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Strategies to maximise the autonomy of neighbourhoods with the integration of renewable energies

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Abstract. A simulation tool (EcoSim) has been developed to analyse the economic and environmental aspects of the integration of several energy conversion units. For a given investment over 25 years, the tool calculates the self-consumption rate, the autonomy level, the levelized cost of energy (LCOE) and the CO₂ emissions. A neighbourhood is modelled using the Rhino software. Then the dynamic simulation software, CitySim Pro, determines the hourly energy demand and solar PV generation. Finally, the techno-economic and environmental parameters are calculated using EcoSim. For this neighbourhood located in Basel, the self-consumption rate is maximised by combining solar PV and battery. With the sale of locally produced electricity to the residents of the neighbourhood, we have shown that the implementation of such a self-consumption community leads to a more economically profitable situation as compared to the current case where electricity is bought from an industrial company.

1. Introduction

Switzerland has decided to progressively withdraw from nuclear energy production; therefore, its focus is shifting to energy efficiency and renewable energies for electricity production. Decentralized energy systems that combine different renewable energy technologies such as solar panels, batteries and heat pumps are becoming increasingly popular to establish more sustainable and autonomous buildings [1, 2]. With the new Energy Ordinance of 1st November 2017 that encourages the creation of a self-consumption community, solar photovoltaics (SPV) is becoming more and more attractive. Since January 1, 2018, it is possible to create a local solar community, which makes it possible to sell the locally produced electricity to the residents of the neighbourhood and to buy electricity directly from the grid at a wholesale price.

The objective of this work is to model and evaluate the integration of energy systems in a large neighbourhood and to validate the previously developed simulation tool (EcoSim) [3] on two real case studies. Different strategies are adopted to maximise the self-consumption by using solar panels and other renewable energies while also looking at the economic profitability.

A neighbourhood located in Basel is considered for the scope of this study. This area contains six buildings with 120 apartments. The electrical part will be addressed by adding solar PV and

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batteries for the Basel neighbourhood. The rest of the paper is structured as follows: first an overview of the model and workflow is outlined. Second, the results are analysed for the Basel case study and finally the conclusion given with some perspectives for this study.

2. Models

The chosen approach is divided in three parts: geometry modelling in Rhino software, demand and solar generation modelling in CitySim Pro and techno-economic simulation in EcoSim.

2.1. Geometry modelling on Rhino software

All the buildings in these neighbourhoods are designed with the help of the Rhino software. This geometrical model can be imported in CitySim Pro either in the DXF format or in the XML format in order to perform a dynamic energy simulation.

2.2. Demand and solar generation modelling on CitySim Pro

CitySim Pro [4] simulates the electricity demand, the heating demand and the solar generation of each building over one typical year by using the Meteonorm dataset [5]. The energy demand of each building is simulated by modelling the behaviour of appliances, lighting and the ventilation system within an hourly assessment over a year.

2.3. Techno-economic simulation in EcoSim

EcoSim is a simulation tool developed to make a techno-economic and environmental assessment for different scenarios. The simulation calculates the self-consumption ratio, the autonomy level, the levelized cost of energy (LCOE) and the CO₂ emissions [3] by using the hourly load curve of electricity and thermal demand and the hourly solar PV generation profile obtained from CitySim Pro software. Figure 1 shows the complete workflow from the design of the building to the techno-economic simulation in EcoSim.

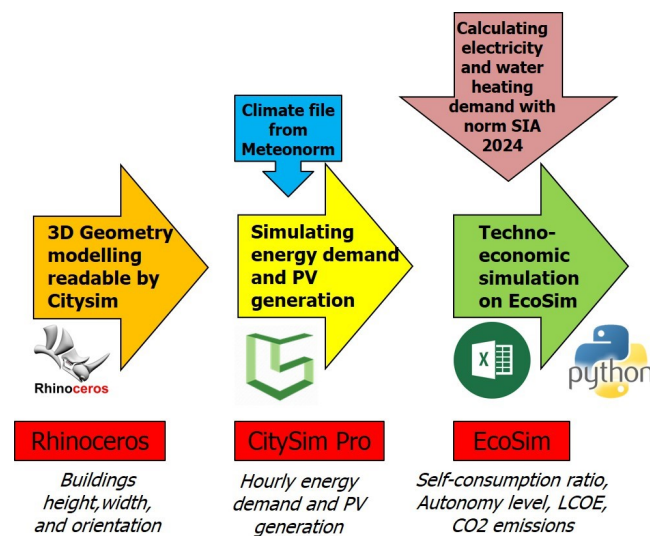


Figure 1. Graphical representation of the workflow

2.4. CO₂ emissions

The specific CO₂ emissions are calculated in Ecosim based on the lifetime of the different types of energy used. The entire PV system life cycle (transport, operation, electrical installation,

construction and production phase) is considered to calculate the CO₂ emissions of solar panels. A previous study [6] showed that the entire CO₂ emissions for a solar PV system are 702.5 kg/kWp which is equivalent to 0.03 kg/kWh. Additionally, the annual CO₂ emissions of lithium ion batteries (Tesla) of 70 kg/kWh [7] are significantly high.

The CO₂ emissions of the electrical grid in Switzerland are 0.151 kg/kWh [8] and are determined based on hourly values of the electricity taken over the network during a specific day in winter, while, the CO₂ emissions of the electrical grid are 0.115 kg/kWh during a specific day in spring. As can be seen in Figure 2, less CO₂ is emitted to produce electricity during a spring day. Finally, an average value for the CO₂ emissions of 0.133 kg/kWh will be used for the electrical grid in Switzerland.

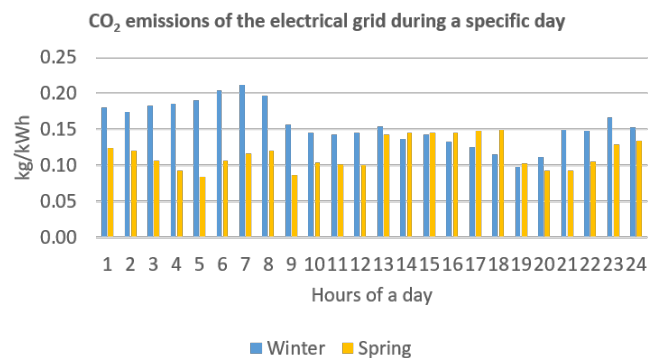


Figure 2. CO₂ emissions of the electrical grid in Switzerland

More details on the CO₂ emissions for each device and other parameters can be found in a previous study [3].

2.5. Self-consumption community

A self-consumption community is a shared power system that enables the sale of locally produced electricity to the residents of the neighbourhood. The members of the community can consume locally the solar electricity produced on the roof. Indeed, the occupants of the rental properties are grouped together in a community of consumers and can benefit individually from the locally produced electricity. When the solar system cannot produce enough electricity, the extra electricity can be bought from the grid.

As can be seen Figure 3, in these communities, the contractor is the manager of the self-consumption community and he becomes the end customer of the electricity suppliers. The Energy Ordinance of January 2018 ('RS 730.01 Ordonnance Du 1 Novembre 2017 sur l'Energie (OEne)' 2017), allows the sale of the electricity to the residents at the bought price. Therefore, the contractor can buy electricity with a lower industrial price from the network and provide all the electrical energy (composed of solar energy produced locally and the energy from the network) to the residents at the same buying price of 15.3 cts/kWh. Hence, the residents pay less for their electricity and can use the locally produced electricity. The inhabitants will not receive an electricity bill from the electricity network company; instead, they will only receive a normal electricity bill from the contractor. This study will thus analyse the economic profitability of such a solar community from the point of view of the consumers as well as from the point of view of the contractor.

The economic assumptions with and without a self-consumption community are explained in Figure 3. On the one hand, without a self-consumption community, the contractor (or the owner of the building) is the owner of the solar PV panels. The inhabitants are completely separate

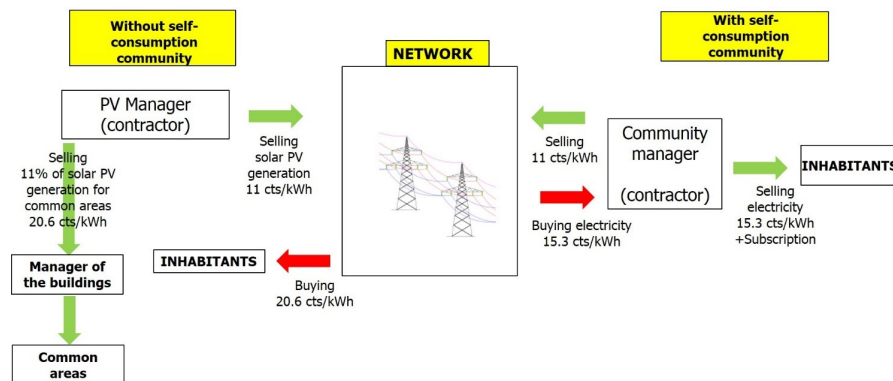


Figure 3. Economic assumptions with/without a self-consumption community for Weidmatt

from the contractor and buy electricity from the grid at 20.6 cts/kWh. Only the common areas of the buildings have access to the locally produced electricity; the common areas self-consume only 11% (calculated by subtracting the appliances power of residential areas) of the solar PV generation (with a solar power installation of 302.4 kWc). The PV manager can sell back the excess electricity to the grid at 11 cts/kWh. On the other hand, a self-consumption community allows the inhabitants to have access to the locally produced electricity and to buy electricity at 15.3 cts/kWh instead of 20.6 cts/kWh.

Additional costs associated with the self-consumption community such as counter installation costs (150 CHF/counter), administrative costs for the management of the community (5 CHF/month/household) as well as the maintenance costs for the counters (4CHF/counter per year) are charged to the contractor. These can then be billed to the customers with a subscription, which is evaluated here with a maximum and an average subscription.

3. Results for the neighbourhood in Basel region

3.1. Electricity demand profile

The neighbourhood of Weidmatt located in the Basel region, will consist of 6 buildings with 120 apartments with a total net floor area of 15'411 m² that is dedicated to residential use. The electricity demand profile includes the electric consumption of the appliances, the lighting and the ventilation systems. The average power for each appliance is taken from Swiss standards for domestic use. The hourly electrical consumption profile using appliances, lighting and ventilation over a whole year is obtained with an hourly resolution.

3.2. PV generation profile

The PV electricity generation can be determined by using the available irradiation obtained from the CitySim Pro software in hourly resolution by using a weather file for Basel. This hourly irradiation data is multiplied with the losses and with PV efficiency to obtain the hourly solar generation.

3.3. Result for solar PV

In Table 1, different values for solar PV power are considered to maximize the self-consumption rate and the autonomy level by decreasing the CO₂ emissions. Covering 70% of the roof with solar PV by considering 302 kWc, was adequate and made it possible to achieve 42% of self-consumption and an autonomy level of 27%.

Table 1. Result for solar PV by varying the solar PV power

PV power [kWp]	Self consumption [%]	Autonomy level [%]	CO2 emissions [kg/kWh]
166	60%	21%	0.131
242	48%	25%	0.130
302	42%	27%	0.130
426	33%	30%	0.134

3.4. *Techno-economic analysis of the community with solar PV panels only*

Figure 4 gives an economical comparison between four different scenarios from the point of view of the contractor and the point of view of the customers by using a solar PV power of 302.4 kWc. If we focus on the economic competitiveness of the system, the best scenarios are those that minimize the LCOE value to be competitive with the standard network price of 21.5 cts/kWh. The internal rate of return (IRR) is often recognized as a basis for selecting between projects. An investment project will be recommended only if its predictable IRR is sufficiently higher than the actual interest rate.

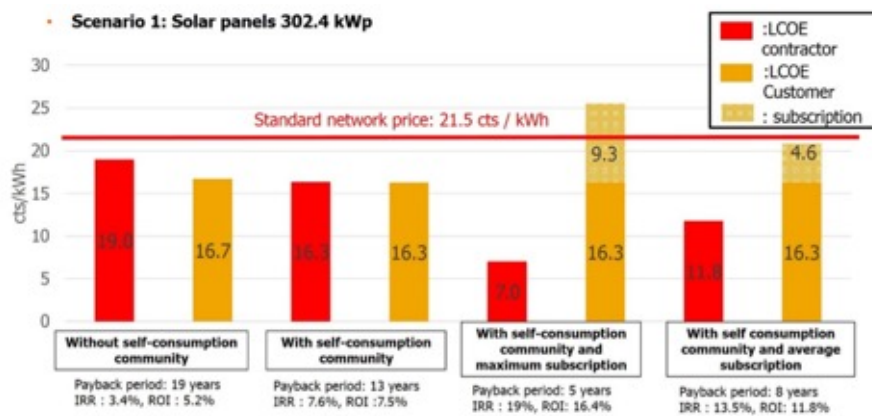


Figure 4. Economic results with solar PV (302.4 kWc)

Without a self-consumption community, even if the LCOE of contractor and customer is competitive with the standard network price, the project is not profitable for the contractor; the IRR is lower than the actual interest rate of 4%. The implementation of a self-consumption community results in decreasing the payback period from 19 to 13 years and to increase significantly the IRR and the return on investment (ROI) values. The implementation of a self-consumption community with an average subscription fee is favourable for the customer as well as for the contractor.

3.5. *Techno-economic analysis of the community with solar PV panels only and batteries*

An autonomy level of 40% and a self-consumption rate of 60% can be achieved by using a solar PV power of 302.4 kWc with a battery capacity of 260 kWh.

Figure 5 also shows an economical comparison between the four different scenarios from the point of view of the contractor and the point of view of the customers by using a solar PV power of 302.4 kWc and a Tesla battery of 260 kWh. As can be seen, with the self-consumption community, the payback period is reduced from 24 to 19 years. The best solution is the fourth scenario “self-consumption community with average subscription”. This case results in an IRR of 6.9 % which is higher than the actual interest rate of 4%, meaning that this project is economically profitable.

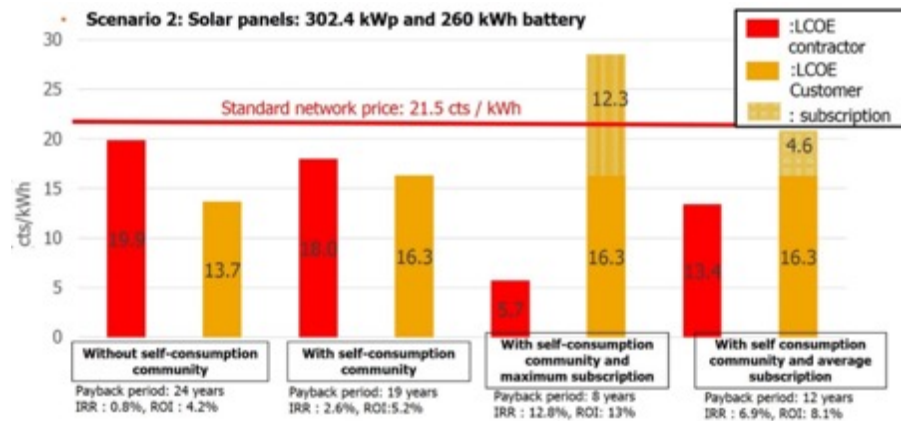


Figure 5. Economic results with solar PV (302.4kWc) and battery (260 kWh)

4. Conclusion

The current study aims to model and evaluate the integration of different energy systems in a large neighbourhood trial by using the EcoSim tool that has been developed previously. The methodological approach used in the scope of this study is applied to a case study in Switzerland. A neighbourhood located in Basel is analysed. The electrical energy demand is satisfied partly by combining solar PV and battery on an area containing only residential buildings. An autonomy up to 40% and a self-consumption up to 63% are reached by using 302 kWc of solar PV and a battery of 260 kWh. The economic profitability is considerably increased by implementing a self-consumption community. Indeed, the implementation of a self-consumption community with a subscription fee allows money savings for the contractor and the customer. Regarding the environmental impact, the recycling of solar batteries needs to be investigated to enable a sustainable cycle of these technologies as we have shown that the inclusion of batteries leads to an increase of 51% in the CO₂ emissions as compared to the current grid emissions of the Swiss grid. In the future, the model will be extended to also analyse the possibility of integrating the thermal demand in the self-consuming communities. More refined CO₂ emissions with hourly time step as well as real-time pricing could be used to improve the model.

Acknowledgements

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