Spatio-temporal Modeling for Renewable Distributed Energy Generation Planning at the Municipal Scale

Luis Ramirez Camargo
Applied Energy Research group, Technologie Campus Freyung, Deggendorf Institute of Technology, Grafenauer Straße 22, 94078, Freyung, Germany
Institute of Spatial Planning and Rural Development, University of Natural Resources and Life Sciences, Vienna, Austria

1 RESEARCH PROBLEM

An energy matrix based mainly on renewable sources will significantly reduce the dependency on fossil fuels and will contribute to reducing the amount of CO_2 concentrated in the atmosphere. In the case of the European Union (EU), goals are set at 20% share of the renewable energy sources (RES) in the gross final energy consumption, and a reduction of 20% of greenhouse gas emissions in comparison to the levels of 1990 by 2020 (CEC, 2007). Furthermore, long term aspirations include a decrease in greenhouse gas emissions of at least 80%, which would imply a share of RES of 75% and 97% by 2050 in the gross final energy consumption and in electricity consumption respectively (EC, 2011). These objectives can only be achieved if there is a transformation from the current centralized energy generation paradigm towards distributed generation (Borbely and Kreider, 2001; Lopes et al., 2007; Asmus, 2010).

Adopting distributed energy generation as a new paradigm entails the challenge of finding technical solutions that should ensure security of supply at minimum economic and ecologic cost and be acceptable for the local population (Wolsink, 2012). One of these necessary technical developments is the virtual power plant (VPP). In the European context, a VPP refers to aggregating renewable-based energy generation plants to supply certain desired demand in a reliable way (Asmus, 2010).

Planning a VPP is, however, not a simple task. On the one hand, the stochastic availability of RES such as solar radiation and wind has to be compensated with the spatial distribution of individual technologies, the combination of different types of RES and the strategic installation of backup and storage systems. On the other hand, the on-site production and the strong relation with use of space implies that small administrative units such as districts and municipalities play an active role in shaping the energy system (Burgess et al., 2012; Mendes et al., 2011).

Tools that properly consider the spatio-temporal complexity of the problem are necessary to support the planning process of VPPs. Geographic information systems (GIS) have been largely used to determinate the spatially explicit potential of RES (Calvert et al., 2013; Angelis-Dimakis et al., 2011). GIS-based procedures allow to stablish favorable sites for RES exploitation by superposing several technical, economic, environmental and/or regulatory constrains (Biberacher et al., 2008a). Nevertheless, most of the available GIS-based tools and procedures for RES potential estimation neglect temporal fluctuations of the resources. In the same way, simulation and optimization tools conceived to deal with the temporal variability of RES fail to consider the RES spatial interdependencies and are not appropriate for detailed modeling of entire municipalities. A tool suitable for VPP planning at the municipal scale is still absent.

2 OUTLINE OF OBJECTIVES

The purpose of this study is to develop a method that combines GIS-based RES potential estimation procedures with models for the simulation of energy generation and consumption profiles in a high temporal resolution. This new method should be able to overcome the deficiencies of previous approaches and serve for planning of VPPs at municipal scale from a technical point of view. Furthermore, the intention is to include a multicarrier approach in which the VPP not only supplies enough electricity but also enough energy for heating and water heating for local energy demand. This consideration of multiple energy carriers will contribute to conceive highly efficient distributed energy generation systems.

In order to achieve these objectives the following questions have to be answered:

Ramirez Camargo L..
Spatio-temporal Modeling for Renewable Distributed Energy Generation Planning at the Municipal Scale.

- Which established spatial models and methods for the estimation of RES potential and determination of the energy demand are suitable to be extended with high temporal resolution models?
- How is it possible to couple spatial and temporal models for RES generation potential and energy demand for entire municipalities?
- Which procedures serve to consider the temporal uncertainties, fluctuations and differences between energy demand and generation? How can they answer questions regarding RES technology combination and sizing for the conception of distributed generation systems, such as multicarrier VPPs at the municipal scale?

3 STATE OF THE ART

A wide range of tools, methods and models have been developed in the last decades to support national, regional and local authorities and private individuals in the planning and development of RES-based projects. These decision and planning support systems include GIS, simulation, optimization, accounting and impact calculation tools, as well as software packages that integrate several of these approaches (Mondal and Denich, 2010; Manfren et al., 2011; Mendes et al., 2011; Angelis-Dimakis et al., 2011; Adhikari et al., 2012).

GIS have been largely used to determine the potential and favorable areas for the deployment of RES (Calvert et al., 2013). As described by Biberacher et al., (2008a) the selection process can be divided in three main steps. It usually begins with the determination of the maximum theoretically available amount of a certain resource (solar radiation, wind, water, biomass and etc.). The next step is the utilization of technical criteria as e.g. land cover type, efficiencies and accessibility in order to reduce the usable area to one that can be exploited under the actual technical possibilities. The final step is the inclusion of economical, ecological and sustainability criteria, which can vary strongly depending on the RES and the region under study. The resulting areas and locations are normally used for two different tasks. On the one hand, they serve as basis for coarse calculations of total available energy from a certain source on a yearly or seasonal basis. On the other hand, they are the starting point for individual detailed assessments, which lead to the definition of the optimal dimensions for the energy generation plants.

There is also a long tradition in using computer-aided simulations and optimization algorithms for sizing hybrid renewable-based energy generation systems. Procedures can be traced back more than a decade ago for example in Ai et al., (2003) and Yang et al., (2003) and have been in permanent development (see e.g. Yang et al., 2007, 2008, 2009). Some of them, as e.g. HOMER (Lambert et al., 2006) have become very popular and powerful planning tools for hybrid systems

However, the combination of GIS-based procedures and simulations in a high temporal resolution for modeling RES-based systems is a field with much less contributions. The examples that can be found normally present a coarse temporal and/or a low spatial resolution and are unsuitable for detailed planning of VPPs at the municipal scale (see e.g. Zeyringer et al., 2012; Biberacher et al., 2008b; Mittlböck et al., 2006; Niemi et al., 2012).

4 METHODOLOGY

An extensive literature review on distributed energy generation including methodological approaches and models for the determination of RES potentials, spatially explicit demand estimation and sizing of renewable-based installations is the basis for answering the proposed questions.

Promising methodological approaches for modeling every individual RES and type of energy demand are then compared and tested for usability and compatibility. The selected spatial models for RES potential and demand estimation will be extended in its temporal component. Moreover, this development is complemented with an algorithm that allows to determine the location and required size of every single plant of the distributed energy generation system to fulfill the local demand. Finally, several case studies with data of municipalities in Germany and Austria are conducted in order to test and calibrate the method and its individual components.

5 EXPECTED OUTCOME

The outcome of the project includes: (1) methods for modeling individual renewable-based energy generation technologies in high temporal and spatial resolutions. (2) Methods for spatio-temporal simulation of energy demand for electricity and for space conditioning. (3) An algorithm for locating and sizing individual plants in a VPP within a municipality. (4) A software tool that allows to repro-

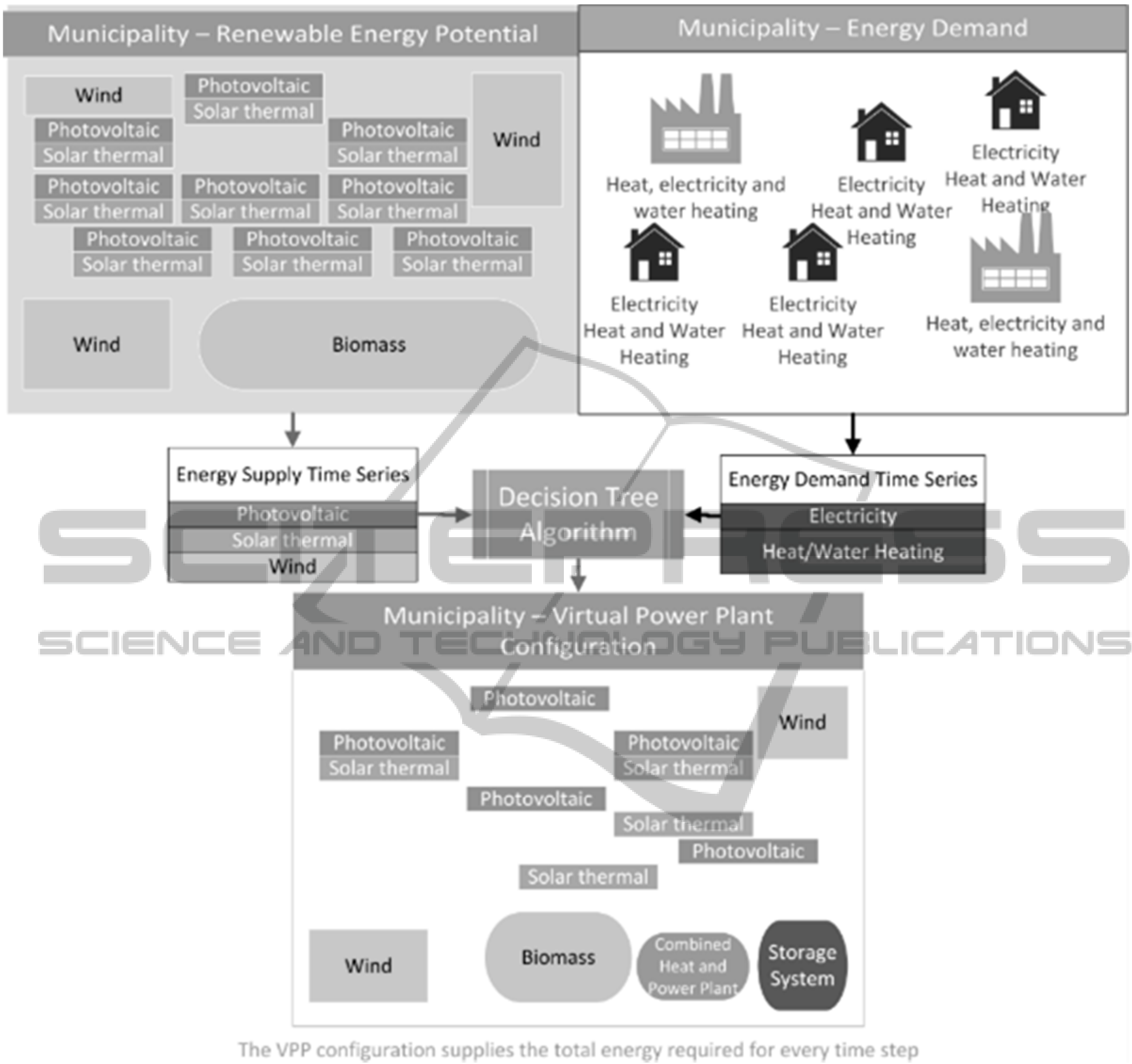

Figure 1: Underlying concept of the method for sizing virtual power plants at the municipal scale.

duce the method in a wide range of municipalities (5) Case studies of at least two municipalities (one in Germany and one in Austria) (6) a proof of the gains in efficiency that can be achieved when considering multi-carrier technologies in distributed energy generation systems. (7) A road-map for the exploitation of RES and a system design of a VPP to cover the local demand for the case study municipalities.

The method to be developed consist of a series of subsequent stages (see Figure 1). First, energy generation potential from RES and the demand from households, commerce and industry are georeferenced. Second, Yearly potential production and demand are disaggregated in a temporal resolution of at least hours. The resulting time series of supply and demand are the input data for a decision tree algorithm. Third, this algorithm selects which plants from the total potential should be build and which size they should have in order to fulfil efficiently most part of the local demand. Fourth, the resulting load and difference with the demand are used to determine the Biomass requirements and the sizes of storage systems and combined heat and power plants to cover the total local energy demand.

6 STAGE OF THE RESEARCH

After the literature review, the focus has been set to model the most promising but also most variable RES, solar radiation and wind. A review of available methodologies and a comparison of proprietary and open source GIS-based tools for estimating solar radiation potentials, as well as a proposal for using them for the estimation of solar radiation in a high spatio-temporal resolution is presented by Ramirez Camargo et al., (2014). A first attempt to test this procedure and the relevance of distributing photovoltaic plants through a region to reduce the fleet-output variability and fulfil a certain demand is available in Ramirez Camargo and Zink (2014). Ramirez Camargo et al., (2015) introduce a GIS-based methodology to generate time series for every potential roof-top photovoltaic plant within a municipality under consideration of real sky conditions, temperature variation and detailed technical parameters of photovoltaic plants. Furthermore, these time series are evaluated against the local demand of residential buildings using a decision tree algorithm. This algorithm configures photovoltaic plants sets that are the best match to the demand when pursuing a certain photovoltaic penetration level. Additionally, a methodology for sizing storage systems for the photovoltaic solution sets is introduced. A thorough evaluation of the resulting system configurations is performed using a pool of thirteen indicators. The resulting system configurations are equivalent to designing a VPP that relies entirely on photovoltaics and storage systems. Figure 2 presents an example of the resulting energy balance time series when using the methodology presented by Ramirez Camargo et al., (2015) for sizing a system to cover 50% of the yearly total demand of 438 residential buildings with photovoltaic systems. The solid line is the difference between the energy produced by the selected set of PV installations and the demand. The point-dash line is the state of charge of an optimally sized storage system and the horizontal dashed line is the optimal storage energy capacity.

Modeling solar thermal systems in high spatial and temporal resolutions is also possible since the main required parameter, solar radiation, is modeled already for the photovoltaic potential calculation.

The wind model is still in development. The aim is to couple spatial models based on ecologic and regulatory parameters, with reanalysis wind data and technical parameters for typical wind farms.

Biomass is considered as the ideal fuel for heat-driven combined heat and power plants. Since biomass is storable and transportable, there is no need to develop a high temporal definition model for estimating its availability. Standard GIS-based procedures are adopted for performing this task.

Concerning energy demand for heating and water heating, the methodology available in Ramirez Camargo (2012) has been actualized. This methodology now works with solar radiation information, calculated in the same way as for the photovoltaic potential, and with building data not only from Germany (as in the original version) but also from Austria. The core of this methodology is the resistance capacitance building model defined in the the EN ISO 13790:2008, which is adapted to operate with limited input data which in turn can be gained whit a GIS-based procedure. The results of the methodology are time series of energy requirements for space conditioning and water heating for every building within a municipality. The software application has been re-written to avoid the use of proprietary software.

The estimation of electricity demand of every building relies in standard load profiles with 15 minutes temporal resolution, and the total electricity consumption per building is determined based on population and building use data.

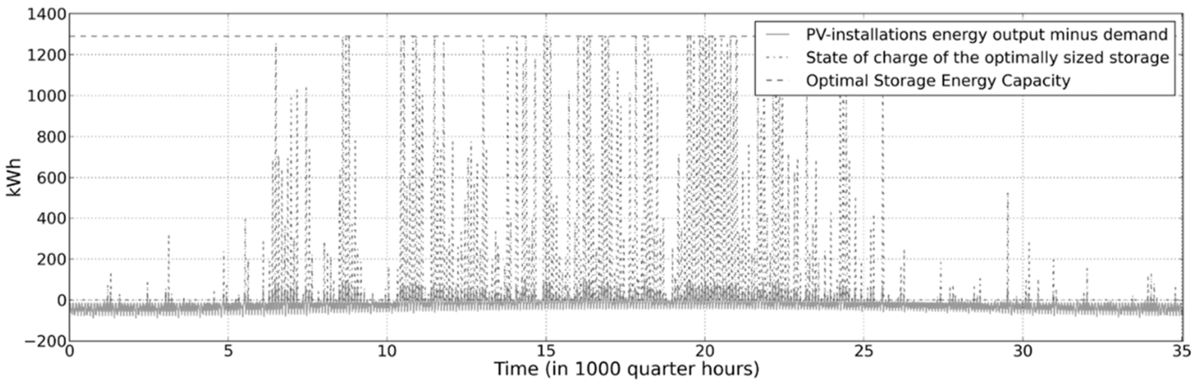

Figure 2: Time series for the selected system configuration when pursuing a photovoltaic penetration rate of 50% of the yearly total demand.

Finally, the algorithm to configure the virtual power plant is partially completed. The first step, in which the combination of energy generation plants from fluctuating RES with the best match to the local demand is selected, is to be perform analogously to the decision algorithm presented by Ramirez Camargo et al., (2015). The match of the demand is not only determined with the amount of properly supplied energy, but also with the excess energy supplied to the local system. Plants contributing with a high amount of properly delivered energy and a low load of excess energy will be preferred. The sizing of storage systems can also be performed, but the algorithm for dimensioning the biomass heat-driven combined heat and power plants as well as the integration with the previous algorithms is still work in progress.

The software developed with every part of the methodology exists in a prototype version that combines bash, python and a series of free and open source software for geospatial applications. The aim is to deliver a software tool that runs entirely on python and the free and open source software for geospatial applications, which should be available for a wide range of users.

REFERENCES

Adhikari, R. S., Aste, N. and Manfren, M. (2012). Optimization concepts in district energy design and management – A case study. *Energy Procedia*, 14, p.1386–1391. [Online]. Available at: doi:10.1016/j.egypro.2011.12.1106 [Accessed: 19 February 2013].

Ai, B., Yang, H., Shen, H. and Liao, X. (2003). Computer-aided design of PV/wind hybrid system. *Renewable Energy*, 28 (10), p.1491–1512. [Online]. Available at: doi:10.1016/S0960-1481(03)00011-9 [Accessed: 4 April 2013].

Angelis-Dimakis, A., Biberacher, M., Dominguez, J., Fiorese, G., Gadocha, S., Gnansounou, E., Guariso, G., Kartalidis, A., Panichelli, L., Pinedo, I. and Robba, M. (2011). Methods and tools to evaluate the availability of renewable energy sources. *Renewable and Sustainable Energy Reviews*, 15 (2), p.1182–1200. [Online]. Available at: doi:10.1016/j.rser.2010.09.049 [Accessed: 20 February 2013].

Asmus, P. (2010). Microgrids, Virtual Power Plants and Our Distributed Energy Future. *The Electricity Journal*, 23 (10), p.72–82. [Online]. Available at: doi:10.1016/j.tej.2010.11.001 [Accessed: 30 January 2013].

Biberacher, M., Gadocha, S., Gluhak, S., Dorfinger, N. and Zocher, D. (2008a). Implementation of a GEOdatabase to administrate global energy resources. In: *Proceedings of the International Congress on Environmental Modelling and Software, Universitat Politècnica de Catalunya, Barcelona*, 2008. [Online]. Available at: http://www.iemss.org/iemss2008/uploads/Main/S15-02-Biberacher_et_al-IEMSS2008.pdf [Accessed: 8 March 2013].

Biberacher, M., Gadocha, S. and Zocher, D. (2008b). GIS based Model to optimize possible self sustaining regions in the context of a renewable energy supply. In: *Proceedings of the International Congress on Environmental Modelling and Software, Universitat Politècnica de Catalunya, Barcelona*, 2008. [Online]. Available at: http://www.iemss.org/iemss2008/uploads/Main/S15-12-Biberacher_1_et_al-IEMSS2008.pdf [Accessed: 8 March 2013].

Borbely, A.-M. and Kreider, J. F. (2001). *Distributed generation: the power paradigm for the new millennium*, Mechanical engineering series. Boca Raton: CRC Press.

Burgess, P. J., Rivas Casado, M., Gavu, J., Mead, A., Cockerill, T., Lord, R., van der Horst, D. and Howard, D. C. (2012). A framework for reviewing the trade-offs between, renewable energy, food, feed and wood production at a local level. *Renewable and Sustainable Energy Reviews*, 16 (1), p.129–142. [Online]. Available at: doi:10.1016/j.rser.2011.07.142 [Accessed: 20 February 2013].

Calvert, K., Pearce, J. M. and Mabee, W. E. (2013). Toward renewable energy geo-information infrastructures: Applications of GIScience and remote sensing that build institutional capacity. *Renewable and Sustainable Energy Reviews*, 18, p.416–429. [Online]. Available at: doi:10.1016/j.rser.2012.10.024 [Accessed: 19 February 2013].

Commission of the European communities. (2007). *Communication from the commission to the European council and the European parliament: An Energy Policy for Europe*. [Online]. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0001:FIN:EN:PDF [Accessed: 2 April 2013].

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*. [Online]. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF [Accessed: 1 April 2013].

Lambert, T., Gilman, P. and Lilienthal, P. (2006). Micropower system modeling with HOMER. *Integration of alternative sources of energy*, 1. [Online]. Available at: https://wwww.homerenergy.com/documents/MicropowerSystemModelingWithHOMER.pdf [Accessed: 7 August 2013].

Lopes, J. A. P., Hatziargyriou, N., Mutale, J., Djapic, P. and Jenkins, N. (2007). Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. *Electric Power Systems Research*, 77 (9), p.1189–1203. [Online]. Available at: doi:10.1016/j.epsr.2006.08.016 [Accessed: 18 February 2013].

Manfren, M., Caputo, P. and Costa, G. (2011). Paradigm shift in urban energy systems through distributed generation: Methods and models. *Applied Energy*, 88 (4), p.1032–1048. [Online]. Available at: doi:10.1016/j.apenergy.2010.10.018 [Accessed: 10 May 2012].

Mendes, G., Ioakimidis, C. and Ferrão, P. (2011). On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renewable and Sustainable Energy Reviews*, 15 (9), p.4836–4854. [Online]. Available at: doi:10.1016/j.rser.2011.07.067 [Accessed: 25 February 2013].

Mittlböck, M., Biberacher, M., Prinz, T., Rieder, W., Strobl, J., Zocher, D., Blaschke, T., Brunner-Maresch, B., Griesebner, G. and Pospischil, W. (2006). *Virtuelle Kraftwerke für Autarke Regionen*. Bundesministerium für Verkehr, Innovation und Technologie, bmvit. [Online]. Available at: http://www.energieder zukunft.at/nw_pdf/0658_virtuelle_kw_autarke_region en.pdf [Accessed: 21 January 2013].

Mondal, M. A. H. and Denich, M. (2010). Assessment of renewable energy resources potential for electricity generation in Bangladesh. *Renewable and Sustainable Energy Reviews*, 14 (8), p.2401–2413. [Online]. Available at: doi:10.1016/j.rser.2010.05.006 [Accessed: 19 February 2013].

Niemi, R., Mikkola, J. and Lund, P. D. (2012). Urban energy systems with smart multi-carrier energy networks and renewable energy generation. *Renewable Energy*, 48, p.524–536. [Online]. Available at: doi:10.1016/j.renene.2012.05.017 [Accessed: 21 February 2013].

Ramirez Camargo, L. (2012). *A GIS-Based Method for Predicting Hourly Domestic Energy Need for Space Conditioning and Water Heating of Districts and Municipalities*.

Ramirez Camargo, L., Pagany, R. and Marquardt, A. (2014). Zeitlich und räumlich hochaufgelöste Modellierung der potentiellen solaren Einstrahlung - ein Methodenvergleich. In: Strobl, J., Blaschke, T., Griesebner, G. and Zagel, B. (eds.), *Angewandte Geoinformatik 2014, Beiträge zum 26. AGIT-Symposium Salzburg*, Berlin: Wichmann, p.143–152. [Online]. Available at: http://gispoint.de/fileadmin/ user_upload/paper_gis_open/537543062.pdf.

Ramirez Camargo, L. and Zink, R. (2014). Photovoltaik in virtuellen Kraftwerken zur Versorgung regionaler Elektromobilitätskonzepte. In: Strobl, J., Blaschke, T., Griesebner, G. and Zagel, B. (eds.), *Angewandte Geoinformatik 2014, Beiträge zum 26. AGIT-Symposium Salzburg*, Berlin: Wichmann, p.153–158. [Online]. Available at: http://gispoint.de/fileadmin/ user_upload/paper_gis_open/537543063.pdf.

Ramirez Camargo, L., Zink, R., Dorner, W. and Stoeglehner, G. (2015). Spatio-temporal modeling of roof-top photovoltaic panels for improved technical potential assessment and electricity peak load offsetting at the municipal scale. Computers, Environment and Urban Systems, 52, p.58–69. [Online]. Available at: doi:10.1016/j.compenvurbsys.2015.03.002.

Wolsink, M. (2012). The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. *Renewable and Sustainable Energy Reviews*, 16 (1), p.822–835. [Online]. Available at: doi:10.1016/j.rser.2011.09.006 [Accessed: 14 February 2013].

Yang, H., Lu, L. and Zhou, W. (2007). A novel optimization sizing model for hybrid solar-wind power generation system. *Solar Energy*, 81 (1), p.76–84. [Online]. Available at: doi:10.1016/j.solener. 2006.06.010 [Accessed: 27 March 2013].

Yang, H., Wei, Z. and Chengzhi, L. (2009). Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. *Applied Energy*, 86 (2), p.163–169. [Online]. Available at: doi:10.1016/j.apenergy.2008.03.008 [Accessed: 4 April 2013].

Yang, H. X., Lu, L. and Burnett, J. (2003). Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong. *Renewable Energy*, 28 (11), p.1813–1824. [Online]. Available at: doi:10.1016/S0960-1481(03)00015-6 [Accessed: 4 April 2013].

Yang, H., Zhou, W., Lu, L. and Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar Energy*, 82 (4), p.354–367. [Online]. Available at: doi:10.1016/j.solener.2007.08.005 [Accessed: 4 April 2013].

Zeyringer, M., Andrews, D., Schmid, E., Schmidt, J. and Worrell, E. (2012). Simulation of disaggregated load profiles and construction of a proxy-microgrid for modeling purposes. In: *9th International Conference on the European Energy Market (EEM)*, 2012. [Online]. Available at: doi:10.1109/EEM.2012.6254816.