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Prosumer Cluster of Single-Family Houses under the Danish Net Metering Policy

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ABSTRACT

In the energy sector, prosumers are typically houses with rooftop PV. With the drastically falling prices of PV panels, the number of installations is rising. Prosumers can have negative impacts, on power grids especially in the distribution grid. In order to mitigate this effect, and for the own benefit of the prosumers, they can function as groups sharing their resources. A literature overview is given focusing on studies that deal with this issue from the prosumer perspective, showing that many optimization studies focus on maximizing economical benefits and others on self-consumption or related indicators by means of energy management strategies and market models, most often hourly based. A case study is presented in the context of the current Danish net-metering scheme. The results show that savings for prosumers and increase of total self-consumption can be achieved by redistributing energy within the building cluster with rule-based control.

KEYWORDS
Energy prosumer, PV, net-metering, single-family house, building cluster

INTRODUCTION

Prosuming buildings are buildings that both “produce” and “consume” energy (Schleicher-Tappeser, 2012). Typically the term prosumer in the energy sector refers to a house with rooftop photovoltaic (PV) panels (www.energy.gov). An estimate of 25-35% of the global cumulative installed PV capacity is at the residential level (Couture et al., 2014). Because of the high electricity tariff, PV has reached grid-parity in Denmark, like in most other European countries (Schleicher-Tappeser, 2012). In order to support renewable energy, some countries have implemented net-metering schemes for residential prosumers. This means that the surplus energy can be stored in the grid within a set period. In Denmark the net metering is on an hourly basis (www.iea.org). Electricity production at the residential level can have a negative impact on the grid, especially at the local scale, amongst others by causing overvoltage in some cases (Vallée et al., 2013). In order to mitigate this, it has been suggested to increase the self-consumption (Luthander et al., 2015). The hypothesis of this study is that the impact on the grid can be decreased and the economical benefit of the users can be increased by forming groups of single-family house prosumers A case study is carried out in the context of Danish hourly based net metering, based on a literature review.

LITERATURE REVIEW OF PROSUMER CLUSTERS

For the present literature search, a systematic search for documents containing the terms “prosumer” and “energy” on Web of Science and Scopus was done. Papers were selected based on the following two rules:

Table 1. – Studies of prosumer clusters

						Technologies		
Objective function	KPI	reference	Time Step	Simulation Time	Method	PV	ES	other
case study	self-consumption	Bellekom et al., 2017	5 minutes	24 hours	5 scenarios combining residential storage and peer-to-peer exchange	x	x	
maximize sef-consumption	profit	Broering and Madlener, 2017	15 minutes	1 month	3 scenarios in the German context varying grid-use and feed-in tariffs	x	battery cloud	
reduce reverse flow	savings	Brusco et al., 2014	1 hour	24 hours	clustering in an energy district, energy management with trading			
maximize profit	net revenue	Giuntoli and Poli, 2014	15 minutes 1 hour	24 hours	MILP for a VPP including prosumers	x	x	CHP, thermal storage
self-consumption maximization	demand and supply ratio	Liu et al., 2016	1 hour	12 hours	dynamic pricing in non-cooperative game	x		Demand response
maximize profit	net loads and profits	Ma et.al., 2016	½ hour	24 hours	heuristic method to reach Stackelberg equilibrium	x	x	CHP, Demand response
minimize cost	cost and spillage savings	Martín-Martínez et. al., 2016	1 hour	12 representative days	MCP for prosumers in microgrid; game theory in imperfect competition case	x	x	Demand response, thermal storage
limit power flows	PV hosting capacity	Palacios-Garcia et al., 2017	1 minute	4 days 1 year	increasing self-consumption, soft and hard curtailment	x	x	
optimize dispatch with constraints	cost savings, self-consumption	Rigo-Marian et.al., 2014	1 hour	24 hours	heuristic methods; sequential forecast; microgrid	x		
investment resiliency	cost savings	Sanduleac et al., 2017	15 minutes	24 hours	Uni-directional Resilient Consumer (UniRCon) architecture	x	x	
minimize loss of delivery and cost	delivery loss, self-consumption, cost	Sha, Aiello, 2016	1 hour	24 hours	flow optimization with "Arc Dynamic Direction Matrix"	x		Wind turbines
minimize cost	simple payback period	Tedesco et. al., 2015	1 hour	1 year	Economic MPC for prosumer microgrid; battery lifetime considered		x	Wind turbines
maximize local consumption	local consumption	Velik, Nicolay, 2014 & 2015	1 hour	30 days	modified simulated annealing triple-optimizer/cognitive decision agent	x	x	
maximize social welfare	power imbalance	Verschae et al., 2016	10 minutes 1 hour	1 day	coordinated management approach based on ADMM	x	x	Demand response
three objectives translated to total annualised cost	cost, CO2 and unavailability	Wouters et al., 2017	1 hour	1 day	MILP for system design of small neighborhood	x	x	CHP

ES = Electric Storage, MILP = Mixed Integer Linear Programming, VPP = Virtual Power Plant, MCP=Mixed Complementarity Problem, ADMM = Alternating Direction Method of Multipliers, CHP = Combined Heat and Power KPI = Key Performance Indicator

1) included Q1 and Q2 journal papers focusing on groups of residential grid-connected prosumers of electricity from renewable energy sources and 2) -excluded the papers that focus on design of trading models, clustering method, demand response models, social science, politics or business, or has a more general viewpoint. An overview is given in Table 1. As can be seen, in the recent years, the number of optimization studies about energy prosumers has been growing rapidly. The objective function in most of these studies is either an economical indicator related to the interest of each prosumer or the prosumer cluster, or a grid-related indicator like maximizing the self-consumption or local consumption. These two objectives are correlated and studies that choose one often pick the other as a key performance indicator. In most studies, the focus is on the operational costs, as opposed to investments. It is difficult to compare the efficiency of the employed methods directly, as different system setups are used. The time step of the simulation is commonly one hour and the simulation time 24 hours. Also, the consumption profiles used are often generic ones, scaled down from national domestic consumption. Based on the above literature study, both economic benefits and self-consumption were chosen as indicators for this study. A one minute based time step is used with the simulation run for one year, in order to gain a helicopter view of the prosumer cluster.

METHODS

Consumption profiles and PV electricity generation

The energy consumption in one minute resolution for 2015 was generated with the open source generator "CREST Demand Model" provided by McKenna & Thomson (2016). Three single family houses of the same building type and each with four residents but with different orientations were considered. The house type was defined by "building index 1" in the CREST Demand Model, which is a detached house of 136 m^2.

The PV production was simulated with TRNSYS. For the weather file, a Meteonorm generated typical meteorological year for Copenhagen Taastrup was used. The Parameters for the PV panel were taken from the datasheet for REC (www.recgroup.com), for a panel with a nominal power of 300W. The model for PV production was validated by comparing the efficiency of the Panel in the simulation against the efficiency stated by the manufacturer.

Setup for simulation scenarios

The three single family houses were oriented towards east, south and west, respectively (see figure 1). The slope of the roofs with the PV panels installed was set to 55°, which is close to the latitude of Copenhagen, as recommended for all-year round PV systems with a fixed slope (Agrawal & Tiwari, 2009; Phadke, 2010). Each house was simulated with 10 PV-modules of 1.67 m^2, and a total PV installation of 16.7 m^2 aperture area. Two scenarios were considered: 1) base case scenario, in which each house is operated separately, and 2) cluster scenario, in which a common controller is used to redistribute energy flows from houses with excess production to houses with energy deficiency. This flow redistribution was performed in each simulation step.

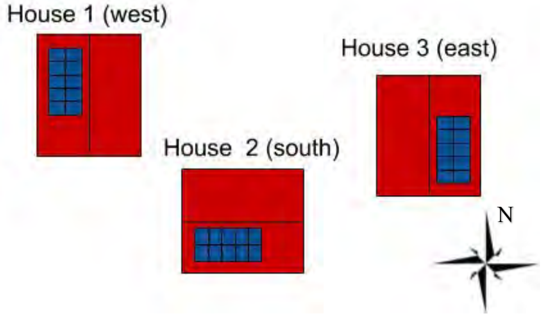

Figure 1. – Houses with orientations

Control algorithm for energy flow redistribution

Rule-based control was used for the flow redistribution. If any house has production at a given time, covering one's own demand is prioritized. After subtracting the energy use from the respective productions in a time step, the net energy flows are assessed and if there is simultaneous surplus and deficit, the surplus is then sent to the house with energy deficit. The prioritization is based on the absolute value of surplus or deficit, meaning electricity is first sent to/from the one with the larger deficit/surplus.

The indicators for the evaluation are self-consumption and electricity cost savings. Self-consumption is defined as the ratio of the momentary consumption of the power produced on-site (Luthander et al., 2015). It was calculated according to the following equations:

$$E_{SC}^{time\ step} = \min(E_{prod}^{time\ step}; E_{cons}^{time\ step}) \tag{1}$$

$$SC = \frac{E_{SC}^{y}}{E_{prod}^{y}} \tag{2}$$

Where $E_{SC}^{time\ step}$ is the self-consumed energy in each time step, $E_{prod}^{time\ step}$ is the energy produced and $E_{cons}^{time\ step}$ is the energy consumed in each time step. SC is the self-consumption ratio, E_{SC}^{y} is the yearly total self-consumed energy and $E_{prod}^{y}$the yearly total energy produced on-site. In the second scenario, the effective self-consumption SC_{eff} (or local consumption), for each house was based on the effective consumption (or local consumption of the energy produced by that house) ($E_{ec,i}^{time\ step}$), calculated as in equation (3), and the on-site production of each house, as in the base case scenario.

$$E_{ec,i}^{time\ step} = E_{cons,i}^{time\ step} + flow_{i\_}^{time\ step} \tag{3}$$

$$SC_{eff} = \frac{E_{ec,i}^{y}}{E_{prod,i}^{y}} \tag{4}$$

Where $flow_{i\_}^{time\ step}$ represents the total redirected flow from the given house i to other houses. The Danish Net-metering scheme is hour-based (iea.org), making it one of the most restrictive carryover provisions. This was taken into account when modelling the cash flow. When the net hourly energy was positive, it was multiplied with the feed-in tariff of 0.07 €. When it was negative it was multiplied with the retail electricity price of 0.31 €. Due to this difference, there is incentive to self-consume as much of the produced electricity as possible, in order to make the PV installation more profitable.

RESULTS

Self-consumption in the building cluster

Table 2. shows the self-consumption and its relative increase after clustering the three buildings and redirecting the surplus flows. The total self-consumption (or local consumption) is based on the total instantaneous production and the total instantaneous consumption.

Table 2. Self-consumption ratio (%)

	Separate scenario	Clustered scenario	Increased, %
House 1	40.56	54.41	34.2
House 2	36.91	51.07	38.4
House 3	44.14	57.61	30.5
Total	40.15	52.93	31.8

Electricity cost and savings

The calculated yearly electricity cost for each house, and in total, are presented in Table 3. For reference, the electricity cost without installed PV panels is shown in the third column. Based on this reference the savings were calculated for both the base case scenario and the clustered scenario. These can be seen in Table 4. The increase in savings of the clustered scenario is calculated in comparison with the separate scenario. The yearly electricity cost is reduced after clustering, with the increase in self-consumption. This is because the retail price of electricity from the grid is higher than the feed-in tariff for surplus electricity sent to the grid.

Table 3. Yearly electricity cost (€)

	Baseline case (no PV)	Separate scenario	Clustered scenario
House 1	1597	1190	1121
House 2	1551	1138	1017
House 3	1661	1236	1138
total	4809	3564	3276

Table 4. Savings compared to baseline case (€)

	Separate scenario	Clustered scenario	Increased, %
House 1	407	476	17%
House 2	413	535	30%
House 3	425	523	23%
Total	1245	1534	23%

DISCUSSIONS

In order to represent the grid-impact and the instantaneous self-consumption more accurately, in this study a time step of 1 minute was used, simulated over a year. The case setup was a simple example to give an indication of the effect on the correlation of the savings with the grid-impact reduction for the given tariff scheme. In this case study, it was assumed that the three houses freely share their surplus energy with rule-based control. The increase in self-consumption was slightly higher than the increase in electricity cost savings. The difference in savings is expected to be more pronounced with no net-metering. In this study the houses had a similar production and shared their surplus production freely and it was not necessary to consider the local trading dynamics. For a more general case, a remuneration has to be agreed upon, with a price between the feed-in tariff and the retail price. Additional wiring and controller costs for the local redistribution should be considered for making a more comprehensive economical analysis that also includes investment costs, for example by calculating the Net Present Value (NPV). This calculation was out of scope for this study. Some technologies for smart grids that enable local energy management are still in early stages and are expected to become more affordable in the future.

CONCLUSIONS

A literature overview was presented, focusing on studies about groups of prosuming buildings with PVs. It was found that most previous studies were on an hourly basis with a 24 hour time-frame. In those studies, both impact on grids and economic gains for users were often investigated. A case study of three prosumer houses was conducted under Danish hourly net metering conditions. Simulations were run for one year to investigate the effect of energy distribution within this building cluster. In the clustered scenario, self-consumption ratio increased 32% in total, indicating a decrease of the impact on the grid. Electricity cost savings with respect to the baseline case with no local production were calculated for both scenarios. In the clustered scenario, the savings increased 23% compared to the separated scenario. It is in line with the expectations that the savings increased when the self-consumption increased, as the electricity retail price is higher than the feed-in tariff. The control in the current study is rule-based. In further research MPC for buildings will be considered with flexible electric load.

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REFERENCES

Agrawal, B., & Tiwari, G. N. (2009). Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions. *Applied Energy*, *87*, 417–426. http://doi.org/10.1016/j.apenergy.2009.06.011

Bellekom, S., Arentsen, M., & Van Gorkum, K. (n.d.). Prosumption and the distribution and supply of electricity. http://doi.org/10.1186/s13705-016-0087-7

Broering, H., & Madlener, R. (2017). Simulation and Evaluation of the Economic Merit of Cloud Energy Storage for Prosumers: The Case of Germany. *Energy Procedia*, *105*, 3507–3514. http://doi.org/10.1016/J.EGYPRO.2017.03.804

Brusco, G., Burgio, A., Menniti, D., Pinnarelli, A., & Sorrentino, N. (2014). Energy management system for an energy district with demand response availability. *IEEE Transactions on Smart Grid*, *5*(5), 2385–2393. http://doi.org/10.1109/TSG.2014.2318894

CITIES Centre for IT-Intelligent Energy Systems in cities. (n.d.). Retrieved June 7, 2017, from http://smart-cities-centre.org/

Consumer vs Prosumer: What's the Difference? | Department of Energy. (n.d.). Retrieved April 3, 2018, from https://www.energy.gov/eere/articles/consumer-vs-prosumer-whats-difference

Couture, T., Barbose, G., Jacobs, D., Parkinson, G., Chessin, E., Belden, A., … Rickerson, W. (2014). *Residential Prosumers: Drivers and Policy Options (Re-Prosumers)*. Berkeley, CA (United States). Retrieved from http://www.osti.gov/servlets/purl/1163237/

Giuntoli, M., & Poli, D. (2013). Optimized thermal and electrical scheduling of a large scale virtual power plant in the presence of energy storages. *IEEE Transactions on Smart Grid*, *4*(2), 942–955. http://doi.org/10.1109/TSG.2012.2227513

IEA - Denmark - Net-metering. (2012). Retrieved January 25, 2018, from http://www.iea.org/policiesandmeasures/pams/denmark/name-42926-en.php

Liu, N., Wang, C., Lin, X., & Lei, J. (2016). Multi-Party Energy Management for Clusters of Roof Leased PV Prosumers: A Game Theoretical Approach. *Energies*, *9*(7), 536. http://doi.org/10.3390/en9070536

Luthander, R., Widén, J., Nilsson, D., & Palm, J. (2015). Photovoltaic self-consumption in buildings: A review. *Applied Energy*, *142*, 80–94. http://doi.org/10.1016/j.apenergy.2014.12.028

Ma, L., Liu, N., Zhang, J., Tushar, W., & Yuen, C. (2016). Energy Management for Joint Operation of CHP and PV Prosumers inside a Grid-connected Microgrid: A Game Theoretic Approach. *IEEE Transactions on Industrial Informatics*, *3203*(c), 1–1. http://doi.org/10.1109/TII.2016.2578184

Martín-Martínez, F., Sánchez-Miralles, A., & Rivier, M. (2016). Prosumers' optimal DER investments and DR usage for thermal and electrical loads in isolated microgrids. *Electric Power Systems Research*, *140*, 473–484. http://doi.org/10.1016/j.epsr.2016.05.028

McKenna, E., & Thomson, M. (2016). High-resolution stochastic integrated thermal-electrical domestic demand model. *Applied Energy*, *165*, 445–461. http://doi.org/10.1016/j.apenergy.2015.12.089

Palacios-Garcia, E., Moreno-Muñoz, A., Santiago, I., Moreno-Garcia, I., & Milanés-Montero, M. (2017). PV Hosting Capacity Analysis and Enhancement Using High Resolution Stochastic Modeling. *Energies*, *10*(10), 1488. http://doi.org/10.3390/en10101488

Phadke, V. (2010). Photovoltaic Power Systems. *US Patent App. 12/976,495*, 1–33. Retrieved from http://www.google.com/patents/US20120080943

REC. (n.d.). rec TwinPeak 2 SERIES datasheet. Retrieved from https://www.recgroup.com/sites/default/files/documents/ds_rec_twinpeak_2_series_ul_rev_f_eng.pdf

Rigo-Mariani, R., Sareni, B., Roboam, X., & Turpin, C. (2014). Optimal power dispatching strategies in smart-microgrids with storage. *Renewable and Sustainable Energy Reviews*, *40*, 649–658. http://doi.org/10.1016/j.rser.2014.07.138

Sanduleac, M., Ciornei, I., Albu, M., Toma, L., & Sturzeanu, M. (2017). Resilient Prosumer Scenario in a Changing Regulatory Environment — The UniRCon Solution. http://doi.org/10.3390/en10121941

Schleicher-Tappeser, R. (2012). How renewables will change electricity markets in the next five years. *Energy Policy*, *48*, 64–75. http://doi.org/10.1016/j.enpol.2012.04.042

Sha, A., & Aiello, M. (2016). A Novel Strategy for Optimising Decentralised Energy Exchange for Prosumers. *Energies*, *9*(7), 554. http://doi.org/10.3390/en9070554

Tedesco, F., Mariam, L., Basu, M., Casavola, A., & Conlon, M. F. (2015). Economic Model Predictive Control-Based Strategies for Cost-Effective Supervision of Community Microgrids Considering Battery Lifetime. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, *3*(4), 1067–1077. http://doi.org/10.1109/JESTPE.2015.2446894

Vallée, F., Klonari, V., Lisiecki, T., Durieux, O., Moiny, F., & Lobry, J. (2013). Development of a probabilistic tool using Monte Carlo simulation and smart meters measurements for the long term analysis of low voltage distribution grids with photovoltaic generation. *International Journal of Electrical Power and Energy Systems*, *53*, 468–477. http://doi.org/10.1016/j.ijepes.2013.05.029

Velik, R., & Nicolay, P. (2014). A cognitive decision agent architecture for optimal energy management of microgrids. *Energy Conversion and Management*, *86*, 831–847. http://doi.org/10.1016/j.enconman.2014.06.047

Verschae, R., Kato, T., & Matsuyama, T. (2016). Energy Management in Prosumer Communities: A Coordinated Approach. *Energies*, *9*(7), 562. http://doi.org/10.3390/en9070562

Wouters, C., Fraga, E. S., & James, A. M. (2017). A multi-objective framework for cost-unavailability optimisation of residential distributed energy system design. *Sustainable Energy, Grids and Networks*, *9*, 104–117. http://doi.org/10.1016/j.segan.2017.01.002