or provided as an energy demand input to Energy System Optimization Models, underlying modeling choices influence the cost-efficient design of the final energy system. To address this issue, in this contribution, we focus on a subset of scenario information, the demand side models and the representation of societal and political factors within them [9], [10].

## 2 Methods

We performed a meta-analysis of selected long-term energy system scenarios for Germany. The reviewed sources include grey literature as well as peer reviewed articles that matched the scope. Grey literature was included since several influential studies are published by large institutions such as the German Federal Ministry for Economic Affairs and Climate Protection, think tanks such as Agora Energiewende and various research institutes, and accordingly are not published in scientific journals due to their broad scope. However, in the discourse of the "informed public" on this topic, especially the reports issued by these institutional actors are important due to their influence on the political debate. For the literature review, we focused on the scope of the model and which parameters actually drive energy demand. Scientific Papers were included if they matched the geographical scope, e.g Germany, and also included all demand sectors. We used Google Scholar, WebOfScience and snowball searching to identify papers that matched these criteria. Search terms that were used are *TS=("Energy System Model") AND TS=Germany AND PY=(2018-2024)*. This resulted in 37 papers of which 15 matched the geographical (Germany), temporal (transformation pathways until 2050) and thematic scope.

For each study, we analyse the study report, supplementary material, provided data and modelling documentation to identify representations of societal and political factors in the demand models. To structure and collect this information, preliminary categorizations based on [11]–[13] and annotations are applied and requirements for an extension of the already existing Open Energy Ontology (OEO) are identified [14]. Additionally, based on this analysis, we derive requirements for an improved structure of the model database of the OEP [15].

## 3 Conclusion

The meta-analysis of energy system studies for Germany indicates that the demand side is often underrepresented both in the modeling process and in the documentation of parameters and methodological concepts. Societal and political factors are potentially over-simplified within demand models, and associated assumptions and their influence on model results not clearly discussed. Through lack of transparent documentation, in particular for the underlying models and their coupling, it might not be clear what exactly is an endogenous, and what is an exogenous factor, and which are inputs and outputs of submodels. These gaps underscore the importance of improving documentation practices and integrating demand-side considerations into broader energy system modeling frameworks.

Our findings demonstrate that while significant progress has been made in documenting supply-side parameters, demand-side modeling remains under explored, with methodological details often inconsistently reported or omitted entirely. Addressing this disparity is vital, as demand-side outputs directly influence the dimensions and costs of energy systems designed to meet future needs. This perspective should also be integrated in the ongoing development of the Open Energy Ontology (OEO), and in the development of enhancements to the model database of the Open Energy Platform (OEP) to better capture demand-side structures.

Looking ahead, we recommend that future research puts the systematic documentation of demand-side models on an equal footing to the discussion of techno-economic parameters and supply-side system data, particularly regarding societal and political

factors that drive energy demand. Such efforts will not only enhance transparency but also enable more robust scenario comparisons and foster a deeper understanding of the drivers and barriers to energy system transformation. By aligning methodological practices with these goals, the energy modeling community can better support policy-makers and stakeholders in navigating the complexities of the energy transition.

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