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The Spreadsheet Energy System Model Generator (SESMG): A tool for the optimization of urban energy systems

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Summary

The Spreadsheet Energy System Model Generator (SESMG) is a tool for modeling and optimizing energy systems with a focus on urban systems. The SESMG is easily accessible as it comes with a browser-based graphical user interface, spreadsheets to provide data entry, and detailed documentation on how to use it. Programming skills are not required for the installation or application of the tool. The SESMG includes advanced modeling features such as the application of the multi-energy system (MES) approach, multi-objective optimization, model-based methods for reducing computational requirements, and automated conceptualization and result processing of urban energy systems with high spatial resolution. Due to its accessibility and the applied modeling methods, urban energy systems can be modeled and optimized with comparatively low effort.

Statement of need

The Spreadsheet Energy System Model Generator (SESMG) meets various challenges of modeling urban energy systems. Planning and optimizing the design of urban energy systems is becoming increasingly complex (Zhang et al., 2018) due to sector coupling, the use of decentralized renewable energy sources with volatile production, the use of diverse energy storage systems, the growing importance of new energy sectors such as hydrogen, as well as the increasing relevance of multiple planning objectives. In this context, urban energy systems are defined as "the combined process of acquiring and using energy in a given spatial entity with a high density and differentiation of residents, buildings, commercial sectors, infrastructure, and energy sectors (e.g., heat, electricity, fuels)" (Klemm & Wiese, 2022). Traditionally, such systems are designed by simulating and comparing a limited number of pre-defined energy supply scenarios without using optimization methods. Individual buildings, consumption sectors, or energy sectors are rarely planned and designed holistically, but rather separately from each other (Lukszo et al., 2018). Finally, planning processes are often only driven by financial interests, rather than considering additional planning objectives such as minimizing green house gas (ghg) emissions, or final energy demand. To fully exploit all synergies and to avoid conflicting interests due to interdependencies of increasingly entangled energy systems (Pfenninger, 2014), it is necessary to carry out holistic planning (Lukszo et al., 2018). Therefore, all energy sectors, planning objectives, as well as an entire spatial entity should be considered within a holistic analysis (United Nations Environment Programme, 2015). Not only certain, but all theoretically possible supply scenarios should be compared by using optimization algorithms (DeCarolis et al., 2017) in order to ensure that scenarios that allow the minimization of the planning objectives by a given ratio are identified (Klemm & Wiese, 2022). All these requirements for planning and optimization methods result in increasingly high computing requirements, especially in run-time and random access memory (RAM) (Klemm et al., 2023). To limit the necessary computing capacities to an acceptable extend, modelers may make decisions regarding the temporal and spatial resolution of the system. Alternatively, model-based or solver-based methods can be used to reduce the computational requirements (Cao et al., 2019), with only slight differences in the quality of the results.

Combining functions of the underlying Open Energy Modeling Framework (oemof) (Krien et al., n.d.) as well as its own functionalities, the SESMG overcomes these typical problems of modeling urban energy systems by

- considering the **multi-energy system (MES)** approach (Mancarella et al., 2016),
- carrying out **multi-objective optimization** by using the epsilon-constraint-method (Mavrotas, 2009), and by
- enabling high spatial resolution results through the applicability of **model-based** methods for the **reduction of computational effort** (Klemm et al., 2023).

The SESMG enables the optimization of multi-sectoral and spatial synergies of entire urban energy systems with an adaptable number of buildings. Due to the multi-criteria results in the form of a Pareto front, transformation processes between status quo, financial cost minimized and ghg emission minimized target scenarios can be identified.

The target groups of the SESMG are (urban) energy system planners and researchers in the field of energy engineering. As it is required for the application of the SESMG and the interpretation of the results, users must have a certain basic knowledge of energy systems and energy engineering. Compared to other tools for the modeling and optimization of urban energy systems, as they have been listed by Klemm and Vennemann (Klemm & Vennemann, 2021), the SESMG provides several advantages regarding user-friendliness due to

- being available under an **open-source license**,
- applicability **without any programming knowledge** through a **browser-based graphical user interface** (GUI),
- **automatically conceptualizing** individual urban energy systems of any size,
- **automatic result processing and visualization** of complex relationships in form of system graphs, Pareto fronts, energy amount diagrams, and more, as well as
- a broad set of **standard (but still customizable) technical and economic modeling parameters** including description and references.

The SESMG comes with a detailed documentation, including step-by-step instructions, explanations of all modeling methods, and troubleshooting with known application errors. In addition, the documentation includes an ongoing list of peer review publications, conference proceedings, study works, research projects, and other publications related to the SESMG.

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