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Evaluation of photovoltaic integration potential in a village

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Abstract

Buildings are expected to significantly contribute to the adoption of renewables, and mainly solar technologies due to largely unutilised roof space. A framework to assist the decision making process towards the optimal integration of solar energy in urban areas, with the focus on photovoltaic panels, considering spatiotemporal aspects, is presented using a village in Switzerland as a case study. Calculating the solar potential of the examined area is the first step towards determining the optimal structures to install photovoltaics. Utilisation of weather station measurements for the solar resource of a built-up area is prone to errors due to the complicated geometry of the built environment. Therefore, modelling in order to accurately determine the solar potential on a spatiotemporal scale is presented as the most promising solution. A workflow utilising Digital Elevation Models (DEM) is presented in order to create solar availability profiles for each building examined, taking into account the different surface orientations, the neighbouring structures, but also the surrounding topography. With the same techniques, the area availability for such installations is also quantified. In the next step, synthetic profiles for the electricity demand of the buildings are created taking into account the different building types. Having modelled the solar resource as well as the demand for electricity in the building stock of the examined area, the energy hub concept is employed to optimise the management of the renewable energy flows, considering multiple objectives. The energy hub output allows us to determine the optimal roof surfaces for solar installations that minimise the cost of meeting the energy demand and/or maximise the amount of solar electricity that can be used locally. Due to the intermittency of solar radiation and the temporal mismatch of solar availability and electricity demand, energy storage is also included in the energy system and its capacity is optimised to increase utilisation of solar electricity.

Keywords: Solar potential; Photovoltaic; Energy hub; Optimisation

1. Introduction

Buildings, while being a significant contributor both in terms of primary energy consumption and carbon emissions, accounting for 32% of the global final energy use and 19% of the energy-related greenhouse gases (GHG) emissions (Lucon et al., 2014), are also expected to play a major role in the high penetration of decentralized renewable energy. Solar energy appears to have the greatest potential for renewable integration due to largely unutilised roof spaces but also due to the maturity of solar technologies. Due to its temporally and spatially varying, intermittent nature, following diurnal and seasonal patterns, solar energy integration within the energy system is a challenge. In this work, the focus is placed on photovoltaic panels for the generation of electricity. They have been chosen over solar thermal panels due to the more

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flexible nature of electricity that can be used for various sectors, like appliances, lighting, heating etc., but can be also easily exchanged between buildings or the national grid.

In order to determine the solar potential for an urban configuration, the first step is to determine the solar resource in terms of radiation, but also the area availability to accommodate the panels. Utilisation of annual solar radiation values is not adequate if the temporal dimension (e.g. daily and more preferably hourly to capture interday or intraday variations, respectively) has to be taken into account. Moreover, the use of measured data from a weather station is also prone to errors due to the complex geometry of the built environment that encompasses different surface orientations for the same building, as well as complex shading patterns from nearby surfaces or neighbouring structures. Therefore, modelling of the solar potential of an urban environment is considered as the most reliable approach to determine solar PV potential.

Transitioning from the potential towards integration, a decision making process regarding energy system design and operation aspects must be initiated considering multiple criteria. Mathematical optimisation techniques are very well-suited to support such energy system design and management problems. In this paper, the energy hub concept (Geidl and Andersson, 2007) is applied to evaluate the integration potential at building and village level. It describes the relation between input and output energy flows and can be used for multi-criteria analysis purposes of energy systems. In the case of the integration of decentralized renewable energy sources in a neighbourhood, the concept can be used to support decisions, such as which buildings should be equipped with photovoltaic panels, the trade-off between costs and renewable energy share, and the integration and sizing of local electrical storage systems.

The objective of this paper is to present a framework, that incorporates solar modelling and energy management techniques, to support the decision making process for integrating photovoltaic panels in a village. The scope of this paper is focused on the energy planning aspect of photovoltaic energy regarding building potentials and utilisation rates based on hourly considerations for the temporal scale. The scope does not include electrical network considerations, such as network characteristics and stability constraints, but it is mostly intended as a decision making tool or an aid towards shaping a local communal policy for the adoption of photovoltaic technologies.

1.1. Previous work

In the literature, there has been a plethora of publications looking into the topic of solar potential for urban configurations. Comprehensive reviews of the modelling approaches for solar energy in the urban environment were written by Jonsson et al. (2012) and Freitas et al. (2015). There are two main approaches to calculate the urban solar potential, based on the way buildings are represented (Jonsson et al., 2012). In the first approach, buildings are represented using vector-based data, e.g. in a Computer Aided Design (CAD) environment. In the second approach, Digital Elevation Models (DEM) are used that are a form of a raster grid in which each cell contains elevation information. For this reason, they are usually labelled as 2.5D. Both approaches have advantages and disadvantages. Even though DEM models are usually available from national topographical services, like *swisstopo* (swisstopo, 2014), or can be generated using LiDAR data, generating vector models is a time-consuming and laborious process (Jonsson et al., 2012). DEM models can also be generated from vector data. Moreover, DEM models allow the representation of the urban area's surrounding topography, such as mountains, which would be almost impossible with vector data due to the amount of work that would be required (Jonsson et al., 2012). An advantage of CAD models is that, due to their 3D nature, they contain information for the vertical surfaces like building facades, while surfaces are represented as smooth planes instead of pixelated in the case of raster maps (Jakubiec and Reinhart, 2013). DEM models can overcome this using a higher pixel resolution but at the expense of increased computational effort. Apart from the two most widely used modelling techniques, other means to investigate urban solar potentials have been examined such as the use of satellite images (Humayun Kabir et al., 2010) and photogrammetry (Wittmann et al., 1997).

A non-exhaustive description of studies applying either of the previously mentioned modelling approaches is given here. Kodysh et al. (2013) and Brito et al. (2012) used DEMs generated from LiDAR data to calculate the solar radiation values and the PV generation potential, respectively, for multiple building rooftops. Jakubiec and Reinhart (2013) created a 3D vector model to be used in the validated Radiance/Daysim backward-raytracing engine. Their new method utilises detailed sky models, measured data, and considers reflections among buildings. Moreover, a rooftop temperature model allows for more accurate conversion efficiency calculation for the photovoltaic panels. Using vector-based models, Compagnon (2004) used RADIANCE to calculate the urban solar and daylight availability for both building roofs and facades with the focus not only being on photovoltaics, but also on active and passive solar heating as well as daylight applications. Kämpf and Robinson (2009), instead of working with a fixed geometry, used the solar radiation availability as the fitness function for an optimisation problem with the objective to optimise the geometric placement of a set of 11 buildings in an urban configuration. Choi et al. (2011) coupled TRNSYS and ArcGIS. In this case, starting from 3D building models, a DEM model is created and shading analysis is performed with ArcGIS to identify the usable rooftop area, while TRNSYS performs the PV performance simulations.