

Adapted Ontology Development Process: A Co-Simulation Scenario Ontology for Energy Systems

Jan Sören Schwarz^{1,2,*} , Philipp Schmurr³ , Corinna Seiwert⁴ ,
Zhiyu Pan⁵ , and Ramiz Qussous⁶ 

¹Carl von Ossietzky Universität Oldenburg, Department of Computing Science, [ROR](#), Oldenburg, Germany

²OFFIS, Institute for Information Technology, [ROR](#), Oldenburg, Germany

³Karlsruhe Institute of Technology, Institute for Automation and Applied Informatics, [ROR](#), Karlsruhe, Germany

⁴Friedrich-Alexander-Universität Erlangen-Nürnberg, [ROR](#), Chair of Computer Science 7 (Computer Networks and Communication Systems), Erlangen, Germany

⁵RWTH Aachen University, [ROR](#), Institute for Automation of Complex Power Systems, Aachen, Germany

⁶University of Freiburg, INATECH, [ROR](#), Emmy-Noether-Str. 2, 79110 Freiburg im Breisgau

*Correspondence: Jan Sören Schwarz, schwarz@offis.de

Abstract. We present our development of a co-simulation scenario ontology that provides a semantic framework for describing, sharing, comparing, and executing simulation scenarios, thereby enhancing interoperability and reproducibility. The ontology is created through a structured development process following the Linked Open Terms methodology.

Keywords: Co-Simulation, Ontology, Simulation Scenario, Linked Open Terms, Open Energy Ontology

1. Introduction

Co-simulation is a central methodology for the development and analysis of complex multi-domain energy systems supporting the transition toward a sustainable energy future. It enables the investigation of complex scenarios based on diverse, specialized simulation models. In a previous publication, we presented the concept for a co-simulation scenario ontology developed within NFDI4Energy, which aims to provide a semantic framework for managing co-simulation scenarios to improve interoperability, reproducibility, and integration into simulation services [1], [2]. This ontology establishes a common base for scenario description and demonstrates initial integration with NFDI4Energy services such as the Simulation-as-a-Service (SimaaS) hub [3] and the assisted creation of simulation scenarios based on a model registry. These integrations aim to support the user in the whole process from finding suitable simulation components to developing the simulation scenario and executing the simulation potentially on provided infrastructure.

The simulation services of NFDI4Energy will be presented with three reference co-simulation frameworks. *VILLASframework* focuses on distributed real-time co-simulation and integration of hardware devices [4], *DaceDS* uses a publish-subscribe middleware approach for co-simulation [5], and *mosaik* focuses on flexible Python-based scenario creation [6]. All three frameworks have different focuses and architectures and together represent a broad range of co-simulation use cases for energy systems.

In the following sections, we describe our process for the development of the co-simulation scenario ontology in Section 2, present examples of our implementation in Section 3, and offer a conclusion and an outlook on the next planned steps in Section 4.

2. Ontology Development Process

For the development, we followed the Linked Open Terms (LOT) methodology [7] which distinguishes four main steps: *requirements specification*, *implementation*, *publication*, and *maintenance* of ontologies. The requirements specification for the co-simulation scenario ontology was already described in [1]. One outcome was a list of relevant terms for the description of simulation scenarios and we decided to integrate the simulation scenario ontology into the Open Energy Ontology (OEO). Because we didn't start with a new ontology, not all parts of the LOT were relevant. The steps of publication and maintenance are mostly covered by the existing infrastructure of the OEO. In the following we will focus on the implementation step, which is subdivided in the LOT into ontology *conceptualization*, *reuse*, *encoding*, and *evaluation*. We describe our process and map it to those sub-steps (see Figure 1).

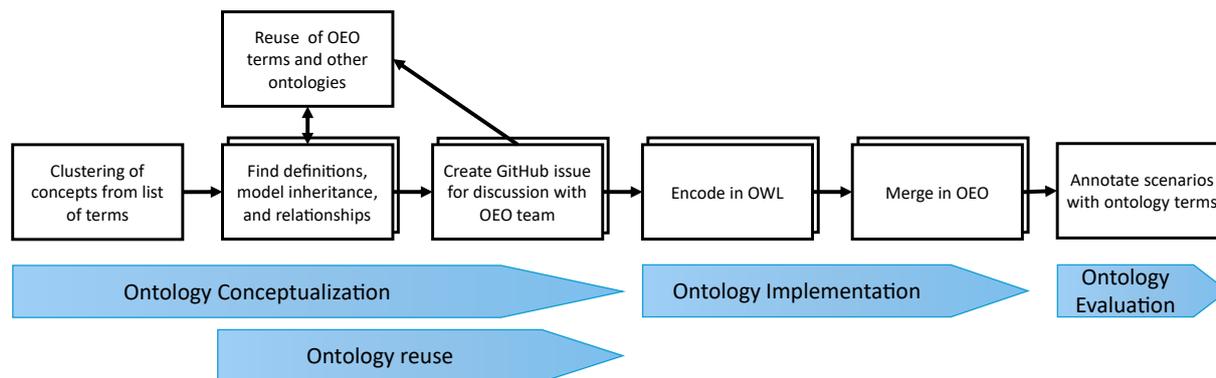


Figure 1. Overview of the ontology implementation process and alignment with the LOT methodology (blue arrows).

We collected crucial terms and concepts for describing co-simulation scenarios during the requirements engineering step based on the three reference frameworks and external existing ontologies [1], [8]. Everything was collected in a Conceptboard, which is an online visual collaboration platform that provides a shared whiteboard where teams can brainstorm, sketch, annotate, and organize ideas collaboratively in real time. Although the LOT methodology proposes strict tooling and clear notation for ontology concepts at this step, we decided to use this more flexible tool to enable collaboration and to involve individuals without extensive ontology modeling experience. After collecting terms, we clustered them into different concepts based on our discussions and began for each of the concept cluster to transform them into a more ontology-compliant form. We therefore selected a definition and a potential parent class for each term and added connections between the different terms, which can represent *is_a* relationships as well as other object properties.

Because we decided to integrate our concepts into the OEO [8], [9], which is based on the Basic Formal Ontology (BFO) [10], we had to map our concepts onto the existing class hierarchy.

We also sought to reuse existing classes from the OEO when possible. We documented finalized concepts in GitHub issues and discussed them with the OEO developer team to obtain feedback for further refinement. Approved concepts were then encoded in OWL and added to the OEO-model module. For the evaluation, we use the ontology to annotate scenarios of the three frameworks.

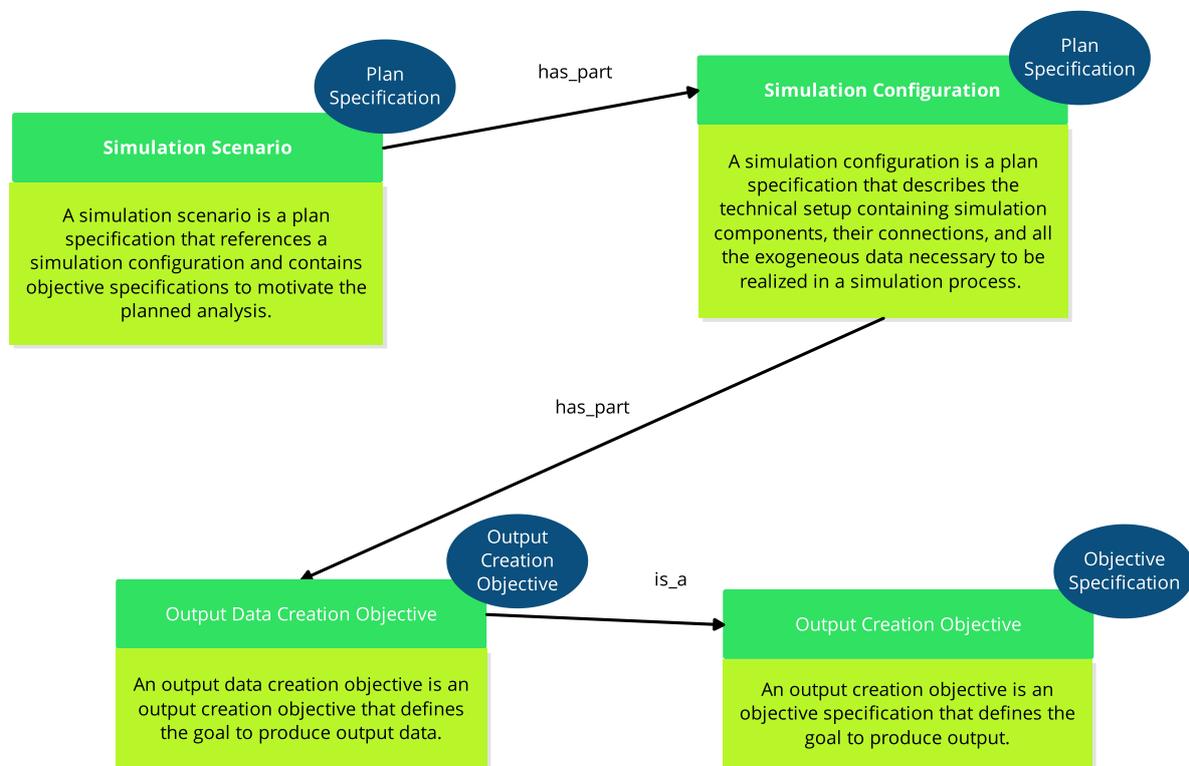


Figure 2. Simulation scenario concept modeled in Conceptboard.

3. Example: Simulation Scenario

As an example, the concept of a simulation scenario is presented in this section, with an overview given in Figure 2. The green boxes represent the label of a class and its definition and the blue ellipses stand for the parent class. Arrows between the boxes are modeled as object properties.

Although the OEO already includes the class `scenario`, its definition emphasizes future narratives, whereas a simulation scenario, while also involving assumptions about the future, primarily specifies a concrete simulation and all requisite components for its execution. Accordingly, we chose `plan specification`, which originally comes from the Information Artifact Ontology (IAO), as the parent class for simulation scenario. It is defined as follows: *a directive information entity with action specifications and objective specifications as parts, and that may be concretized as a realizable entity that, if realized, is realized in a process in which the bearer tries to achieve the objectives by taking the actions specified* [11]. The definition contains many terms from the BFO and we cannot explain all of them in detail here, but we focus on some of them. We decided to model only the mentioned `objective specifications` and not the `action specifications`, as this is not the focus of our work for now. One crucial part of a simulation scenario is the objective of the analysis, which will be conducted based on the simulation results.

To represent the more technical part of a simulation scenario, we defined the term `simulation configuration`, which is part of the `simulation scenario` and contains all

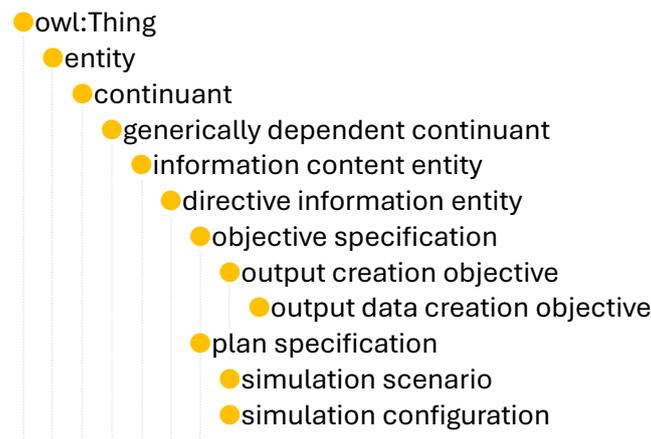


Figure 3. Class hierarchy of the simulation scenario concept.

technical descriptions required to run a simulation: simulation components, connections, and data. We also defined two new objective specifications. One is the generic output creation objective, which can be reused by a broad range of classes and the other is the output data creation objective, focusing on the creation of data, as is always the case for a simulation configuration. The class hierarchy is shown in Figure 3 with the newly added classes highlighted. During the discussion of this concept, a GitHub issue was used to document the discussion and make it transparent [12].

Additional concepts – not shown here in more detail – include simulation components, connections between simulation components, and parameters, which can be modeled at the system, scenario, and component level. More detailed documentation of all the concepts will be published in the future.

4. Conclusion and Next Steps

We presented our approach for developing a new co-simulation scenario ontology from brainstorming and collaborative modeling to the ontology code. It will serve the basis for further development of simulation services in NFDI4Energy. The first concepts for representing simulation scenarios were integrated in the OEO, but more are currently under discussion and will be added in the future [12]. We plan to use the ontology as the basis for the scenario definition for the three reference frameworks on the SimaaS hub.

We also plan to represent more domain specific elements, like the grid topology, which plays a central role in energy system simulation as it serves as the structural backbone to which most other simulation models are linked. Consequently, the ontology needs to incorporate a formal representation of grid topologies and should adopt an established standard such as the Common Information Model (CIM) [13] to ensure consistency and interoperability.

Data availability statement

Our submission describes the process and an exemplary concept of our ontology and is not based on data. All other material is available and listed in the next Section.

Underlying and related material

The following material associated with the co-simulation scenario ontology is available:

- OEO repository. <https://github.com/OpenEnergyPlatform/ontology>. "Repository of the OEO, in which the scenario ontology is integrated in the oeo-model module."
- Ontology repository. <https://github.com/NFDI4Energy/simulation-scenario-ontology>. "GitHub repository for collecting other relevant ontologies and other resources related to the ontology."
- Requirements documentation. <https://github.com/NFDI4Energy/simulation-service-requirements> "Documentation of the requirements and use cases of the simulation service in NFDI4Energy."

Author contributions

Conceptualization: J.S.S., P.S., C.S., Z.P., R.Q.; Methodology: J.S.S., P.S., C.S., Z.P., R.Q.; Project administration: J.S.S.; Writing – original draft: J.S.S.; Writing – review & editing: J.S.S., P.S., C.S., R.Q.;

Competing interests

The authors declare that they have no competing interests.

Funding

The authors would like to thank the German Federal Government, the German State Governments, and the Joint Science Conference (GWK) for their funding and support as part of the NFDI4Energy consortium (www.nfdi4energy.org). The work was funded by the German Research Foundation (DFG, German Research Foundation) under the National Research Data Infrastructure – NFDI4Energy – 501865131.

Acknowledgements

The authors of this article have used various preparatory works from NFDI4Energy to create this document, and references have been made where possible. We are grateful to all the people who have helped to shape and support the structures and results presented here. With regard to this article special thanks go to all additional participants in Measure 5.2 of NFDI4Energy (Laura Fuentes Grau, Nan Liu, Alexandro Steinert) for their participation in the discussion and development, which lead to the results presented in this document. We also thank the OEO developer team and especially Mirjam Stappel and Eugenio Salvador Arellano Ruiz for the valuable feedback and discussion about the integration into the OEO.

References

- [1] J. S. Schwarz et al., "Towards an ontology for co-simulation scenarios of energy systems", in *2. NFDI4Energy Conference*, Karlsruhe, Germany: Zenodo, Mar. 2025. DOI: [10.5281/zenodo.15061653](https://doi.org/10.5281/zenodo.15061653).
- [2] J. S. Schwarz et al., "Developing an ontology for co-simulation scenarios of energy systems", in *2nd Conference on Research Data Infrastructure (CoRDI)*, Zenodo, Aug. 2025. DOI: [10.5281/zenodo.16736210](https://doi.org/10.5281/zenodo.16736210).
- [3] C. Seiwert et al., "Towards a simulation-as-a-service hub for the energy domain", in *2. NFDI4Energy Conference*, Karlsruhe, Germany: Zenodo, Mar. 2025. DOI: [10.5281/zenodo.15065996](https://doi.org/10.5281/zenodo.15065996).

- [4] S. Vogel, M. Mirz, L. Razik, and A. Monti, "An open solution for next-generation real-time power system simulation", in *2017 IEEE Conference on Energy Internet and Energy System Integration (EI2)*, 2017, pp. 1–6. DOI: [10.1109/EI2.2017.8245739](https://doi.org/10.1109/EI2.2017.8245739).
- [5] M. Gütlein and A. Djanatliev, "On-demand Simulation of Future Mobility Based on Apache Kafka", *Lecture Notes in Networks and Systems*, vol. 306, no. ViM, pp. 18–41, 2022, ISSN: 23673389. DOI: [10.1007/978-3-030-84811-8_2](https://doi.org/10.1007/978-3-030-84811-8_2).
- [6] C. Steinbrink et al., "CPES Testing with mosaik: Co-Simulation Planning, Execution and Analysis", *Applied Sciences*, vol. 9, no. 5, p. 923, 2019, ISSN: 2076-3417. DOI: [10.3390/app9050923](https://doi.org/10.3390/app9050923).
- [7] M. Poveda-Villalón, A. Fernández-Izquierdo, M. Fernández-López, and R. García-Castro, "LOT: An industrial oriented ontology engineering framework", *Engineering Applications of Artificial Intelligence*, vol. 111, p. 104755, May 2022, ISSN: 09521976. DOI: [10.1016/j.engappai.2022.104755](https://doi.org/10.1016/j.engappai.2022.104755). Accessed: Feb. 26, 2024.
- [8] J. S. Schwarz et al., "Deliverable 5.2.1.1 – registry of existing/usable domain ontologies", OFFIS, Institute for Information Technology, NFDI4Energy project deliverable, 2024. DOI: [10.5281/zenodo.14521502](https://doi.org/10.5281/zenodo.14521502).
- [9] M. Booshehri et al., "Introducing the open energy ontology: Enhancing data interpretation and interfacing in energy systems analysis", *Energy and AI*, vol. 5, p. 100074, 2021, ISSN: 2666-5468. DOI: <https://doi.org/10.1016/j.egyai.2021.100074>.
- [10] R. Arp, B. Smith, and A. D. Spear, *Building ontologies with basic formal ontology*. MIT Press, 2015.
- [11] IAO development team, *Class: plan specification*, 2025. Accessed: Nov. 18, 2025. [Online]. Available: https://ontobee.org/ontology/IAO?iri=http://purl.obolibrary.org/obo/IAO_0000104.
- [12] J. S. Schwarz, *Add concepts for description of co-simulation scenarios – OEO GitHub Meta Issue*, 2025. Accessed: Nov. 18, 2025. [Online]. Available: <https://github.com/OpenEnergyPlatform/ontology/issues/2089>.
- [13] M. Uslar, M. Specht, S. Rohjans, J. Trefke, and J. M. Gonzalez Vazquez, *The IEC Common Information Model*. Berlin: Springer, 2012. DOI: [10.1007/978-3-642-25215-0](https://doi.org/10.1007/978-3-642-25215-0).