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eTraGo: electric Transmission Grid optimization

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Software

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Summary

eTraGo is an open source Python tool designed for analyzing the energy system transformation considering electrical grids. It enables electricity grid planning on extra-high and high voltage grid levels, optimizing grid and storage expansion as well as power plant dispatch. eTraGo thereby considers sector coupling and includes the possibility of taking into account various flexibility options. These include flexibilities arising from sector coupling, such as heat stores, gas stores, or shifting electric vehicle charging times, as well as electrical flexibilities like demand-side management and dynamic line rating. eTraGo is also compatible with the open source tool eDisGo (eDisGo Developer Group, 2025) through the grid planning tool eGo (eGo Developer Group, 2025), enabling consistent grid and flexibility optimization across all voltage levels.

Statement of need

Transforming the energy system is vital for achieving a climate-friendly and environmentally sustainable future. Therefore, electricity generation shifts from conventional, centralized sources to decentralized, often weather-dependent, renewable sources. Within Germany, the transmission grid experiences significant stress due to the presence of substantial wind energy capacity in the rural northern regions, which is in contrast to the industrial demands located mainly in the central and southern regions. Meanwhile, the decarbonization of many other sectors, such as the mobility sector or the heating sector, can be achieved most efficiently through electrification. As a result, the fluctuating, weather-dependent feed-ins are offset by increased demand and changed demand patterns due to the advancing sector coupling.

Therefore, electrical grids must be further developed and adapted to the new requirements. However, scaling technologies such as battery storage units can support the grid if dispatched grid-friendly. In addition, the integration of other sectors presents novel opportunities for flexibility, which can be exploited to reduce the necessity for grid expansion Fridgen et al. (2020).

These developments require careful investigation within holistic analyses to obtain robust solutions for an efficient future system. There is a consensus among researchers that this includes analyses with high temporal and spatial resolution (Aryanpur et al., 2021; Fodstad et al., 2022; Lopion et al., 2018; Pfenninger et al., 2014; Ridha et al., 2020). Furthermore, cross-grid level analyses are becoming increasingly necessary (Cußmann et al., 2024; Rossini et al., 2023). At the same time, transforming the energy system is an important and challenging task that we need to tackle as a collective endeavor. This is why stakeholders and experts need to have access to data and tools. Transparency and accessibility enable important discourse to identify and realize targeted measures on the path to a clean energy system.

eTraGo enables integrated analyses across the extra-high and high voltage grid levels, with the option to extend to the remaining lower voltage grid. It co-optimizes grid and storage expansion

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needs, considering a variety of flexibility options to achieve a cost-optimal, system-wide energy system. Thereby, it offers various functionalities to manage high spatial and temporal resolution. As an open-source tool, it provides valuable support to various stakeholders in identifying suitable transformation pathways.

Functionalities

eTraGo is an open source tool based on PyPSA (Brown, Hörsch, et al., 2018). The functionalities are divided into different modules. An overview is given in Figure 1. The different steps are briefly described afterwards; a more detailed description is included in the read-the-docs.

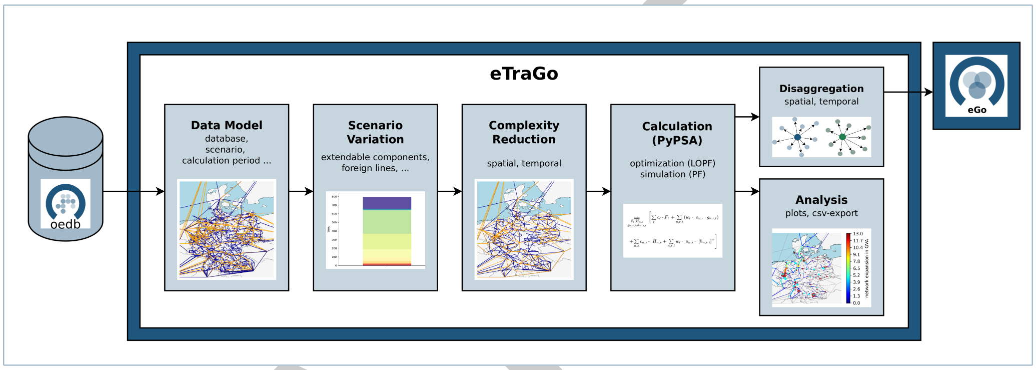

Figure 1: Overview of eTraGo's functionalities.

eTraGo is compatible with open sector-coupled **data models, representing different scenarios** of the German Energy system generated by eGon-data (eGon-data Developer Group, 2025). These models include electricity grid models from extra-high and high down to medium and low voltage grid levels, and are therefore characterized by a high spatial and temporal resolution within Germany. Depending on the specific scenario, the data models also cover gas grid models. Furthermore, they encompass sectoral demands and flexibilities from electricity, gas, heat, and mobility systems. Several scenarios are available to be used within eTraGo, e.g. a status quo scenario, a mid-term scenario for 2035 or a scenario characterized by 100% renewable generation. eTraGo includes methods to **customize these scenarios**, e.g. by selecting components that are optimized in terms of capacity.

The grid model is characterized by a high spatial (about 8,000 electrical nodes) and temporal resolution (8,760 timesteps). To **reduce the complexity** of the resulting optimization problem, several methods can be applied to reduce the data complexity in spatial and temporal dimensions (Esterl et al., 2024).

eTraGo provides different options to **optimize the transmission grid** and its expansion needs. The energy market can be integrated into the grid optimization with nodal pricing (Büttner et al., 2024) or as a separate optimization step, allowing the consideration of current market regions (Büttner & Müller, 2024). When a separate market optimization is conducted, the grid optimization encompasses cost-based redispatch. Within both approaches, linearized optimal power flows are conducted to optimize grid and storage expansion, flexibility dispatch, and (re)dispatch of generation in one optimization problem. The objective is to reduce overall system costs. Various constraints model the technical behavior, e.g. AC-load flows or weather-dependent limits for renewable generation. A non-linear **power flow simulation** can be conducted afterwards to check the technical feasibility of the optimized dispatch and expansion results.

The optimization results can be **disaggregated in both temporal and spatial dimensions**. This is especially required when results should be transferred to eDisGo (eDisGo Developer Group,

2025) to allow consistent grid and flexibility optimization across all grid levels (Büttner et al., 2025).

In addition, eTraGo is equipped with a range of functions that facilitate the **analysis of optimization results** in graphical, cartographic, and tabular formats. Examples from (Büttner et al., 2024) are given in Figure 2.

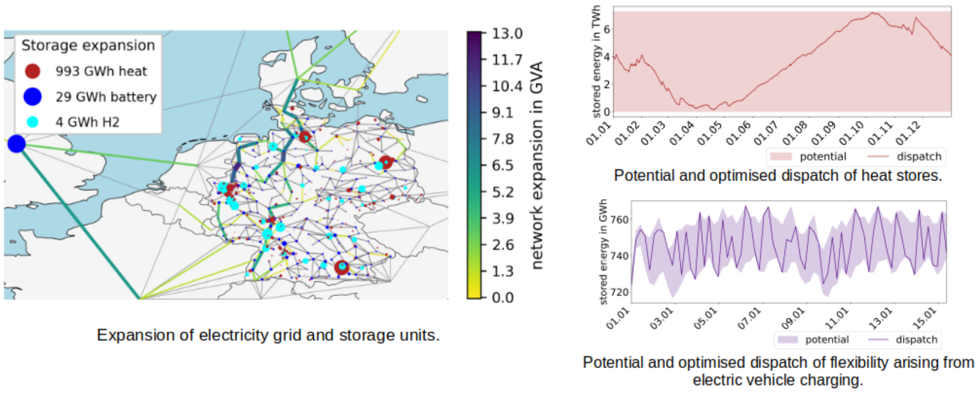

Figure 2: Exemplary result plots.

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