Towards studying collective dynamics of electricity sharing systems

Thomas Brudermann\textsuperscript{a,*}, Yoshiki Yamagata\textsuperscript{b}

\textsuperscript{a} University of Graz, Merangasse 18/1, 8010 Graz, Austria
\textsuperscript{b} National Institute for Environmental Studies, Tsukuba, Japan

Abstract

In this paper, we propose an agent-based model for investigating collective dynamics in community-based electricity sharing systems. In our simulations, we assume the absence of electricity grids and telecommunication infrastructure – a situation which might be induced by a big natural disaster or a large-scale black-out. Under such circumstances, electricity sharing systems based on decentralized, small-scale renewables could help meeting basic electricity demand. Since real-world tests are hardly possible for such a scenario, we analyze possible collective reactions via means of social simulation.

Keywords: Urban resilience; decentralized electricity generation; photovoltaics; human behavior; agent-based modeling

1. Introduction and Background

Sharing systems are increasingly getting relevant in many domains of every-day life. People are sharing appliances, apartments, cars, and many other things. Under certain circumstances, sharing electricity might become vital as well, e.g. in times of major and long-lasting black-outs.

The increasing amount of electricity generated on a small scale, e.g. via PV modules on roofs of detached houses or farms [1], building-integrated photovoltaics [2], small-scale wind [3] or agricultural biogas plants [4], provides the basis for electricity sharing systems. While these plants are connected to the grid in the normal mode of operation, they do also have the potential to cover basic demand locally during black-outs or grid shut-downs. Batteries of electric vehicles could serve as energy storage devices [5], and electric vehicles as a means to transport energy over short distances, e.g. from a PV plant to a nearby neighborhood. The wide-spread implementation of (community-based) electricity sharing systems...
based on renewables thus has two main advantages: First, renewable power plants contribute to greenhouse gas reduction and to climate change mitigation. Second, such a sharing system increases resilience of communities in the face of extreme events. Driven by climate change, the number of extreme events and natural disasters is expected to rise. The consequences of long-lasting black-outs and grid collapses could be alleviated, if basic demand would be covered with decentralized sources in such situations. Thus, electricity sharing systems can also be considered a measure for climate change adaptation.

While the functionality of electricity sharing systems can easily be tested for every-day situations, real-world tests are not quite possible for major and longer-lasting black-outs, when central electricity provision and maybe even payment systems are out of operation. In such situations, supply is limited and storage of electricity not easily possible. Traditional market mechanisms might be absent. Human behavior also might differ from routine every-day behavior. The objective of our research is to investigate respective black-out scenarios. In particular we are interested how communities self-organize and re-organize around such a sharing system without a functioning electricity grid. Individual behavior traits in post-disaster situations are to a certain degree known from previous research [6], [7], but not much is known about collective dynamics – i.e. the complex patterns of collective behavior that might emerge from individual decision making in such situations. In order to address this issue, and to explore potential scenarios, we apply agent-based modeling (ABM).

2. Methods

ABM is a popular method for social simulation, which is increasingly gaining relevance across social sciences [8]. ABM is a particularly suitable method for closing the gap between micro-level data and interaction, and macro-level outcomes [9], since it follows a bottom-up approach [10]: Behavior of individuals – so called ‘agents’ – is described on the micro-level, as well as the interactions of these agents with each other, and interactions of agents with the environment. Both, interactions and behaviors are dynamic elements which might change over time as a result of previous interactions or external influence. The effects which micro level interactions and behaviors possibly have on the macro level are explored via simulations. Besides contributing to our research questions, ABM might also provide insights into the questions whether an electricity sharing system can replace the electricity market in exceptional situations, and under which prerequisites. Though, one word of caution has to be added: ABM is in general not very well-suited to provide concrete and accurate predictions. But it enhances the understanding for complex interconnections between micro and macro level [8], and aids analysis of collective behavioral dynamics. It therefore represents a useful tool for enriching our understanding of possible scenarios. Additionally, empirical data (e.g. number and size of plants, available storage, minimum demand, etc.) can be included to provide a quantitative basis for the simulations.

3. Towards an Agent-based Model

Based on the ODD protocol (Overview, Design concepts, and Details) suggested by Grimm et al. [11], [12], the model can be described as follows.

Purpose: The purpose of the model is to study possible collective dynamics that might emerge around electricity sharing systems in times of long-lasting black-outs. The model should deliver hints how communities self-organize and re-organize around such a sharing system when an electricity grid is not available and market mechanisms might be absent.

Entities, state variables, and scales: Agents follow different cooperation strategies, exhibit different levels of cooperativeness, and need electricity. The variable battery level indicates the remaining reserve. Agents have a fixed location (home), but will move if their battery reserves fall below a critical level. Moving decreases battery reserves as well. Electricity producing agents (PA) are characterized by an
electricity surplus which is available for sharing (assuming that own demand is ranked with higher priority). Non-producing agents (NPA) have a list of electricity providers they know about. This list is ordered according to their preference – i.e. they will rather re-visit a PA where they were successful in the past. Depending on a ‘willingness-to-share-information’ variable, information about providers will be exchanged with other agents. Decision making of agents is based on heuristic principles [13].

Process overview and scheduling: Agents aim to cover their electricity demand. PA will cover their demand autonomously, and offer surplus for sharing with others. NPA will search for a nearby PA and queue up for charging their battery, if reserves fall below a threshold level. Whether the transaction is successful depends on whether the agents decide to cooperate, the available surplus, and the length of the queue. NPA who successfully charge their battery return to their home location until re-charging becomes necessary. Information about available providers and queues is exchanged with other agents, when agents are in communication distance with each other and willing to share information. Telecommunication is assumed to be absent. To avoid long queues, NPA will look for alternative providers, if queues are too long and battery reserves are still sufficient for moving.

Design concepts: The ODD protocol suggests eleven design concepts. The most relevant design concepts implemented in our model are emergence (we expect different collective patterns to emerge depending on different parameterizations of the model), adaptation (NPA will adapt to queue lengths), objectives (NPA rank alternatives according to prior experiences and acquired information), learning (from previous interactions), sensing (screen environment for agents) and interaction (exchange information and to share electricity).

Initialization: The model will be initialized with a prototypic neighborhood (100-150 agents), consisting of 10% agents who provide electricity on a small scale, and 90% agents who demand electricity. Agents will have access to batteries, which are initialized with different states of charge (randomly distributed). Simulation runs will be carried out with variations of the PA/NPA ratio.

Input data: The model will first be based on a prototypic neighborhood. A quantitative basis will be added in a later stage.

Submodels: Potential submodels will simulate neighborhoods with different characteristics, and different cooperation strategies of agents [14]. Quantitative information will be integrated as well. Furthermore, different agent groups (representing e.g. different socio-economic background or ethnicity) could be implemented, and agents could follow different cooperation strategies for agents inside and outside their own group.

4. Concluding remarks and outlook

A first executable version of the model will be implemented in NetLogo and is expected to be available at the time of the conference. The prototype will allow for a preliminary analysis of possible collective dynamics. In our analysis and further development of the model we will consider that, dependent on cultural aspects, an alternative market for electricity might emerge over time, maybe based on barter trade. We also consider that people might step back from full electricity demand to a basic demand (relinquish air conditioning, elevators etc.) in post-disaster scenarios with limited energy supply.

References


**Biography**

Thomas Brudermann is an assistant professor at the Institute of Systems Sciences, Innovation and Sustainability Research at University of Graz. He holds a master degree in computer science and a doctoral degree in economic psychology. His research interests include human decision making, human-environment interactions, complex systems and collective dynamics.

Yoshiki Yamagata is a principal researcher of the National Institute for Environmental Studies, Japan. He is a member of the International Study Association, editor of Applied Energy Journal. His research interests include integrated land-use modeling with heterogeneous agents, international environmental regime network analysis, global climate change risk management and smart cities.