FOSS4G-based energy management system for planning virtual power plants at the municipal scale

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Abstract
The exploitation of renewable energy sources (RES) implies a transformation of the current energy supply infrastructure towards a spatially decentralized structure. This process has a significant impact on the use of space because energy is no longer generated far away from the demand, but it can be provided directly on-site. Hence, geographic information systems (GIS) have become a well established tool for the determination of sites for RES plants for heat and electricity generation. However, planning energy supply systems with a high share of RES, such as virtual power plants (VPPs), requires to consider also the temporal variation of the generation profiles of RES and the local energy demand. This paper presents the work in progress on a FOSS4G-based tool for the spatio-temporal modeling of municipality wide VPPs. The detailed simulation of potential RES-based supply alternatives and energy demand allows to identify suitable locations and to define the optimal size and technical characteristics of the individual RES energy generation plants in a VPP. This information can serve to assess technical renewable energy potentials at the municipal scale and to design a RES deployment roadmap customized to better fulfil the local energy demand.

Keywords
Integrated spatial and energy planning, renewable energy, virtual power plants

1 Introduction
A high share of renewable energy sources (RES) in the energy matrix will contribute to put an end on the dependency on fossil fuels and to reducing the amount of CO\textsubscript{2}. In the case of the European Union the goal is set at 80% decrease in greenhouse gas emissions from the level of 1990, which would imply a share of 75% RES in the gross final energy consumption and 97% in the electricity consumption by 2050 (EC 2011). These ambitious objectives require a change in the energy generation paradigm away from centralized generation towards distributed generation.

With this transformation of the current energy supply infrastructure to a
spatially decentralized structure two urgent problems arise: (1) wind and photovoltaics (PV) have a strong temporal variation and (2) total annual yield as well as the temporal variation strongly depend on the location of the plant. The temporal variation in power generation is not only a disadvantage of the meteorological influenced wind and PV technologies, but also applies for controllable combined heat and power (CHP) biomass plants, if the plants are driven by the heat production. Virtual power plants (VPP) were established as a concept to interconnect individual plants to compensate these spatio-temporal variations of one technology through variation of plants at different locations. Furthermore, VPPs compensate the deficits of one technology through the use of a portfolio of different technologies. Research based on GIS technologies has already led to a number of concepts to identify optimal locations considering a maximisation of annual yield (Zink, 2010; Angelis-Dimakis et al., 2011; Calvert, Pearce & Mabee, 2013). However, there is still an open gap between the annual yield modelling of locations, using GIS, and the planning of VPPs, considering the strong regional and temporal variations of different technologies at a minute-by-minute or hourly basis.

2 Energy management system for planning virtual power plants at the municipal scale

The proposed tool consists of three modules (see Figure 1): (1) a series of GIS-based components, used to determine the technically usable potential for renewables within a municipality at a high spatio-temporal resolution (individual installations of up to one square meter spatial resolution and hourly or intra-hourly time steps). (2) A GIS-based bottom-up model for estimating the energy demand for heating, water heating and electricity of buildings at a high temporal resolution (up to a quarter hours). (3) A newly developed VPP design module to select the plants configuration with the best match to the local energy demand. In addition, the required installed capacity of manageable RES, such as biomass, and the energy and power storage capacities, which are necessary to fulfil the demand of the local energy system is calculated. All modules are implemented in Python and rely on GRASS GIS, gdal, ogr, and Pktools.

The GIS-based modules to determine technical RES generation potential include the estimations of photovoltaic, solar thermal and wind energy potential. The potential estimation of the first two technologies relies on high resolution digital elevation models, vector data of the building footprints, global radiation, temperature data and technical parameters of common building-integrated photovoltaics and solar thermal plants. Calculation tools are the modules r.horizon and r.sun of GRASS GIS. The wind energy generation potential is assessed using a combination of reanalysis data and a GIS-based wind park location selection methodology.

The bottom-up model for estimating energy demand for heating, water heating and electricity demand of buildings requires georeferenced vector data in form of building’s footprints or, if available, 3D-buildings with level of detail 1 (LOD1) combined with historical data to match the individual buildings to building typologies. The typologies provide data for building's envelope
components quality that is necessary to run an adapted version of the resistance capacitance model defined in the EN ISO 13790:2008. This methodology is used for the calculation of the energy requirements for space conditioning. Further input parameters such as the dimensions of the building’s envelope components and the heating use areas are also estimated from the building’s footprints or retrieved from the LOD1 building models. The electricity demand of every building is defined with standard load profiles and the total electricity consumption per building is determined based on population data.

Figure 1 - Overall workflow of the tool.
The module to determine the VPP configuration searches for the combination of energy generation plants from fluctuating RES that has the best match to the local energy demand. The match to the demand is evaluated considering the amount of properly supply energy as well as the excess energy that every plant would contribute to the municipal energy system. The result is a data set representing the selected plants. Furthermore, dispatch profiles for biomass heat-driven CHP plants and storage systems are calculated in order to achieve a loss of power supply probability of zero. This means that the demand is fulfilled in all simulated time steps. The computed dispatch-profiles are the basis to calculate the CHPs and storage systems sizes. The algorithm based on a decision tree solves the problem firstly for every individual building for the heat and water heating demand and secondly municipality wide for the electricity demand.

3 Interim results

First results using the algorithm based on a decision tree approach to match supply and demand and the algorithm for sizing the storage system with data from a German rural municipality (Waldthurn, Bavaria) were presented in detail in Ramirez Camargo et al. (2015). A first VPP design calculated by the system for a part of Waldthurn in order to achieve a PV penetration rate of 40% of the yearly total demand is presented in Figure 2. This scenario was calculated for the electricity demand of 438 domestic buildings. Also the state of charge (SOC) of a storage system that does not allow any energy dumping and the state of charge of an optimally sized storage system were calculated (red and blue lines respectively). The SOC is based on the corresponding time series of the PV energy production minus the demand. The black and the dashed red colored lines in Figure 2 represent the power and energy capacities of the storage system that do not allow any energy dumping. The dashed yellow and dashed blue lines are the energy and power capacities of the optimally sized storage system.

![Figure 2 - Time series for selected PV-configuration for a penetration rate of 40% of the yearly demand.](image-url)

A preliminary version of the GIS based bottom-up model for predicting the energy demand for heating is available in Ramirez Camargo (2012). This was implemented as a combination of Visual Basic for Applications (VBA) and the proprietary software ESRI ArcGIS. The current version that is presented here is
programmed in Python and relies on GRASS GIS. Besides of the improvements in calculation time, the estimation of the solar radiation hitting the building`s envelope is improved by using the output of the r.sun module of GRASS GIS. Moreover, the model can work with LOD1 3D data and not only with German but also Austrian buildings typologies. Additionally, the calculation methodology is now compatible with German standard load profiles of electricity demand.

4 Future research

The proposed tool in its current status integrates relevant algorithms to determine renewable energy potentials as well as energy demand. The solar thermal potential and wind module as well as the sizing algorithm for the CHP plants are in progress. The merge of all modules and the test of the tool in at least two case study municipalities, one in Germany and one in Austria, are the next milestones. The final objective is to deploy the tool for municipalities and regional suppliers allowing them to concretize a technically appropriate RES deployment roadmap and conceive itself as VPP. The fact that the tool relies on well established FOSS4G components is not only an advantage in terms of flexibility and computational efficiency, but should also facilitate its use and distribution.

References


✔ European Commission (2011). Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions: Energy Roadmap 2050.


