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Achieving energy sustainability in future neighborhoods through building refurbishment and energy hub concept: a case study in Hemberg-Switzerland

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Abstract

This study aims to investigate the role of distributed generation through the energy hub concept and refurbishment of existing buildings. More specifically, a computational platform combining (i) the urban energy modelling tool CitySimPro and (ii) the microgrid simulation tool Homer is developed. The energy flow on hourly basis is assessed for buildings in Hemberg, a small village in Switzerland, considering occupancy, lighting and appliances profiles, as defined by the Swiss normative. System design of the energy hub is optimized considering three energy system configurations: (i) present scenario, (ii) energy hub catering electrical demand, (iii) energy hub catering both electrical and thermal demand including heat pumps. Results for the integration of an energy hub on site show that the current use of renewables can be increased from 0.15% to over 60% by integrating heat pumps in the city energy network.

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Keywords: Energy hub; building refurbishment; energy efficiency; renewable energy integration

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1. Introduction

Switzerland has ambitious goals for increasing the use of renewable energy and reducing CO_2 emissions. In particular, the Swiss Energy Strategy 2050 aims at phasing out of nuclear energy by 2035 and a possible 50-80% reduction in CO_2 emission by 2050. Buildings have the largest share in energy demand in Switzerland: heating, ventilation, and air conditioning account for roughly 40% of the overall energy demand; 32% of the national electricity demand is also caused by buildings (HVAC, lighting, space heating). Therefore, transition towards (i) low-carbon energy supply technologies and (ii) increased energy efficiency of buildings (primarily through the building envelop, retrofitting, and user behaviour) are an important part of the "Swiss Energy Strategy 2050". In order to make cities environmentally sustainable, integrating renewable energy technologies in the built environment and improved building energy-efficiencies are scenarios of great potential. Several studies focus only on integrating renewable energy technologies (e.g. solar PV and micro-wind turbine) in the built environment [1,2] using different energy system modelling tools and approaches [3, 4]. Also, many studies propose solutions for the energy efficiency of buildings through improvements at system level such as HVAC, improvements in the building envelope, or improvements at the component level such as window glazing and insulation materials for walls [5, 6, 7, 8]. Very few studies, however, explore the possibility of combining solutions for renewable energy integration in buildings and to improve their energy efficiency and minimize the carbon footprint of buildings [9]. Also, as regards energy system improvements using the energy hub concept, many studies focus on the building scale while very few studies explore the optimization of energy systems at neighbourhood or district scale [9, 10]. Improving energy efficiency of buildings through retrofitting, integrating renewable energy technologies into buildings, and optimizing energy systems at neighbourhood scale are three closely interconnected activities that cannot be simply formulated as a simple optimization problem. Therefore, each activity should be assessed and linked to the others in order to propose a promising path towards a sustainable energy strategy for future neighborhoods. In this preliminary study, we develop a computational platform using several existing software programs to handle this process. Section 2 of the article presents a brief overview of the computational methods and tools used for (i) energy demand and potential estimation, (ii) energy system components and related costs. Section 3 of the article presents a brief overview of the village and the available data in order to explore a comprehensive assessment of the village energy system. Section 4 presents the results of the study. In Section 5, conclusions for the study are presented focusing on a sustainable energy strategy for the village.

2. Methodology and tools

2.1. Energy demand and energy potential estimation

In order to optimize the energy hub, an hourly profile of the village energy demand must be provided. The software CitySim Pro has been used to simulate the energy demand of the buildings in the village. CitySim Pro is an urban energy modelling tool which has been developed at Ecole Polytechnique Fédérale de Lausanne (EPFL). It allows us to simulate building-related resource flows by taking into account the location (climate and horizon data), the physical characteristics of buildings (shape, material, occupancy) and the energy conversion systems. The input data are as follows: 3D-geometry of the buildings coming from QGIS and Rhinoceros 5, climate and horizon data, and several other parameters including occupancy, materials as well as roofs, floors and walls insulation, opening properties, and surface reflectance. The original heating system is considered to be a boiler and there is no cooling system. As regards energy potential, short-wave irradiation is one output of CitySim. Short-wave irradiation is useful to optimize the PV panel layout and estimate the PV electricity production.

2.2. Energy hub components

The Energy Hub Concept has been implemented through the software HOMER. The software HOMER is a micropower optimization model developed by the U.S. National Renewable Energy Laboratory. It allows choosing a design for the energy hub and optimizing it. The designs are not only differentiated by their electricity and heating production systems but also by the storage options and the optional grid connection. Several components are