Modelling a prosumer-consumer pair for investigation of local self-consumption of renewable energy

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Abstract. *In this paper we investigate modelling of a consumer-prosumer pair as a starting point for understanding consumers and prosumers in emerging energy communities, better utilizing PV generation and potentials of battery storage systems. With different scenarios, we analyzed developed agent based models how flexibility of energy community members affects self-consumption of green energy within the energy community.*

1 Introduction

Present energy system has to meet challenges and demands of European energy policy [1], with a transition to more sustainable energy system while guaranteeing the security of supply and competitiveness, with massive integration of renewable energy sources (RES) [2][3].

It means that the current energy supply and demand systems need modifications. Required modifications in this green transition are a challenge, but through the evolution of the EU energy policies [1], the consumer's is taking the central role.

The increasing active role makes the consumer an active participant in the energy transition [3]. An active role promotes a consumer to a prosumer, who both generates and consumes energy [3]. There is potential for consumers and prosumers to better benefit using green energy from RES, such as rooftop PV, together with use of energy storage systems.

The process where the producer consumes generated energy directly is described as self-consumption. Self-consumption concepts can focus on one building or it can be considered for a group of buildings, where several consumers use electricity from local RES [4].

Prosumers and consumers could be formed in energy communities, based on modern ICT, where generated energy surplus is shared among the energy community members. As a result, energy communities produce, store and exchange renewable energy locally between their members and with the energy system [5].

The idea of energy communities also promotes the renewable generation and consumption to increase self-consumption. In this case, all sides have benefited since the prosumers locally share unused energy, on the other hand, the consumers use more locally generated energy, contributing to more stable grid [5].

A 100% self-consumption means than no locally generated energy is remained unused locally. Nevertheless, the disparity between generated energy and energy community members' consumption remains, which means that typically generated energy cannot be fully utilized [5]. Energy community members can actively participate by managing their energy consumption and change their habitual consumption patterns in response to price signals or incentives.

The concept of flexibility demands all energy community members to actively participate in a modern, ICT supported energy system [5]. The pervasiveness of ICT could lead to new concepts that enable members to have free access in the process of energy exchange. Technologies, such as blockchain, can play significant role. It provides a decentralized system, which means that no intermediaries are needed in the energy exchange.

With a high level of complexity, energy communities need to be analyzed as complex socio-technical systems through the concept of modelling [3]. Modelling is used for understanding how events are related and how behavior and interactions influence the output of the system. Modelling allows the modification of the system to improve it to test the model with various parameters and details that are not part of the real world [6].

The well-accepted approach to analyze and represent the complexity of the prosumer's and consumer's roles within the energy community is the agent-based modelling (ABM) [3]. Energy community members, described as agents, are actors in these socio-technical systems with their behavior and ability to make decisions. They also interact with others and can be influenced by the environment [6].

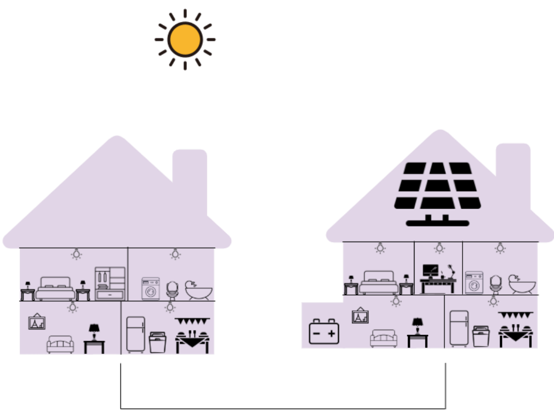

Figure 1. Prosumer - Consumer pair

With the selected case study, we modelled the prosumer/consumer pair (Figure 1) as part of investigation how selected parameters influence self-consumption of locally produced green energy.

2 Modelling prosumer-consumer pair

In agent-based modelling approach, the energy community is modelled from the bottom-up. Such approach allows better insight into details of the system under investigation. In initial models, a simple prosumer/consumer pair was developed without the ability of shifting their loads to better understand their behavior. Once we gained an understanding of self-consumption principles, we applied the acquired knowledge to more complex systems, including flexible behavior, the energy storage system and the formation of the smaller energy community with more energy community members [5]. Our agent-based models were implemented with AnyLogic.

Table 1: Prosumer's(+) and consumer's(●) load profiles

	Kitchen	Living r.	Study room	Bedroom	Water h.	Refrigerator	Dishwasher	Laundry m.
00:00-05:00						• +		
05:00					+	• +		
06:00				• +	+	• +		
07:00						• +		
08:00-14:00						• +		
15:00-17:00						• +		
17:00						• +		
18:00	• +	• +				• +		• +
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21:00	• +	• +	+	• +		• +	• +	
22:00			+	• +		• +		
23:00			+			• +		

Each household is represented as one agent whose behavior is described with its load profile and its flexibility. Their consumption profiles are adapted from [5] and consist of: lighting, electric water heater, hot water consumption, refrigerator, dishwasher and laundry machine, as presented in Table 1.

Taken into consideration that some activities in the household are not necessarily needed when they are scheduled, agents might be willing to shift them for a few hours. These loads are described as flexible and shaded in Table 1 (a laundry machine and a dishwasher). On the other hand, non-flexible loads have to be operated accordingly to the schedule and they cannot be shifted (lighting, electric water heater, hot water consumption and refrigerator) [5].

The prosumers have an important role in the energy community as they produce and share the energy surplus with the consumers [5]. The prosumer's behavior is modelled with parameters related to their flexibility, the availability of the energy storage system and a set of parameters such as time, the consumption of flexible and non-flexible loads.

Data for PV generation are also adapted from [5] and presented in Figure 1. The consumer is used to imitate the consumption of the household without the PV generation. The consumer's behavior is modelled with parameters related to their flexibility and their consumption profile of flexible and non-flexible loads.

The prosumer and consumer agents communicate with each other, where the prosumer offers generated energy surplus, and the consumer accepts or declines the offer. The outside input from the environment is information of current PV generation (Figure 2) [5].

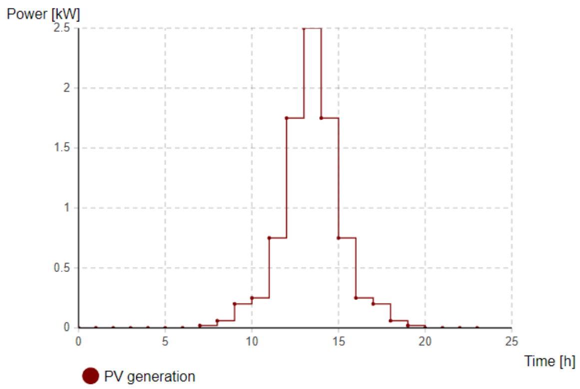

Figure 2. Prosumer's PV generation profile

The decision-making procedure depends on the availability of green energy from prosumer's PV, the presence and status of the energy storage system and user's response to the tariffs or incentives [5].

The initial model implemented the case where the prosumer and the consumer form a pair to use energy generated and shared by the prosumer (Figure 1). As the prosumer does not use all green energy as it is produced at specific times, the surplus is offered to the consumer. If the consumer rejects the offer, the unused energy is offered to the grid.

As a benchmark case for later flexibility scenarios we considered that both agents are inflexible, using their initial schedules. As their schedule is not flexible all loads need to be operated on time. With the inflexible behavior the prosumer and the consumer do not contribute to the overall goal to improve local self-consumption [7].

For flexibility scenarios, we considered prosumer's and consumer's willingness to shift their loads to better fit time intervals with local PV generation, which is typically during the day.

In this paper we focus on two flexibility scenarios, implementing incentive-based flexibility with and without energy storage system. The incentive-based flexibility motivates them to shift their flexible loads based on the available energy from the prosumer's PV [7]. Another possibility would be to investigate tariff-based flexibility, which is not part of this case study [7].

3 Results

In this section we present main results of model simulations in AnyLogic, following two flexibility scenarios, implementing incentive-based flexibility with and without energy storage system.

Figure 3 presents generated energy and the sources of energy for providing the prosumer's loads at a certain time with potential to shift the flexible loads.

Figure 4 shows sources of supply for the consumer during the day. The consumer uses a certain amount of green energy when flexible loads are incentive-based shifted, but still, non-flexible loads are dominantly supplied with the energy from the grid, following user's daily routine.

Since load shifting to the period when the PV generation is high is not sufficient, we further investigated how an energy storage system can contribute to the self-consumption goals. In this case, the prosumer uses generated energy for supplying the loads and energy surplus is offered to the consumer. If there is remaining green energy available, it will be stored in the prosumer's energy storage system. Ultimately, if the energy storage system is fully charged, the energy surplus is offered to the grid.

Prosumer's consumption profile, together with generated energy, is presented in Figure 5. The prosumer's PV generation is highest around noon, and the prosumer uses generated energy for supplying the loads, while the energy surplus is offered to the consumer. After the consumer accepts the offer and a part of green energy still remains unused, it will be stored in the energy storage system and available for usage later during the day.

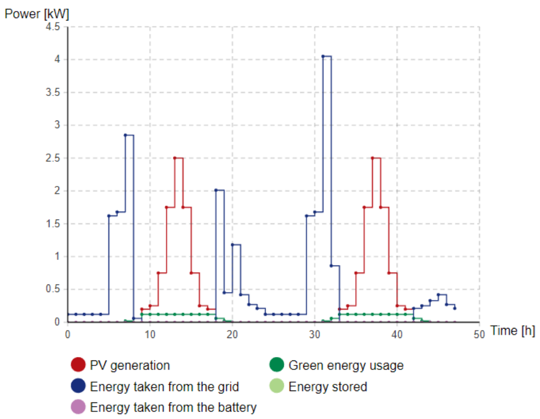

Figure 3. Prosumer consumption profile for incentive-based flexibility without energy storage system [7].

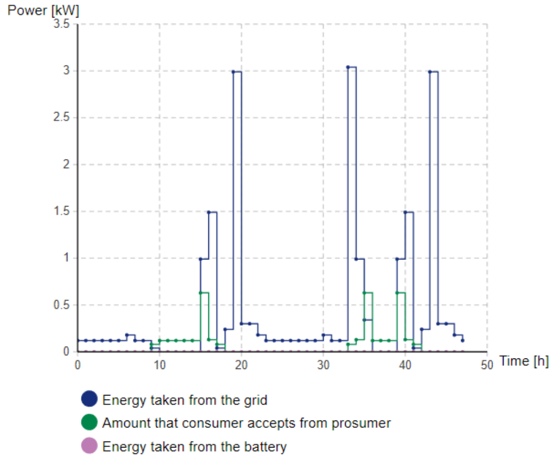

Figure 4. Consumer consumption profile for incentive-based flexibility without energy storage system [7].

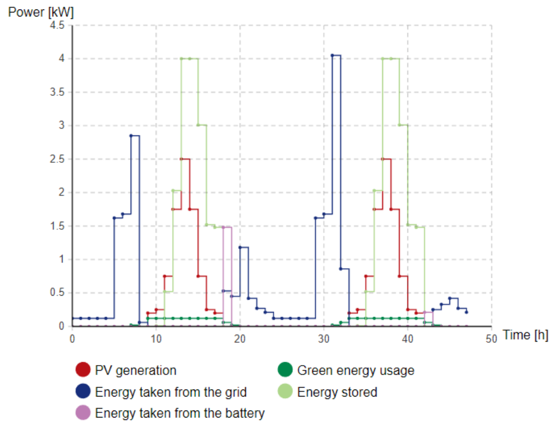

Figure 5. Prosumer consumption profile for incentive-based flexibility with energy storage system [7].

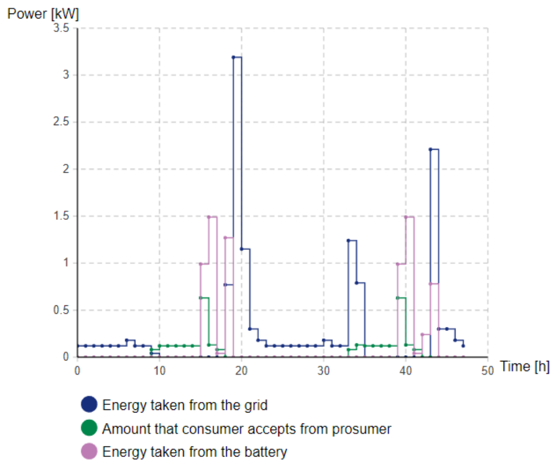

Figure 6. Consumer consumption profile for incentive-based flexibility with energy storage system [7].

Figure 6 presents energy sources for the consumer's loads during the day. In this case consumer’s goal is to fully utilize green energy, either from the PV panels or from the energy storage system. In case the available green energy is not sufficient, the consumer accepts the energy from the grid. However, we see that the consumer supplies a certain number of loads by the energy provided from the energy storage system, which, together with load shifting, contributed to the increase of self-consumption.

4 Discussion

To achieve full self-consumption, the energy surplus needs to be fully consumed by the two agents. If the prosumer and the consumer are characterized by inflexible behavior with very similar schedules, and additionally, the prosumer does not have the energy storage system (Case 1 in the Table 2), more than half of the generated energy is offered to the grid and not used by the prosumer or the consumer.

	Prosumer	**Consumer**	**To the grid**
Case 1 inflexible behavior	9.52 (16%)	9.8 (16%)	40.6 (68%)
Case 2 incentive-based flexible behavior	8.68 (14%)	11.16 (19%)	40.08 (67%)
Case 3 incentive-based flexible behavior and energy storage	12.67 (21%)	34.66 (58%)	12.59 (21%)

Table 2: The comparison of the results based on the self-consumption [7]

To increase self-consumption, prosumer's and consumer's consumption patterns need to be changed (shifted) to use more green energy generated by the prosumer. In the first step, we investigated how to increase self-consumption by the incentive-based flexibility (Case 2 in Table 2). However, more than half of generated green energy is offered to the grid, since non-flexible loads are supplied by the energy from the grid, when green energy is not available. To minimize the percentage of unused green energy, this concept of incentive-based flexibility can be upgraded by adding the energy storage system at the prosumer's household (Case 3 in Table 2). Since the energy storage system stores the generated energy surplus for later use, this scenario provides better results and represents an improved approach for energy communities. In this case, less than a quarter of the generated energy remains unused and offered to the grid. This value equals to generated energy when the energy storage system was already fully charged. These results motivate us to upgrade the prosumer/consumer pair to a smaller energy community, where this unused green energy could be further shared among consumers [7].

5 Conclusions

This paper presents initial steps in energy community modelling. The agent-based modeling starts from the bottom-up, with a prosumer/consumer pair. With different scenarios, we analyzed the influence of different parameters on the model of this simple energy community. We analyzed the influence of flexibility on self-consumption of green energy and impact of adding an energy storage system. With acquired knowledge, we analyzed how increased number of prosumers and consumers influences the total use of green energy.

With this simple agent-based model we can investigate how self-consumption can be increased if the generated energy surplus is shared among the energy community members. In our research, we reached the goal of 100% self-consumption within the energy community under described conditions, composed of one prosumer and five consumers, characterized as incentive-based flexible willing to shift their flexible loads within the agreed interval [7].

Acknowledgement

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