

# Representation of societal and political factors in long-term energy system scenarios

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## Abstract:

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## 1 Introduction

Long-term energy system scenarios provide important information about feasible transformation pathways, trade-offs between different system design choices, or sensitivities on cost developments or other boundary conditions. Since individual quantitative results generally depend on modelling choices and specific parameter settings, transformation studies often do not limit their investigation to a single scenario, but compare different scenarios to infer robust findings beyond single modelling outcomes [1], [2]. The *Ariadne* project, for instance, applies several sectoral and system models to investigate a range of scenarios, which follow different narratives like a focus on electrification or hydrogen imports [3]. Similarly, also the project *Langfristszenarien* emphasizes the value of comparing different scenarios in their study [4]. More general review approaches extend such scenario comparisons by synthesizing and evaluating findings from various studies. The project *Energy Systems of the Future*, for instance, combined own modelling, expert consultations and a detailed scenario comparison to identify options for action for the German energy system transformation [2], whereas in [5] key strategies for the transition to climate neutrality in Germany were identified from a scenario meta-analysis across various studies.

Such scenario comparisons are facilitated by a thorough documentation and publication of modelling choices and assumptions, parameter settings and full input and output data [6], [7]. Nevertheless, even if such information is provided by the individual projects or study authors, the extent, format and details of the data might differ. This issue is addressed by projects like the *Open Energy Platform* or the current *NFDI4Energy* consortium in one of its use cases [8]–[11]. In this contribution, we focus on a particularly challenging subset of scenario information, the representation of societal and political factors [12]–[14].

## 2 Methods

Many techno-economic input parameters and modelling results like final energy demand, renewable generation capacities or cost assumptions occur in similar form across different models and scenario studies. Although exact definitions might differ, these similarities facilitate the comparison and the integration of techno-economic parameters into comprehensive databases. In contrast, societal and political parameters can be featured very differently, including actual numerical values, sectoral model mechanisms or scenario narratives without specific model representations. Issues of social acceptance with respect to wind power expansion, for instance, could be represented by a reduction of available land of certain type, an overall limit of installed capacity, limited expansion rates, or through dedicated mechanisms in the system modelling. Similarly, energy demand for car use could be an abstract energy demand extrapolated from historical values, could be based on population data, individual distance travelled and availability of different transportation options, or could be the result of a sector model which factors in cost developments for different mobility options and availability of certain infrastructures.

We approach this issue through a meta-analysis of selected long-term energy system scenarios for Germany. The focus is on system studies, which do not only integrate the energy supply sector, but also energy demands, flexibility options or technological developments in the building, industry and mobility sector. 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 modelling assumptions, scenario narratives, parameter settings or interpretation of study results. To structure and collect this information, preliminary categorizations and annotations are applied and requirements for an extension of the already existing Open Energy Ontology (OEO) are identified [10].

## 3 Results and conclusion

Preliminary results indicate the need for establishing suitable terms in the Open Energy Ontology for the representation of societal and political factors in long-term energy system scenarios. Whereas time series or techno-economic parameters and results often could be (and often are) structured in tabular form, the variability of these parameters suggests the use of more flexible concepts based on ontologies and the Open Research Knowledge Graph (ORKG) [15]. One challenge of such a representation is to assure that the information is accessible for a wide range of target groups, ranging from expert energy system modellers extracting specific parameters or modelling concepts to researchers from other disciplines seeking information about the narratives and assumptions in such scenarios. The interdisciplinary consortium NFDI4Energy thus provides an ideal research environment to establish methods and databases to facilitate access to such information, both for already existing studies and future investigations.

### Author contributions

Conceptualization, R.L.G., M.S., R.Q., A.W.; methodology, R.L.G., M.S., R.Q. writing—original draft preparation, R.L.G., M.S.; writing—review and editing, R.L.G., M.S., R.Q., A.W., J.L., F.M.H., N.K., C.S.; supervision, C.W., A.W.

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## Competing interests

The authors declare that they have no competing interests.

## References

- [1] F. M. Hoffart, E.-J. Schmitt, and M. Roos, “Rethinking economic energy policy research—developing qualitative scenarios to identify feasible energy policies,” *Sustainable Development of Energy, Water and Environment Systems*, vol. 9, no. 2, p. 1 080 331, 2021. DOI: [10.13044/j.sdewes.d8.0331](https://doi.org/10.13044/j.sdewes.d8.0331).
- [2] M. Ragwitz, A. Weidlich, D. Biermann, et al., *Szenarien für ein klimaneutrales Deutschland. Technologieumbau, Verbrauchsreduktion und Kohlenstoffmanagement*, Schriftenreihe Energiesysteme der Zukunft, München, 2023.
- [3] Kopernikus-Projekt Ariadne, *Ariadne-Report: Deutschland auf dem Weg zur Klimaneutralität 2045 - Szenarien und Pfade im Modellvergleich*, 2021. DOI: [10.48485/pik.2021.006](https://doi.org/10.48485/pik.2021.006).
- [4] Fraunhofer ISE, Consentec, ifeu, and TU Berlin, Fachgebiet Energie- und Ressourcenmanagement, *Langfristszenarien 3. Wissenschaftliche Analysen zur Dekarbonisierung Deutschlands*, 2022. [Online]. Available: [www.langfristszenarien.de](http://www.langfristszenarien.de).
- [5] F. Wiese, J. Thema, and L. Cordroch, “Strategies for climate neutrality. Lessons from a meta-analysis of German energy scenarios,” *Renewable and Sustainable Energy Transition*, vol. 2, p. 100 015, 2022. DOI: [10.1016/j.rset.2021.100015](https://doi.org/10.1016/j.rset.2021.100015).
- [6] M. M. Dekker, V. Daioglou, R. Pietzcker, et al., “Identifying energy model fingerprints in mitigation scenarios,” *Nature Energy*, vol. 8, no. 12, pp. 1395–1404, 2023. DOI: [10.1038/s41560-023-01399-1](https://doi.org/10.1038/s41560-023-01399-1).
- [7] C. v. Hirschhausen, B. Steigerwald, F. M. Hoffart, C. Kemfert, J. Weibezahn, and A. Wimmers, “Energy and climate scenarios paradoxically assume considerable nuclear energy growth,” *DIW Weekly Report*, vol. 45/49, pp. 293–301, 2023. DOI: [10.18723/DIW\\_DWR:2023-45-1](https://doi.org/10.18723/DIW_DWR:2023-45-1).
- [8] M. Schäfer, R. Qussous, L. Hülk, J. Lilliestam, and A. Weidlich, “NFDI4Energy Case-Study: Comparative Analysis and Visualisation of Long-Term Energy System Scenarios,” in *Proceedings of the Conference on Research Data Infrastructure*, vol. 1, 2023.
- [9] L. Hülk, B. Müller, M. Glauer, E. Förster, and B. Schachler, “Transparency, reproducibility, and quality of energy system analyses—a process to improve scientific work,” *Energy strategy reviews*, vol. 22, pp. 264–269, 2018.
- [10] M. Booshehri, L. Emele, S. Flügel, et al., “Introducing the open energy ontology: Enhancing data interpretation and interfacing in energy systems analysis,” *Energy and AI*, vol. 5, p. 100 074, 2021.
- [11] K. Reder, M. Stappel, C. Hofmann, et al., “Identification of user requirements for an energy scenario database,” *International Journal of Sustainable Energy Planning and Management*, vol. 25, pp. 95–108, 2020.

- [12] C. Speck, P. Jaquart, C. Weinhardt, *et al.*, “Transparency and involvement of society and policy in a data sharing platform,” in *Proceedings of the Conference on Research Data Infrastructure*, vol. 1, 2023.
- [13] M. O. Dioha, M. Montgomery, R. Almada, P. Dato, and L. Abrahams, “Beyond dollars and cents: Why socio-political factors matter in energy system modeling,” *Environmental Research Letters*, vol. 18, no. 12, p. 121 002, 2023. DOI: [10.1088/1748-9326/ad0a54](https://doi.org/10.1088/1748-9326/ad0a54).
- [14] F. M. Hoffart, “What is a feasible and 1.5°C compatible H2 infrastructure for Germany? A multi-criteria economic study based on socio-technical energy scenarios,” *Ruhr Economic Papers*, no. 969, pp. 1–38, 2022. DOI: [10.4419/96973144](https://doi.org/10.4419/96973144).
- [15] S. Auer, “Towards an Open Research Knowledge Graph,” Zenodo, Jan. 22, 2018. DOI: [10.5281/zenodo.1157185](https://doi.org/10.5281/zenodo.1157185). [Online]. Available: <https://zenodo.org/record/1157185> (visited on 10/04/2023).