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REMix: A GAMS-based framework for optimizing energy system models

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Summary

REMix is a framework for modeling energy systems of almost any temporal, spatial, and technological scale and detail. It can be used to model processes of extraction, storage, conversion, transfer and demand for any commodity, usually representing energy carriers such as electricity, gases, or heat, and to flexibly link them with each other. All processes can be characterized by indicators such as costs or CO_2 emissions. The mathematical core of the framework allows integer and continuous decision variables and the objective function includes one or more indicators. Energy system infrastructures can be considered for both economic dispatch and capacity expansion planning along either single target years or full infrastructure pathways. Research subjects are usually regional to continental systems, and their transformation to a climate-neutral energy supply.

Statement of need

For policy makers and companies in the energy sector, energy system optimization models are helpful tools for planning the transformation process. Depending on their background, stakeholders have different main interests such as energy costs, business models, emission reduction targets or security of supply. With this in mind, various energy system modeling frameworks with different design and implementation have already been published. Among the most established are OSeMOSYS (Howells et al., 2011), oemof-solph (Krien et al., 2020), PyPSA (Brown et al., 2018), and TIMES (IEA-ETSAP, 2024). Similarly to these modeling frameworks, REMix was developed to investigate future energy system designs. It is primarily applied to determine the infrastructure requirements in systems that rely entirely or predominantly on the use of time-varying renewable energy sources. The view across energy carriers provides in-depth insights into the optimal design of energy systems and enables, for example, an integrated planning of power and hydrogen infrastructures. While the application focus of REMix to date was on continental or national energy systems, it allows also for consideration of smaller-scale systems. Earlier versions of the framework were used to build numerous energy system models (Cao et al., 2019; Cao, Pregger, et al., 2021; Cebulla & Fichter, 2017; Gils et al., 2017, 2021; Gils & Simon, 2017; Sasanpour et al., 2021; Scholz, 2012; Scholz et al., 2017). They form the basis for the version published here. Its novelty consists in the combination of multiple features required to address current challenges of energy systems research (Pfenninger et al., 2014). These include the optimization of consistent transformation pathways of sector-integrated systems, multi-criteria optimization and evaluation, and the ability to efficiently compute models of ever-increasing complexity by its link to the parallel solver PIPS-IPM++ for High Performance Computing. This version of REMix is used in numerous ongoing research projects, including (DLR, 2019-2023, 2020-2023, 2021-2024). Resulting publications include (Manjunath, 2020; Nitsch et al., 2024; Wetzel et al., 2023).

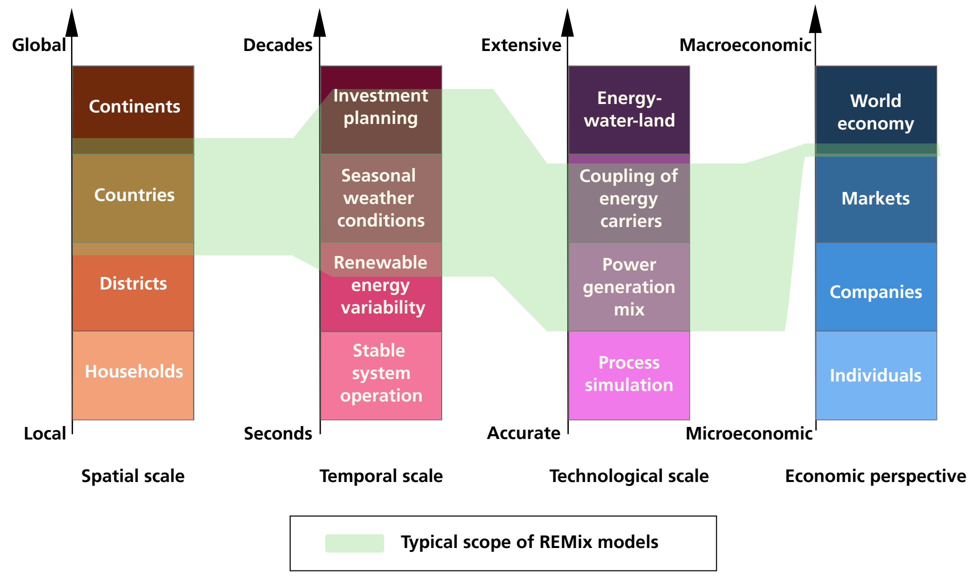

Figure 1: Classification of REMix in the categories of energy system models according to Cao, Haas, et al. (2021).

Model design

The REMix framework is designed to model highly complex systems in a flexible and user-friendly way based on a data-driven approach. While the mathematical optimization is implemented in GAMS, the data handling and interfaces are implemented in Python. Models built in REMix feature a regional, a temporal and a technological dimension. Additionally, networks in high spatial detail can be flexibly aggregated to simplified networks to address computational complexity. Modeled time intervals are typically defined as years encompassing 8760 time steps, although other temporal resolutions can be implemented. REMix consists of only a few modules. Their very generic nature facilitates the creation of models to answer a wide range of research questions.

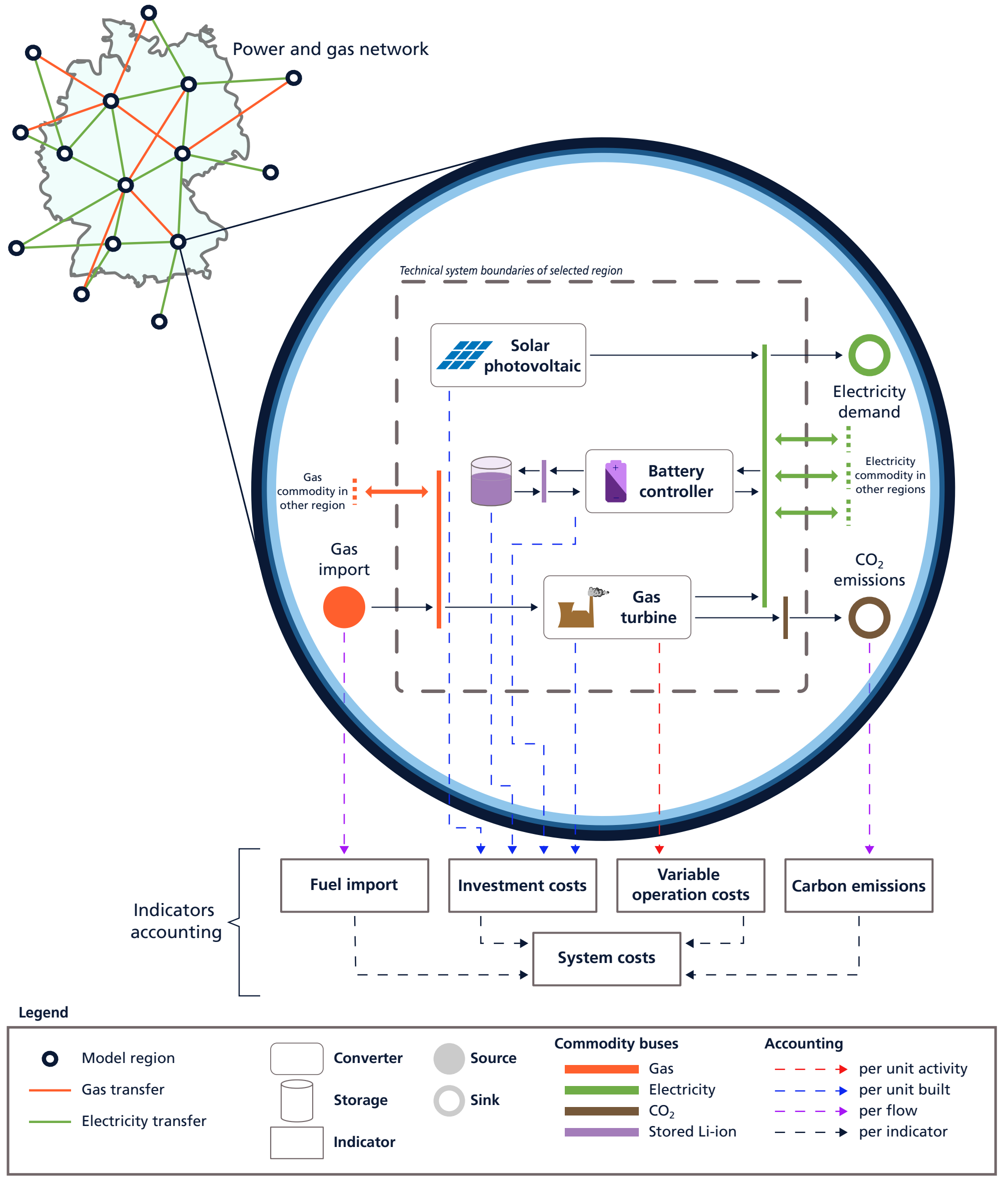

Figure 2: Structure and logic of REMix models, illustrated by a highly reduced example of a system of photovoltaic plants, battery storage and gas-fired power plants.

Technology modeling

According to the possible abstraction of energy systems, all technologies in REMix are characterized as source, sink, converter, transfer links, or storage of commodities. The corresponding modules feature techno-economic parameters, limit the technology activity and allow for building and decommissioning of units between different model years. Sources and sinks allow for flows of commodities into and out of a model's boundaries, e.g. representing exogenous demands, fuel imports, and emissions. Converters allow for the transformation of any number of input commodities into any number of output commodities. Converters can be given activity profiles to model time-constraint activities such as the availability of variable renewable energy sources. In contrast to converters, storage reservoirs are defined for one specific commodity. They are usually set up with one or more converters that fill and empty the storage. The transfer module enables commodity flows between model regions. For electric grids, direct-current optimal power flow (DC-OPF) is implemented as a way of modeling alternating current grids. The technology modules are complemented by a balance module that employs a conservation equation for every commodity bus across all model regions and time steps.

Indicator accounting

The indicator module allows linking the technology components to indicators and defining the objective function. Indicators in REMix are used for general accounting purposes and can be freely defined. Typically, indicators include both system costs and carbon emissions as the most commonly used metrics in energy system modeling. REMix implements a hierarchical indicator model to allow indicators to either be derived from the individual system components or from other indicators. This allows, for instance, for the separation of cost components into investment, decommissioning, and operational costs. Any defined indicator can be used in conjunction with any number of model regions and any number of years, to enable e.g. modeling of carbon budgets. Furthermore, indicators can be declared as variable indicators to allow for slack variables in the indicator accounting model.

Methods

The objective function is generated by declaring one of the indicators to be either maximized or minimized. The indicator concept of REMix is tailored to enable multi-criteria optimization using different weight factors in a straightforward fashion. Similarly, models with solution methods for Pareto fronts and modeling to generate alternatives (MGA) can be easily set up. Similar to bounds on any indicators the objective function is automatically reformulated to a single equation.

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