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A systematic approach to calculate future electricity load scenarios based on open-source geoinformation data: A case study for Berlin in the year 2045

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The transition towards the decarbonization of energy systems means a significant shift towards electrification, which concurrently leads to increasing electricity demands and higher grid loads. On the other hand, in urban energy systems large installed capacities of PV systems on rooftops can lead to grid congestion during peak generation times, when generation exceeds local demand significantly. As a response, electricity grids must be strenghthened to handle these additional requirements. However, there are large uncertainties about the scale of investments needed to strengthen the infrastructure. Various factors, such as future developments in PV expansion, the share of central and decentralized heating systems, and the growing usage of electric vehicles, but also expected grid friendly behaviour of storage units or demand side management influence the resulting grid loads. All these uncertainty factors contribute to the complexity of estimating future loads. Furthermore, the resulting grid loads can vary significantly locally depending on structural differences. This study seeks to address the critical question: How do PV systems installed in urban areas influence load occurrences across different PV expansion scenarios in urban energy systems? For this purpose different scenarios w.r.t to critical development factors are calculated in a case study for the city of Berlin.

To explore this question, a systematic bottom-up approach for load estimation was developed utilizing open-source data. This data includes geoinformation data, e.g. the Berlin energy Atlas (Senatsverwaltung für Wirtschaft, Energie und Betriebe), municipal building records, standard load profiles, and projections on development factors based on existing studies as well as political targets. A Python toolchain was created to calculate hourly load profiles at the neighborhood level, based on projected annual demands for electricity, heating, and mobility to the year 2045. For this the following steps were undertaken: Previously conducted studies were used to project electrification shares in heating and mobility sectors (Bernd Hirschl et al., 2021; Reusswig et al., 2014; Senatsverwaltung für Umwelt, Mobilität, Verbraucher- und Klimaschutz, 2021; Stryi-Hipp et al., 2019). The distribution of residential, public, and various commercial users was subsequently used to generate resulting load profiles for each neighborhood. Individual building data, including roof area orientation and tilt, was used to generate PV generation profiles. Based on load and generation profiles resulting residual load profiles were calculated. The applied calculation scheme is summarized in Figure 1. A case study focusing on Berlin was conducted, in which load scenarios were developed by using a consistency assessment approach, clustering factors that lead to either higher or lower loads. These load scenarios were combined with various PV expansion scenarios considering different growth targets and market conditions for PV installations across diverse market segments, e.g. residential single-family homes, multi-family homes, commercial entities, and public buildings, as well as parking lot and balcony PV systems. Grid-friendly battery storage solutions were also considered.

The findings from the Berlin case study reveal a significant rise of grid load due to the electrification of the sectors mobility and heat. A substantial increase in peak loads on the power grid is expected, with an average peak load projected to be 2.9 to 3.6 times higher than current levels for the entire city. Also, when using the PV potential to a high extent, strong peak loads emerge, although this does depend on the various districts and their structures. Notable disparities were observed between central and surrounding suburban areas: in central locations with limited PV potential, load increases are primarily driven by population growth and the electrification of e-mobility and heating sectors. Conversely, in suburban areas with ample PV potential, even greater peak loads may arise from solar generation on middays during summer. Additionally in decentral areas higher peaks during winter months result from high shares of decentralized electric heating. The study concludes that PV expansion in central areas, where market conditions have previously hindered development, is essential. On the other hand, utilizing the PV potential to the maximum capacity in suburban neighborhoods can bring the risk of generating excess energy, that cannot be used locally, and exacerbate peak loads. Implementing grid-friendly battery storage solutions, that are not only used for enhancing self-consumption but also for mitigating peak loads, is recommended. These systems can alleviate excess generation during peak times and reduce wintertime load peaks caused by electric heating. Nonetheless, the widespread deployment of building-mounted PV systems may necessitate curtailment during peak hours to maintain grid stability. Figure 2 shows the estimated peak loads for the considered neighborhoods in Berlin for 2045 in the high load scenario with full utilization of PV potential as a fraction of 2023 peak loads. Blue colors indicate that peak loads occur in winter due to high demands, yellow indicates higher peak loads in summer due to solar generation.

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