Analyzing scale effects of energetic autarky with an economic capacity and dispatch optimization model

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Overview

The German Government has formulated an ambitious target of 80% electricity generation from renewable energy sources (RES) by 2050. The majority of RES electricity has recently come from wind energy and photovoltaic (PV) and this trend is likely to continue. The achievement of grid parity for PV in Germany, along with the fact that PV is typically a decentralized technology which is connected to distribution rather than transmission grids, has recently drawn increased attention to self-supply through PV electricity. Thus there is increased interest in decentralized (electricity and heat) storage technologies, in order to achieve high levels of self-supply or even a degree of energy autarky, but there is a trade-off associated with additional costs for storage.

Previous studies have aimed at optimizing the sizing of PV and battery storage systems whilst minimizing overall costs (e.g. Weniger et al. 2013), but these have mainly focused on electricity supply. On the other hand, there have been several efforts aiming at a more holistic energetic autarky for larger energy systems such as municipalities and/or villages (cf. Jenssen et al. 2014, Schmidt et al. 2012). Attempts to formalize these approaches and develop a general framework for energy autarky are mainly qualitative in nature (cf. Müller et al. 2011; Rae & Bradley 2012). In addition, whilst there are some general quantitative frameworks for assessing the level of autarky on the dwelling level, such as for net zero energy buildings (Sartori et al. 2012), which develop indicators to assess the degree of integration of a building into the surrounding (electricity) network (load matching and grid integration, LMGI), there is a lack of research into the scale effects on energy autarky.

This contribution investigates the scale effects on attempts at achieving energetic (both electricity and heat) autarky by extending an existing optimization model. The focus thereby lies on electricity-generating technologies as opposed to heat pumps and/or solar thermal because, due to the high transportability of electricity, they are most relevant to the decision regarding self-supply or feed-in. Stylized demand classes are defined through a combination of scale (number of buildings) and demand types (households, services, industry); thus the optimal sizing and dispatch of heat and electricity systems is determined and generalized conclusions can be drawn about the scale effects on attempts to achieve energy autarky.

Methods

Firstly, a general quantitative framework for energy autarky at an arbitrary scale is developed, and secondly, this framework is applied in the context of an energy system model (cf. Figure 1). To do this, an existing optimization model for the sizing and dispatch of micro-CHP systems in residential buildings (Merkel et al., forthcoming) is extended to consider the following aspects. Firstly, the PV and battery storage technologies are integrated into the model based on a current techno-economical parameterization, including solar irradiation profiles, investment, running costs, performance ratios etc. Secondly, several stylized demand cases are defined based on the combination of scale (single building, several buildings, city quarter etc.) and demand structure (residential, industrial, services, and combinations thereof). Each of these demand classes is defined by an aggregated electricity and heat demand over the year, based on the specific demand side structure. In each case the supply of electricity and heat is optimized, i.e. demand side management (DSM) is not considered, so that the system sizing and operation throughout the year is determined resulting in minimum overall system costs.

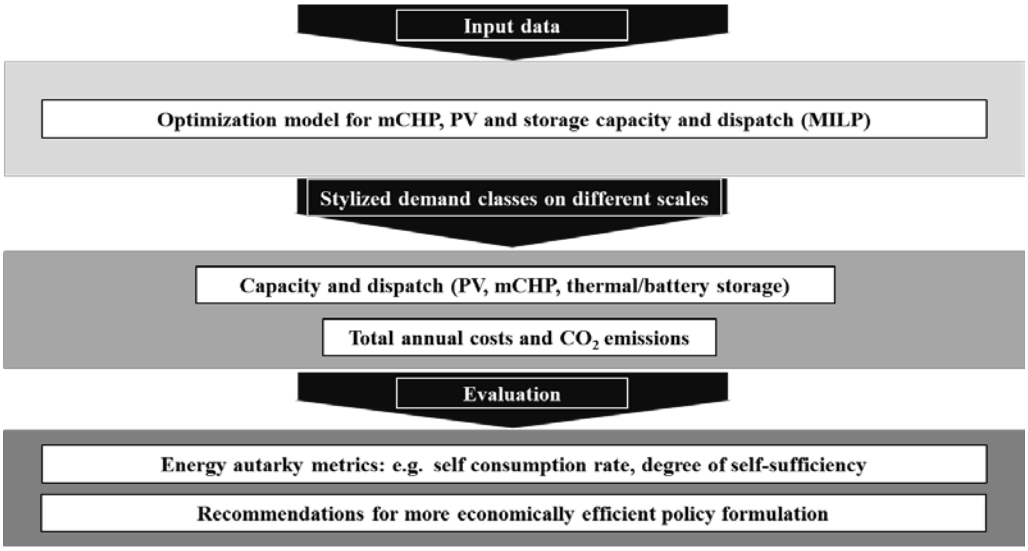

Figure 1 – Schematic overview of the employed methodology

Results and conclusions

The results from the optimization of the selected demand cases are compared in terms of annual heat, electricity and total energy supply costs as well as CO_2 emissions and degree of energy autarky. For the latter metric the distinction is made between the percentage of PV and CHP self-generated electricity that is used on the premises, and the fraction of the total electricity demand that is met by self-generation. Policy recommendations can be made about the meaningfulness, or otherwise, of such energy autark ambitions. This is especially poignant in the context of current discussions in Germany about the feed-in tariffs for PV and CHP, as well as the extent to which own consumption should be eligible for economic support. Sensitivity analyses are employed to validate the results and investigate their sensitivity to crucial energy-political framework conditions, especially related to the support for PV and CHP. The methodology is also critically evaluated, in particular the assumptions made regarding to the demand classes and neglecting heat and electricity networks, and suggestions are made for future work.

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