BLOCKCHAIN-BASED SELF-CONSUMPTION OPTIMIZATION IN LOCAL ENERGY COMMUNITIES

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ABSTRACT

Due to a turnaround in energy policy and an alienation from fossil fuels, a steady increase in the number of smaller renewable energy producers emerges, differing from the conventional ones in their volatility and amount of produced energy. Former consumers are becoming prosumers uniting the role of producers and consumers and aiming to perform peer-to-peer-trading in the future.
A simulation model is created representing a local energy community consisting of different households, each of them equipped with a photovoltaic power plant, a battery storage system, and grid access. These households shall cooperate with the aim to maximize the self-consumption of the entire community. Several scenarios are created, for instance extending the cluster with a community electricity storage and a community photovoltaic power plant. The aim is the self-organization as a virtual power plant offering flexibility services and following a given load-profile by utilizing all system components in an optimal way. Finally, a comparison between the different scenarios is presented and possible implementations of the Blockchain technology are evaluated.

INTRODUCTION

Due to a turnaround in energy policy and an increase in renewable energy producers, differing from the conventional ones in volatility and amount of produced energy, new challenges in distribution grids arise like preserving the flexibility on electricity markets. Former consumers are becoming prosumers, which are uniting the role of producers and consumers and should be able to perform peer-to-peer-trading in energy communities in the future. General concepts for peer-to-peer energy trading have already been shown in other scientific publications (cf. [1], [2], [3])

The Austrian research project *"SonnWende+"* deals with the analysis of Blockchain technology in the context of renewable electricity producers and flexibility as enabler for innovative service concepts, tested in simulations on one hand and in the innovation-lab *"Energie Innovation Cluster Südburgenland"* on the other hand [4]. The goal is to find new and efficient Blockchain-based solutions for services in energy management and trading on a local level (cf. [5]). Innovative methods for maximizing the self-consumption of photovoltaic generation within buildings, quarters, and regions are developed.

On the simulation level, a MATLAB model has been created representing a local energy community (LEC) and its participants. Different households, each with a photovoltaic power plant, a battery storage system, and grid access are simulated. These households shall cooperate aiming to maximize the self-consumption of the whole cluster of households using the Blockchain-technology. Several scenarios and different optimization strategies are defined, to self-organize as a virtual power plant and offering flexibility services as well as following predefined load-profiles. An ideal scenario – created with an optimization tool – with minimum aggregated energy costs within local energy community is used as baseline.
A comparison between the different scenarios based on the costs of each single customer is drawn. It's being investigated, which parameters are necessary, for running different algorithms decentralized on a blockchain and which technological options are available. A concluding comparison gives a recommendation, which mechanisms of energy distribution and technologies are bearing the highest potentials for development.

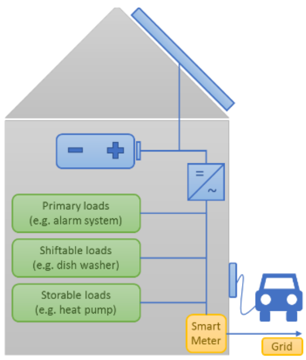

Figure 1: Household with different types of loads (primary, shift-able, storable), PV, battery, inverter, smart meter, electric vehicle, and grid connection

Home Energy Management Systems (HEMS) can combine a photovoltaic power plant, a battery storage system, an inverter, a charging station for electric vehicles, different types of loads, a Smart Meter, and a central computing unit. An example illustration is shown in Figure 1. The PV-module is controlled by the inverter that it works on its power-maximum (MPT) and that safety-criteria are fulfilled. The Sunspec-Alliance works on a standardized communication protocol for this purpose, underlying is the MOBDUS TCP (Transmission Control Protocol) [6]. The energy storages enable compensation of production and consumption peaks. Smart Meters are measuring data and sending them to the grid operator and to the local computing unit.

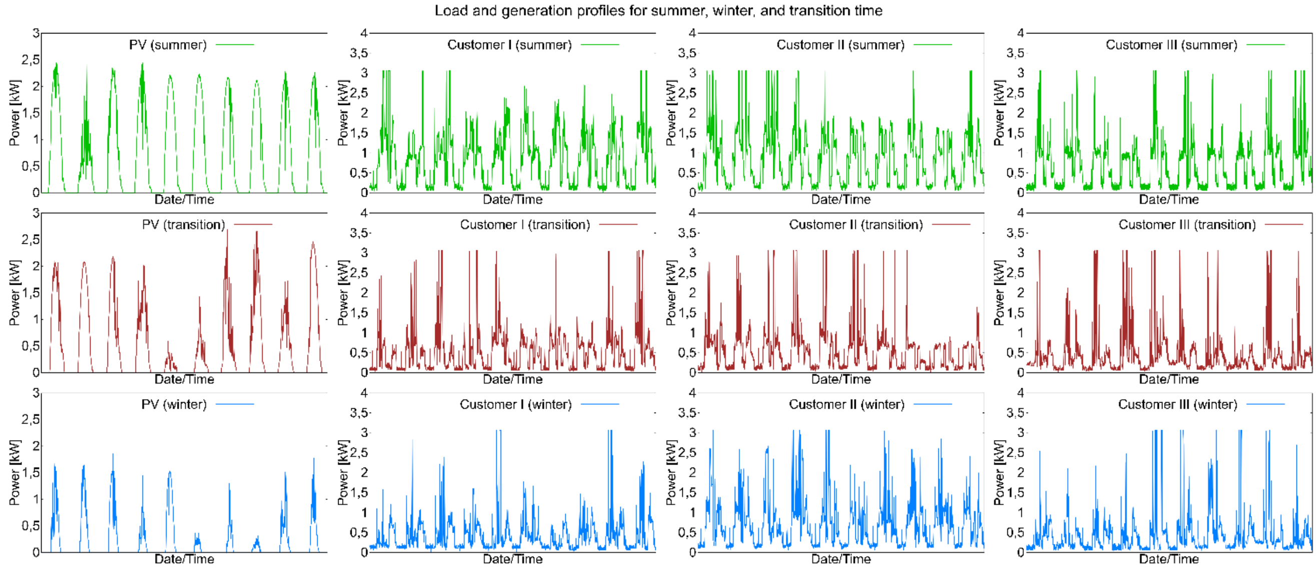

Figure 2: Generation and load profiles for different households and seasons (summer, winter, transition period).

Based on the measurement data and tariff information, a local algorithm can decide whether to use, store, or sell the produced energy [7]. Furthermore, given load profiles which need to be followed can be provided from the network operator. Capacities of electric vehicles can be used to store production peaks and thus, increase grid stability. Discharging the EV-batteries again into the grid for flexibility purposes (V2G) isn't profitable at the moment though [8]. Loads which are shiftable in time (e.g., washing machine, dish washer) or storable loads (e.g., air conditioning, heating, cooling) could be also used to preserve grid stability. To ensure this functionality a direct communication from these devices with the central communication unit or Wi-Fi-controllable sockets are needed [9].

METHODOLOGY

In cooperation with *"Energy Innovation Cluster Südburgenland"* different Blockchain-relevant service concepts and peer-to-peer-trading scenarios are tested on a conceptual level [4]. In this work, a MATLAB model is shown, representing a local energy community aiming to ideally distribute the energy within the community, whereas voltage and current levels aren't considered.

All components (e.g. PV, battery storage) are modeled separately and can be integrated in the participating households or used in the community itself as common resource. A global Energy Management System (EMS) is responsible for providing an ideal distribution of produced and consumed energy within the community. Algorithms aiming to maximize the self-consumption of the local energy community are implemented, an ideal model (created with an optimization tool) is used to find the minimum aggregated costs for all households. Aspects like the contribution to a stable grid and different battery stresses through different usage are considered, too.

To achieve representative results, recorded generation and consumption profiles from the innovation lab are used. Figure 2 shows the profiles for three customers. In the first column, the generation profile is illustrated for summer (top), transition period (middle), and winter (bottom). From column two to four, the load profiles for three different customers and seasons are shown.

The simulations are performed for a period of ten days each for summer, winter, and transition time.

Since the Blockchain could serve as an interface for data exchange, provide a clearing system, and might be able to perform the proposed algorithms, it's being investigated which data needs to be provided on a Blockchain to fulfil the requirements for these purposes. Based on the findings, recommendations for the realization of a Blockchain-based system will be given.

IMPLEMENTATION

Figure 1 illustrates the implementation of a single household for the simulation, equipped with a photovoltaic power plant on the roof, a home battery storage system, an inverter, different types of loads (primary loads which cannot be controlled, shiftable loads which can be shifted within a predefined time window, and storable loads), a private charging station for electric mobility, as well as a Smart Meter and a grid connection point.

In the simulation model it is assumed that the solar radiation is equal in every location of the local energy community and there is no shading due to trees or buildings. Furthermore, an equal PV panel is assumed for each customer and therefore, the same generation profile is used for all households – without loss of generality. Owing to a lack of information about the characteristics of the loads (type, shiftable, storable), all loads are modeled as primary loads, which means that they need to be served immediately, either by using the own PV production, by discharging the battery, or by consuming energy from the grid. The data from generation and load profiles are averaged over 15 minutes. As storable load a battery storage system is assumed for each customer, but could also be some kind of boiler or heat pump. It is modeled as blackbox with charging and discharging power as input parameters. Based on these values as well as on the

efficiency and self-discharge, the state-of-charge of the battery is calculated for the each timestep. The inverter is modeled as a hybrid inverter. This means that the battery can be charged on the DC-side through an extra output resulting in three different efficiencies, one from DC to DC, AC to DC, and DC to AC. Different characteristics of the parameters for all components are distributed over the different households within the community.
In the simulation, three households are created and connected to a global EMS. Furthermore, for some scenarios a community storage and a community photovoltaic power plant are also considered and connected to the EMS.
Figure 3 shows the model of the simulated LEC with different households connected to the EMS, a community storage, a photovoltaic power plant, a global EMS as well as the possibility for providing flexibility services and following a given load profile.

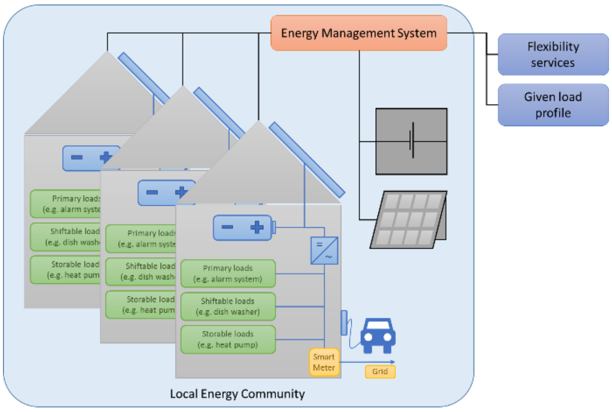

Figure 3: Model of a local energy community with different households, community storage, and PV, providing flexibility services and following a given load profile.

Each household is able to operate in two different modes:

- Egocentric mode: Covering the full own energy demand first, energy surplus is saved into the battery and finally fed into the grid.
- Minimalistic mode: Covering only primary loads first and providing the surplus to the community.

The global EMS is communicating with all households continuously and able to retrieve information about their energy surplus or lack, state of charges, etc. After having a complete overview about the states of all households within the community, the EMS is calculating the amount of energy which must be provided or taken by each household or how much energy will be transferred into the battery. EMS is responsible to determine a fair distribution of energy surplus and vice versa.

SCENARIOS

Six different scenarios have been investigated with varying requirements. These scenarios can be categorized by their objectives:

- Optimization on household level (*HH_xxx*)
- Optimization on community level (*LEC_xxx*)

In the following, the investigated scenarios are explained in detail:

Baseline: As already mentioned, one scenario was created as baseline for comparison. Here, each household is equipped with a photovoltaic power plant but without a battery storage. Consequently, the generated energy can be consumed at the customer immediately or it will be fed into the grid.

Scenario I (HH_Opt): In the first scenario (and in the following ones), each household is equipped with a PV power plant and a battery storage. The usage of the battery is calculated by an optimization tool. Different types of forecasts (price, generation, consumption) are used as input parameters. In general, the quality of the used forecasts has an extensive impact on the optimization and thus, on the energy costs of each customer. In the simulation model, optimal forecasts (real behavior is equal to the forecast) are assumed for generation and consumption.

Scenario II (HH_Heu): This scenario is based on a heuristic approach for optimizing the behavior of each household. Each customer uses its own generated energy to cover its consumption. PV-surplus is stored in the battery first, and fed into the grid if the battery is already fully charged. On the other hand, if the demand is higher than the production, energy from the battery will be used first, then it is consumed from the grid.

Scenario III (LEC_Opt): In this scenario, the aggregated energy costs of the community are minimized by using an optimization algorithm. Due to this higher-level optimization, PV-surplus can be distributed to other customers within the community and thus, the energy transfer on the gird connection point can be minimized (depending on the price) compared to the scenarios above.

Scenario IV (LEC_EMS): In the fourth scenario, an Energy Management System is used on community level with access to all customer data (generation and consumption of each customer, battery state-of-charge). The implemented EMS is not using any kind of forecasts.

Scenario V (LEC_EMS_Ext): The previous scenario (*LEC_EMS*) is extended by a community battery storage and a community PV power plant. Both devices are chosen in their characteristics to cover 100 percent of the consumption in summer.

Scenario VI (LEC_VPP): The last scenario is based on the previous one, extended by a given power profile which should be followed by the community (aggregated power of all customers).

Table 1 shows an overview about the scenarios and their characteristics.

Table 1: Features of different investigated scenarios

Scenarios	Features							
	Objective: HH	*Objective LEC*	*EMS*	*LEC PV & Battery*	*Given load profile*	*Price/Tariff*	*Forecasts*	*Optimization tool*
HH_Opt	✓	✗	✗	✗	✗	✓	✓	✓
HH_Heu	✓	✗	✗	✗	✗	✗	✗	✗
LEC_Opt	✗	✓	✗	✗	✗	✓	✓	✓
LEC_EMS	✗	✓	✓	✗	✗	✗	✗	✗
LEC_EMS_Ext	✗	✓	✓	✓	✗	✗	✗	✗
LEC_VPP	✗	✓	✓	✓	✓	✗	✗	✗

RESULTS

As already mentioned, the simulation was performed for ten days in summer, winter, and transition period with realistic (dynamic) tariffs. Afterwards, the costs for each household and each scenario have been evaluated. Figure 4 illustrates the results in costs per customer and day in euros for the baseline and the first four scenarios.

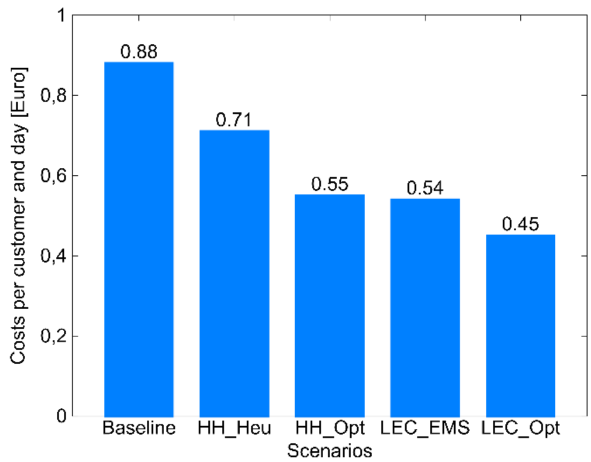

Figure 4: Costs per household in euros per day for different scenarios.

Obviously, the baseline has the highest costs because there is no battery storage available and thus, the energy can be consumed immediately or fed into the grid. In the scenarios with focus on single households (*HH_Heu* and *HH_Opt*) the energy costs per day can be reduced, due to the utilization of the battery storage whereas better results can be achieved when using an optimization algorithm instead of a simple already deployed heuristic.

Finally, the lowest energy costs for each customer arise when optimizing the costs at the community level (*LEC_EMS* and *LEC_Opt*). Due to the knowledge of the demand and surplus of all households, the global optimization will result in distributing the energy in an optimal way between the households. Furthermore, consumption from the grid never takes place by any household if other households still have a surplus to provide. With these ideal conditions and by using ideal forecasts, the price is much lower than in other scenarios. The scenario *LEC_EMS* is a good alternative to *LEC_Opt*, because it needs neither an optimization tool nor forecasts. It can also be easily scaled-up while the performance of an optimization tool might dramatically decrease with the number of customers.

The scenarios with community energy storage system and PV are not evaluated in Figure 4 because the acquisition costs of the installation can't be included properly in the price results. It's assumed, that the single battery storages are already available in the households and just need to be implemented in the system of a local energy community. If more resources would be purchased by the community, further investment calculations would be necessary. Otherwise it might appear that the profit of the community rises limitless with the amount of storage and PV. The investment calculation shows that the revenues don't counterbalance the original expenses, neither now nor in the near future, at least with current energy prices.

In Figure 5 the percentage of coverage of the proprietary requirements of the households depending on the size of the community battery storage is shown. Only in summer, 100 percent can be reached but only with very large inefficient energy storage systems.

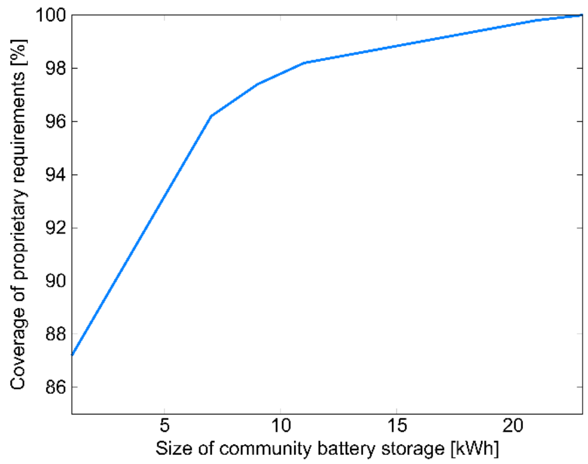

Figure 5: Percentage of coverage of proprietary requirements when varying size of an additional community energy storage, for three households

CONCLUSION & OUTLOOK

It turns out that it is profitable for the participants of a local energy community to invest in storage technologies, as long as energy production costs aren't exceeding the subscription costs from the grid. This is not the case for the circumstances we have today. Only higher price differences from PV-generation to conventional power plants can enable a rentable operation. In the future, there will also be the possibility for network operators to save costs by providing community electricity storage systems which would lead to lower costs through installed load and control energy. This could result in savings for both network operators and participants of the local energy

community. Another outcome is that it's better to invest in a community battery with less losses than in personal energy storage systems.
If there are already home storage systems available, a feasible opportunity is to use them as a shared resource within the community. This operational mode protects the batteries due to a consistent distribution of charging and discharging.

On a Blockchain, every household could know everything about the other participants, which could enable an easier cooperation of households. Furthermore, easy and safe transactions can be ensured. The algorithm can be proceeded either centralized or decentralized, but providing data to each other is a necessity. Via Smart Contracts, which define the terms of contract and can be concluded anytime between private individuals, distribution and payment could be combined without any further intermediaries. Purchases and sales could just take place autonomously, based on personal preferences of house owners.

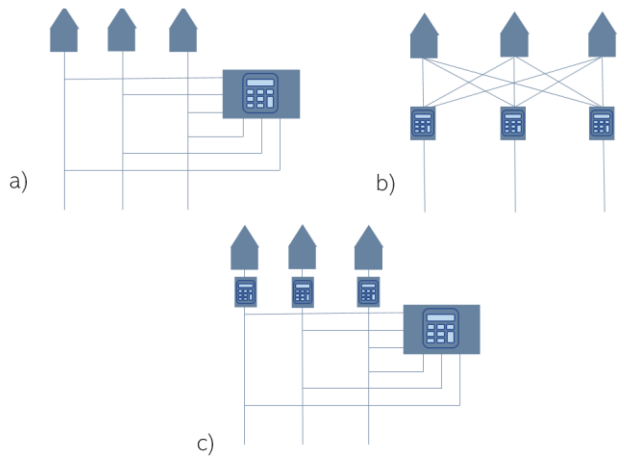

Figure 6 Different architectures for realizing a common EMS: a) Centralized b) Decentralized (every household has access to all information of the other households, possibly by using a blockchain) c) Mixed (division of tasks in centralized and decentralized ones).

The used algorithms for managing the energy transfer within the community can be implemented in different types of architectures:

- Centralized (Figure 6a): The algorithm is implemented centralized (e.g., on a cloud). The Blockchain itself is used for exchanging values, parameters, and results of the algorithm.
- Decentralized (Figure 6b): All values and parameters are available to all customers. The algorithm is running on their own Blockchain node.
- Mixed (Figure 6c): The last design works in a mixed way. Each household is covering its own demand and sends its resulting values to the Blockchain where further calculations are performed. The results will be transferred back to the households.

ACKNOWLEDGEMENT

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