EXPLORING THE TECHNICAL AND ECONOMIC FEASIBILITY OF COMPLETE MUNICIPAL ENERGY AUTONOMY: A CASE STUDY FOR GERMANY

Jann Michael Weinand, Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute for Technology (KIT), Hertzstraße 16, 76187 Karlsruhe, Germany, Tel.: 0721 6084 4444, Email: jann.weinand@kit.edu
Russell McKenna, Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute for Technology (KIT), Hertzstraße 16, 76187 Karlsruhe, Germany, Tel.: 0721 6084 4582, Email: mckenna@kit.edu
Wolf Fichtner, Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute for Technology (KIT), Hertzstraße 16, 76187 Karlsruhe, Germany, Tel.: 0721 6084 4460, Email: wolf.fichtner@kit.edu

Overview

In recent years, the rapid expansion of renewable energy capacities in Germany has been dominated by decentralised wind, photovoltaic (PV) and bioenergy plants (BMWi 2016). The spatial diversification and, in some cases, unpredictability of these resources requires an increasing use of integration measures such as curtailment, supply and demand-side flexibility, storage capacities and grid reinforcements. Indeed, decentralised autonomous municipal energy systems could be one solution to the large-scale integration of renewable energies. Achieving grid parity in some renewable energy technologies has increased the desire of municipalities to become independent of central markets (e.g. Boon & Dieperink 2014; Volz 2012; McKenna 2018). Whilst many municipalities in Germany are already striving for so-called energy autonomy, the overwhelming majority of these do so only on an annual basis and focus on electricity (Engelken et al. 2016). In the context of annual energy autonomy, an energy autonomy degree indicates how large the share of self-generated and consumed energy in total energy consumption is (McKenna et al. 2015). In all of the studies assessing municipal energy autonomy (e.g. Jenssen et al. 2014; Peter 2013; Scheffer 2008; Schmidt et al. 2012; Woyke & Forero 2014), only one theoretical or real municipality has been investigated. But a closer examination shows that these examined municipalities cannot be regarded as representative for all German municipalities. Furthermore, only standard technologies such as photovoltaic, wind turbines and biomass plants, as well as solar thermal systems are considered. The studies therefore show that energy autonomy can only be achieved with very high storage costs. This is why alternative technologies such as geothermal power plants should be included in an overarching optimisation of the municipal energy system in order to examine their influence on the economic viability of energy autonomy (Peter 2013).

Methods

With the help of a cluster analysis, the 11,131 German municipalities were divided into 10 clusters on the basis of 34 socio-energetic indicators, as shown in Figure 1. The socio-energetic indicators on a municipal level include indicators for the consumption sector of private households (e. g. building age classes), the transport sector (e. g. number of cars) and indicators for estimating the potential for renewable energies (e. g. hydrothermal temperature). Hence the clusters are intended to provide a basis for optimising (decentralised) municipal energy systems.

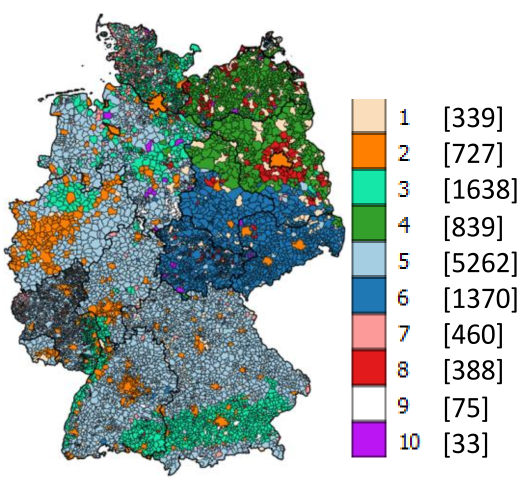

Figure 1: Illustration of all German municipalities with their allocation to the 10 clusters

From three of the ten clusters, the average municipality is selected whose optimal energy system (e.g. minimum cost, minimum CO_2 emissions) is determined by means of a linear mixed-integer optimisation. The optimisation problem includes, among other things, heat storages, batteries, photovoltaic roof systems and wind power plants. In this study, particular focus is placed on geothermal power plants for providing base load power. The geothermal power plants are modelled as binary organic rankine cycles and use the hydrothermal wells in Germany as a heat source. In addition, cost functions for the geothermal plant are derived from the literature. These cost functions are divided into areas depending on the drilling depth in order to linearise the functions for the optimisation problem.

Results

The average municipalities from the three clusters are subjected to a comparative analysis. The results will show that it is necessary to include baseload technologies such as geothermal power plants in studies on energy autonomy in municipalities to increase the degree of energy autonomy at reasonable costs. Hence the results demonstrate how a completely autonomous energy system for each of the three municipality clusters could be dimensioned, and allow a comparison of their economic and environmental implications. In addition, the optimal dispatch of the technologies is determined with the optimisation problem.

Conclusion and outlook

The study examines the energy systems of representative German municipalities with regard to energy autonomy. It is evident that the evaluation of energy autonomy should neither only include standard technologies not just focus on electricity. Rather, technologies such as geothermal power plants could make a major contribution to achieving energy autonomy, and heat supply must also be analysed. In addition, the study gives an overview of municipalities in Germany that could be best suited for energy autonomy. By way of an outlook, the implications for the national energy system of large numbers of fully energy-autonomous municipalities can be qualitatively explored.

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