LokalPower: Enabling Local Energy Markets with User-Driven Engagement

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Abstract
With the advent of decentralised energy resources (DERs), there has been increased pressure on classic grid infrastructure to manage non-dispatchable resources. In face of these challenges, microgrids provide a new way of managing and distributing DERs and are characterised as core building blocks of smart grids. In this context blockchain technology enables transaction-based systems for keeping track of energy flows in between producing and consuming parties. However, such systems are not intuitive and introduce challenges for the user's understanding. In our current work, we introduce a user-centric approach to utilise a transactional data structure, providing transparency and understanding for when and from where electric energy is consumed. We present our approach for an engaging user interface and a preliminary study with feedback from solar installation owners and close with remarks on our future research plans.

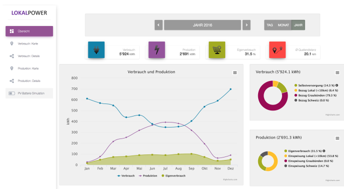

Figure 1: The initial screen of the dashboard shows an overview of production and consumption of electric energy over a specified period of time.

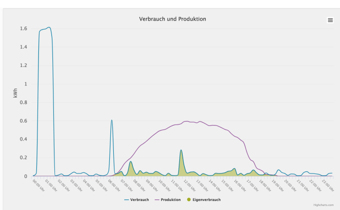

Figure 2: The dashboard shows a graph for displaying the production (purple), consumption (blue), and self-consumption (green area) for a selected period (here: one day).

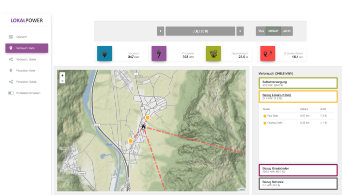

Figure 3: A map-view is available showing locations and listing sources in a categorised fashion.

Context & Motivation

The rise of decentralised energy resources (DERs) in the past years, such as photovoltaic (PV) systems, wind, and hydro systems, challenges classic grid structures to handle the additional load on substations and lower grid levels. In Switzerland, the adoption of the Energy Strategy 2050 (Energiestrategie 2050) mandates that the share of renewable energy in the electricity supply must increase. With the planned phase-out of nuclear energy, solar power in particular will be responsible for filling in a large portion of the future energy gap left behind by nuclear. As PV systems will be primarily integrated in a decentralised fashion in the medium- and low-voltage-networks [2], many house-owners will transition from solely consumers to both consumers and producers of electric energy. The ongoing transition has aptly coined the term 'prosumer'. Judging by interviews and comments from prosumers, we found a strong knowledge base about the principles of energy production and consumption. Based on that, we are positive about a growing interest and awareness of energy also on the consumer side.

The potential yearly solar energy yield in residential areas in Europe is typically in the range of $900 - 1200 kWh/kWp$ [9]. With this level of solar radiation, home owners possess the potential to generate a significant portion of their own energy consumption from renewable and self-sufficient sources. From this, the concept of a microgrid refers to a local group producing and consuming participants on a common power bus, and provides local services like demand management and storage. Microgrids can operate independently or in parallel with the main grid, enabling residential communities to maximise their self-sufficiency and promote energy independence. Thus, in the future, home owners' adoption of rooftop PV systems could be a major factor in the transition towards solar DERs and the rapid development of local development of local microgrids.

One of the key challenges to microgrid participants is removing their reliance on utility companies for managing how they share energy with their neighbours. In conventional grid transactions, utility companies, or their contractors, perform the billing process and keep the data proprietary. Even though energy is naturally flowing from peer to peer, services from utility companies do not reflect this, lack transparency and do not offer users control or feedback on where and when their electric energy is produced and consumed. Blockchain has been recently introduced as a technology capable of keeping an immutable transaction ledger, which enables secure and instantaneous energy transaction management in a transparent way. This concept has been used to perform local microgrid energy transactions peer to peer and further enable user control on their energy sourcing.

Such a system would inform microgrid participants of their energy usage, the self-sufficiency of the community, and provide transparency for the sources of their consumed energy. In this work we built a user interface that aims to provide the user with an understanding of the electrical grid and the dynamics of energy production and consumption and break the barrier to wider technology adoption.

Background and Related Work

Eco-feedback on energy consumption has a history extending back more than 40 years, and covers a variety of domains including water usage, transportation and fuel consumption [8]. However, according to the number of publications in environmental HCI (20 out of 41), the most active sector of eco-feedback is on electrical energy consumption [5]. Darby et al. 2006 [3] state that in a microgeneration

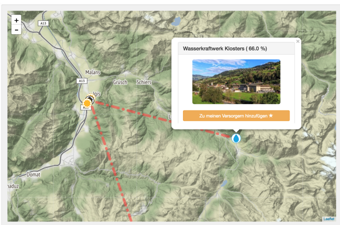

Figure 4: A map-view is available which shows the aggregated energy transactions for the desired period (day, month, year).

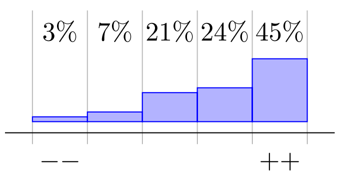

Figure 5: "Concerning my electric energy I prefer local generation." ($N = 29$)

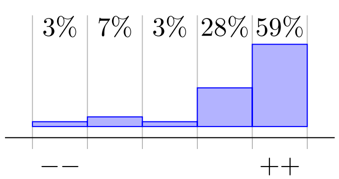

Figure 6: "Concerning my electric energy I prefer generation from renewable sources." ($N = 29$)

context it is important to make the process of importing and exporting electricity as visible as possible for the user. As such, user-centred feedback systems in microgrid contexts such as external displays and web-based interfaces have recently been iteratively conceptualised [10].

Research and development on microgrids has been active and ongoing in Europe for a long period of time. Microgrid structures are considered a basic feature of future distribution networks in order to take full advantage of DERs. Previous initiatives led by the EU (Microgrids & More Microgrids) reached fundings of over €13 million, resulting in demonstration sites across Europe [6].

Blockchain technology was introduced in 2009 with the application of the digital currency Bitcoin as a first test case [7]. Blockchain, in general, is an implementation of a distributed ledger technology (DLT) where a common ledger is held by a multi-party user group to keep track of common data. In Bitcoin, this data represents transactions of the virtual currency and balances of users are calculated from unspent transactions to their account. In other implementations, such as Ethereum, the block-data represents a list of transactions between accounts holding embedded data and including mediating and governing programs called Smart Contracts [1]. The first real world demonstration projects using blockchain for logging energy transactions have started surfacing in 2016 with the Brooklyn Microgrid project [4] and gained traction with startup companies utilising the concept, such as PowerLedger (Australia) and GridPlus (USA).

Comparing available user-interfaces to microgrid systems, we found that the viewing options of the available data to end-users were limited and not as granular as hoped. In case of the Brooklyn Microgrid, users are mainly presented with an overall daily consumption value and the share of energy that was sourced from the community.

Research Questions

A microgrid system built on Blockchain technology removes the dependency on utility companies, and provides transparency on the sources of consumed energy. These systems could reliably and accurately inform participants of their energy usage and the self-sufficiency of the community. However, such a system naturally has a high number of transactions between multiple participants and continuously evolves throughout time. This complexity introduces significant challenges for users and severely limits acceptance of the technology. To help tackle this problem, break the barrier to wider technology adoption, and develop a private consumption community, we strive to answer the following research questions:

RQ1: Is there a consumer demand for the sourcing of local electrical energy, i.e. similar to renewable energy demand?

RQ2: Can information technology foster the understanding of production and consumption of energy and build trust in local and renewable energy resources?

RQ3: What are potential barriers to a trusted and open energy market and how can these be overcome by technology?

Research Approach, Methods and Rationale

To address these questions, our goal has been to provide potential users with an overview of their energy consumption and production, in order to convey transparency over the time of consumption and location of production. For our first prototype, called LokalPower, we have built a dashboard to visualise the dynamics of energy production and consumption, informed by the design of common fitness

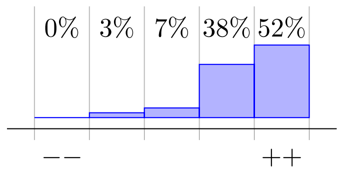

Figure 7: "I understand the concept of *LokalPower* and could explain it to a friend." ($N = 29$)

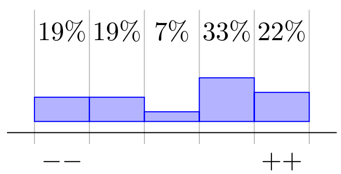

Figure 8: "As PV owner I would agree to publish the location of my installation." ($N = 27$)

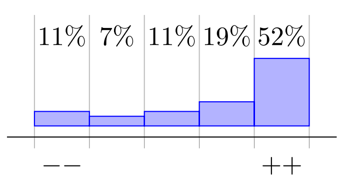

Figure 9: "As PV owner I would agree to publish the performance data of my installation." ($N = 27$)

dashboards. In order to populate this dashboard with realistic information and acquire user feedback, we collaborated with a local energy company in Switzerland. In this regard, we obtained transaction details accounting for the supplier and recipient of energy over a one year period. Our base data consists of smart meter measurements, with a resolution of 15 minutes, from 10 prosumer- (with PV systems installed) and 20 consumer-households. Additionally, we created profiles for surrounding power plants based on their type of base energy: 2 x hydro, 2 x PV, 1 x biomass. As a first step, we transformed this data to follow the nature of a Blockchain based ledger system for energy and mimic its resulting data structure. The actual matching of energy demand and supply was achieved by calculating a minimum cost network flow optimisation for every individual time slice with the edge-weight representing the Vincenty distance between the participants. This optimisation yielded a datastructure of transactions keyed by supplier and consumer for every participant and time slice, similar to the data a microgrid-blockchain ledger would hold.

It is worth mentioning that the transactional data can be utilised by any entity controlling the data of the productions and consumptions. Even though our matching algorithm does not specifically rely on a blockchain ledger to attain the transaction-based structure, we have built the system with our future research in mind.

With the developed dashboard, prosumers and consumers are able to visualise and comprehend the amounts of energy they have consumed or produced and where this electric energy was produced or consumed at a certain point in time. Figures 1 to 4 outline the developed dashboard, where the overview screen demonstrates a user's consumption, production, and self-consumption. In Figure 1 the overview screen is shown demonstrating a user's consumption, production, and self-consumption in the main graph (cf. Figure 2 for detail). On the right hand side, the user is shown the sources for their consumption and the sinks of their production, categorised by their distance (self-consumption, local, regional, or other). Figure 4 shows a close-up of a map view visualising the locations and types of energy sources with a pop-up showing more information about a selected power plant or (if disclosed) other participating prosumers.

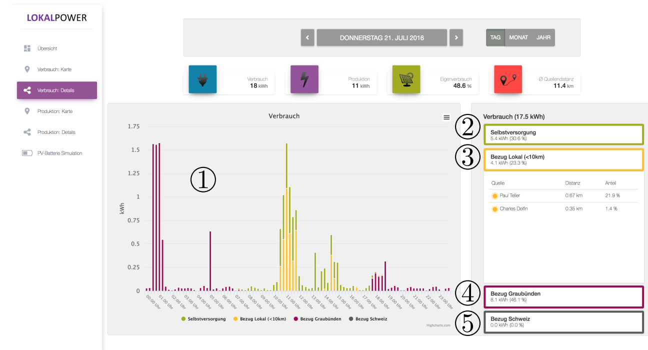

Figure 10: A detail view (1) of the contracted sources is available and shows the categories of the consumed energy: 'self consumption' (2), 'local production (<10km)' (3), 'regional production' (4), 'other sources' (5).

Preliminary Results

As we finalised the design of the dashboard, we engaged 29 prosumer participants in a customer event and introduced the user interface of the dashboard as well as the idea of locally sourced energy in communities. The presentation of the dashboard was structured in three blocks starting with a 30 minute demonstration of the information contents and functionalities of the dashboard based on an

User Feedback Comments

"I did not realise how much of my electric energy can actually be covered by surrounding solar installations - this is a great way of showing it." **Consumer**

"LokalPower is the right approach but it should not be just marketing." **Prosumer**

"It would be great to have an external display additionally to the web-based dashboard." **Prosumer**

"I am ready to pay a premium for this." **Prosumer**

"I would really like to invest in a neighbour-owned PV system as it is not viable on my own roof." **Consumer**

"Maybe large load devices (e.g. heat pump, boiler) could be identified and displayed." **Prosumer**

example prosumer, and then followed up with a survey consisting of five questions regarding the aforementioned research questions and finished with a discussion to get comments and ideas on the overall perception and design. The results of the survey are shown in Figures 5 to 9 with the questions in the description.

The survey results regarding our research question 1 (cf. to fig. 5 & 6) give indications to an existing demand for local energy, as the preference for local energy is similarly high (among prosumers) as for renewable energy.

With respect to our second research question, the presented answers (cf. to fig. 7) reflect that the idea and principle behind consumption communities such as a microgrid and the energy reporting tool is understandable.

However, when it comes to sharing data, PV owners are predominantly concerned with sharing the location of their system (cf. to fig. 8) which constitutes a clear barrier to a location-based approach like the one we chose.

The presented first results of our research on a transaction-based dashboard show that not only is there a home-owner interest in renewable sources of energy, but also in using local sources of energy. By presenting potential microgrid participants with the information that a local energy market can provide in an understandable and user-engaging format, we have shown that the users themselves are willing to participate in such a system but also seek the use of methods to preserve their privacy.

Future Work

With positive user feedback, our project is progressing towards the development of a field-test implementation of a Blockchain-based microgrid community in Switzerland. Within this setting, our future research plans to provide consumers and prosumers with a real-time energy market and engage them to actively participate by setting prices for buying and selling their electric energy. We strive to give the opportunity to maximise not only for local consumption, but also for most cost efficient consumption and to show an aggregated view of savings against a standard kWh-tariff.

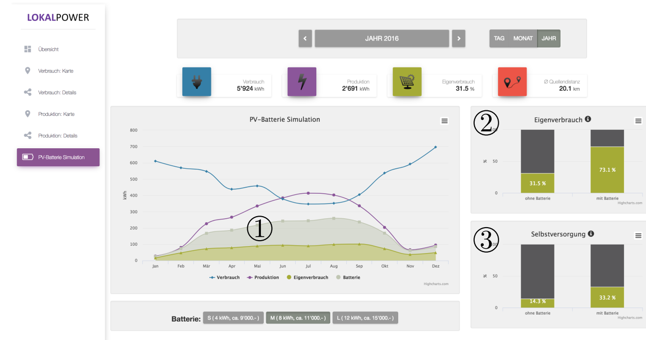

Figure 11: This screen shows a battery simulation available to a prosumer. The potential energy consumption covered by the battery is shown in the lighter green area (1). The bar graphs on the right show the differences with or without battery for self-sufficiency (2) and autarky (3).

In addition to consumption and production feedback, we included a battery simulation section (see figure 11), showing prosumers the potential to increase their self-consumption and autarky with an investment into personal storage. With the future interface, we plan to provide a stationary electric energy storage (EES) to the users and allow participating prosumers to allocate a certain capacity to buffer their times of overproduction and give the opportunity to share their capacities with consumers in the community. In our case, the planned storage will be realised by a 25.6 kWh Lithium-

Ion battery with a peak power of 24 kW. The idea behind combining this functionality with the market working in the background is, that prosumers can rent a the storage according to their needs and pay in accordance to their actual use (i.e. $/kWh) while still being able to sell the saved surplus energy directly to the community members.

A field-test setup has the potential to generate awareness of local and renewable energy production and sustainable consumption, and with it brings the need to convey this information in an engaging format. By incorporating the home-owners in this process, we encourage higher rates of adoption of solar technology in decentralised communities, which is vital to meeting the goals of the future energy transition quota for renewables.

Acknowledgements

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