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ScienceDirect

Energy Procedia 97 (2016) 133 – 140

Energy Procedia

European Geosciences Union General Assembly 2016, EGU
Division Energy, Resources & Environment, ERE

Impact of small-scale storage systems on the photovoltaic penetration potential at the municipal scale

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Abstract

High penetration of grid-connected roof-top photovoltaic power plants (GCRT-PV) is restricted by electric energy grid quality requirements and available storage capacities. This study evaluates how far small-scale storage systems can contribute to increment GCRT-PV penetration at municipal scale. To accomplish this, the GCRT-PV potential of a municipality is calculated in high spatiotemporal resolution and various scenarios of storage systems penetration are evaluated with a series of indicators. The adoption of a low share of storage systems improves energy utilisation, variability and reliability indicators; while an increased penetration of storage systems only marginally improves these indicators.

Peer-review under responsibility of the organizing committee of the General Assembly of the European Geosciences Union (EGU)

Keywords: Geographic information systems; roof-top photovoltaics; small-scale electric energy storage systems

1. Introduction

The yearly cumulated technical energy generation potential of grid-connected roof-top photovoltaic power plants (GCRT-PV) can be significantly larger than the demand for electric energy in sparsely populated regions in Europe [1]. In Germany for instance, 3,736 (32%) of all municipalities could become self-sufficient in terms of electric energy supply if it would be possible to make use of the full yearly GCRT-PV potential [2]. However, an energy balance with

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Peer-review under responsibility of the organizing committee of the General Assembly of the European Geosciences Union (EGU)
doi:10.1016/j.egypro.2016.10.037

cumulated annual values does not deliver the right picture of the actual potential for photovoltaics because it disregards too many technical requirements and restrictions. The temporal mismatch between generation and demand creates hard limitations for the deployment of the theoretical energy generation potential of GCRT-PV [3]. The actual penetration of GCRT-PV is also bounded by energy quality requirements of the grid and/or the available storage capacity for the electricity production beyond self-consumption.

The advantages of small-scale electric energy storage systems are manifold but would lead to electric energy self-sufficiency based on GCRT-PV only under very specific conditions. Fraunhofer ISE [4] has shown that a German single family household with an annual consumption of 4,700 kWh can achieve self-consumption of 100% of the electric energy generated by a 2 kWp PV installation if a battery of 4 to 6 kWh is installed. For a PV system able to produce as much energy as the household demands in one year, the same storage system sizes would only enable self-consumption of 50% to 70%. Due to the temporal mismatch not all produced energy can be consumed by the household and only larger PV and storage system sizes would achieve self-sufficiency. This, however, occurs at cost of a permanently decreasing self-consumption rate [4], which means that excess energy either has to be fed into the grid or that curtailment would be necessary. Denholm and Margolis [5] found that a storage system capacity close to half the average daily demand enables PV to provide about 50% of the system's energy. Similarly, Mavromatidis et al. [3] determined that a maximum of 64% of the energy demand of a Swiss village can be provided by GCRT-PV, in case an electricity storage capacity of 43% of the average daily demand is installed. For the case of entire municipalities Mainzer et al. [2] stated in a study for Germany that there are 53 (mainly residential and rural) municipalities that could use GCRT-PV to cover 100% of their electric energy demand, if short-term storage systems sized around 57% of the daily (winter/workday) electricity demand are installed (this is in average 6 MWh for these 53 municipalities). Nevertheless, this will only happen if the available GCRT-PV capacity is several times larger than the installed capacity that would be necessary to produce as much energy as demanded per year. If the installed GCRT-PV capacity in a German (mainly residential and rural) municipality is sized to produce 100% of the total yearly electric energy demand, only a storage sized about 44 times larger than the average daily demand would enable a 100% self-sufficient energy supply [6]. Larger PV system sizes or smaller storage capacities would generate either reverse loads or will obligate to use curtailment during certain periods of the year. While the impact of small-scale storage systems in terms of self-sufficiency and self-consumption rates for individual installations have been widely discussed, detailed studies for entire municipalities not only concerning these but further indicators, such as energy generation variability or frequency and magnitude of peaks, are still missing.

This study is a first approach to a highly detailed evaluation of the impact of small-scale storage systems on the adoption of high shares of GCRT-PV in municipalities, considering more than self-sufficiency and self-consumption aspects. For this a high resolution spatiotemporal approach is used to study the relations and dependencies between technical GCRT-PV and small-scale storage systems potential. The approach will be tested in a case study region, a small rural municipality in Germany. The objective is to evaluate how far small-scale storage systems can contribute to increment the GCRT-PV penetration at a municipal scale while considering energy utilisation, energy generation variability and system reliability indicators.

This paper is structured as follows: Section 2 describes the case study municipality and the methodology, while section 3 presents the results of the high spatiotemporal resolution analysis and section 4 draws final conclusions.

2. Data and methodology

2.1. Case study municipality

Waldthurn, a mainly residential and rural municipality, located in northeast Bavaria (Germany), was selected as case study area. This municipality with only 2,019 inhabitants but 2,518 buildings has a yearly GCRT-PV energy generation potential almost 4 times larger than the total electric energy demand when assuming PV systems with 14.4% efficiency [6]. The buildings can be divided in 650 main buildings (e.g. one family houses, multi-family houses or business) and 1,868 secondary buildings (e.g. stables, garages or tools deposits), distributed over 30.97 km². Basic