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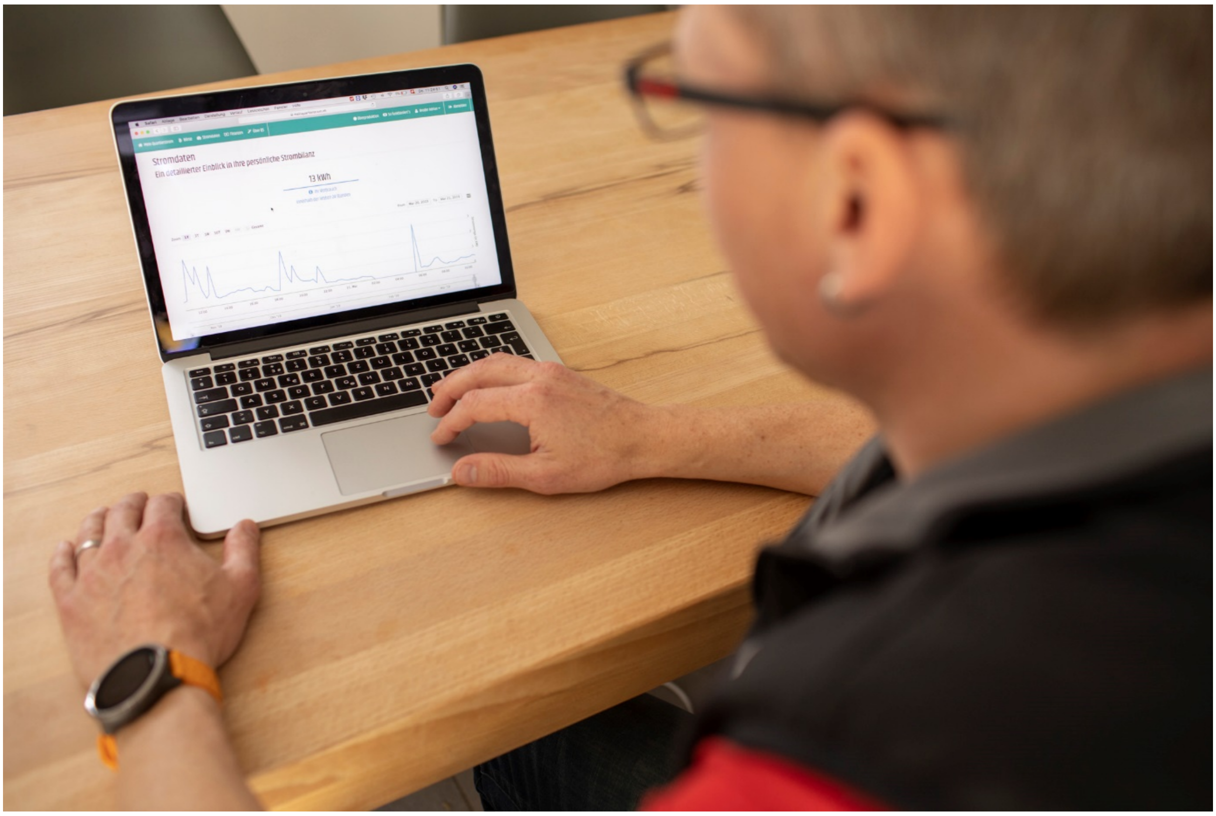
Community energy network with prosumer focus

Quartierstrom (Proposal entitled: “PowerID”)

Quartierstrom



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Summary

The distributed generation of renewable energy plays an increasingly important role in meeting the goals put forward in the Swiss Energy Strategy 2050 and to cover future electricity demand while reducing greenhouse gas emissions. Local energy markets may increase local balancing, enable consumers to actively influence energy sourcing, and provide incentives for investments in renewable generation. Advances in distributed ledger technologies have spurred ambitions to create such decentralized energy markets in which prosumers can directly sell excess renewable energy from peer to peer. However, only a limited number of projects have been implemented successfully in practice, as peer-to-peer (P2P) energy markets face challenges on multiple fronts, including technical complexity, the availability of suitable infrastructure, questions regarding the market design, user behavior and acceptance, data privacy, potential business models, and regulatory hurdles.

The Quartierstrom project (proposal titled “PowerID”), which has been supported within the flagship program by the Swiss Federal Office of Energy, is among the first to create and examine a real-world P2P energy market. In close cooperation with the local utility company EW Walenstadt, the project team has implemented Switzerland’s first peer-to-peer energy market based on blockchain technology with 37 participating households and a retirement home in the town of Walenstadt (Canton of St. Gallen). Prosumer households, who already owned a PV-panel, could sell their excess solar production directly to neighboring households without interference or reliance on a trusted third party. Via a user interface, both prosumers and consumers were able to indicate prices at which they were willing to sell / buy locally produced solar energy. The transactions were automatically calculated, managed and stored on a blockchain system in real time. If energy demand or supply could not be traded within the local community, the local utility provider, EW Walenstadt, served as backup to fill excess capacities at fixed tariffs.

The distributed system secured data integrity and conformity with the rules of the local energy market without requiring a centrally managed database. This ensured that the stored data could not be tampered with by one malicious actor and provided the necessary trust within a network of peers, who do not know each other. Such consensus-based trust establishing is particularly beneficial in large, open communities, where an absence of corresponding legal settings or enforcement thereof exists. Furthermore, a distributed ledger can provide higher security, as there is no single point of failure. Another benefit of the introduced solution is related to data privacy and compliance with the General Data Protection Regulation (GDPR) of the European Union: No personal data was published on the blockchain; no association between the public key and the household’s true identity that holds the private key was published on the blockchain at any point in time. Through the use of self-sovereign identity, in which private data remains stored on the device of the peer and access-control is provided over a distributed ledger, anonymity and the right to forget/revoke are provided as basic functionalities to all peers within the network.

After the prototypical system had been designed and implemented by an interdisciplinary team of researchers and members from industry led by the Bits to Energy Lab at ETH Zurich, participants were trading on the system for a period of an entire year. The system was thus tested under seasonal variations and user behavior was observed over a period of 12 months. During the one-year field phase of the project, the solar panels in the Quartier have produced over 250 MWh and the participating households have consumed almost 470 MWh, 70MWh were sold from household to household within the community.

More in detail, the Quartierstrom project has investigated

A) the technical feasibility of a blockchain-based community energy system with a particular focus on the local utilization of solar energy,

B) the optimal market design and resulting prices over time,

C) user behavior, in particular interaction with the user interface, price preferences and participants' motivation for participating in the local energy market and has explored

D) privacy aspects, the technical scalability of the solution, the regulatory environment, and potential business models.

The findings of this project are manifold, but most notably, the acceptance among the participants as well as the public interest that the project receive were outstandingly positive. The project received extensive and positive media coverage including in outlets like SRF, CNN Money, Blick, and the World Economic Forum blog. The technical implementation and design of the system represents pioneering work and demonstrates the technical feasibility of a P2P energy market using modern smart metering and communication infrastructure. In the conception phase of the project, the identification and implementation of a suitable market design revealed itself as fundamental for the proper operation of the P2P energy market; consequently, substantially more work than originally anticipated was dedicated to these aspects. Market prices for trading energy within the Quartier (resulting from the participants' bids in the user interface) fluctuated between the feed-in tariff as the lower bound and the residential retail tariff as the upper tariff. Participants' interaction with the user interface exceeded the team's expectations and the vast majority of participants seemed to understand the fundamental mechanics of the auction mechanism implemented, despite its complexity. Although many participants stated an appreciation for their ability to directly influence the price they paid/received for local electricity, towards the end of the project, a majority of them expressed a preference for a system with a higher degree of automation. At the same time, the project also revealed operational difficulties in deploying such a transactional system on existing smart meter infrastructure and in identifying a promising business model for a blockchain-based system, in particular under the current Swiss legislation for self-consumption communities.

Zusammenfassung

Die dezentrale Erzeugung von erneuerbarer Energie spielt eine immer wichtigere Rolle, um die in der Schweizer Energiestrategie 2050 formulierten Ziele zu erreichen, den zukünftigen Strombedarf zu decken und gleichzeitig die Treibhausgasemissionen zu reduzieren. Lokale Energiemärkte können den lokalen Ausgleich erhöhen, den Konsumenten eine aktive Einflussnahme auf die Energiebeschaffung ermöglichen und zugleich Anreize für Investitionen in die Stromerzeugung aus erneuerbaren Energien bieten. Fortschritte in Distributed Ledger Technologien haben Ambitionen zur Schaffung dezentralisierten Energiemärkte beflügelt, in denen Prosumenten überschüssige erneuerbare Energie direkt in der Nachbarschaft verkaufen können. Allerdings wurde bislang nur eine sehr überschaubare Anzahl von Projekten erfolgreich in die Praxis umgesetzt, da Peer-to-Peer- (P2P)-Energiemärkte mit Herausforderungen an mehreren Fronten konfrontiert sind. Dies bedinhaltet die technische Komplexität, die Verfügbarkeit geeigneter Infrastruktur, Fragen bezüglich der Marktgestaltung, bezüglich Nutzerverhaltens und Akzeptanz, bezüglich Datenschutz, potenzieller Geschäftsmodelle und bezüglich regulatorischer Hürden.

Das Projekt Quartierstrom (ursprünglicher Titel "PowerID"), das im Rahmen des Pilot-, Demonstrations- und Leuchtturmprojekt-Programms des Schweizer Bundesamt für Energie unterstützt wurde, gehört zu

den ersten Projekten, die einen realen P2P-Energiemarkt geschaffen und untersucht haben. In enger Zusammenarbeit mit dem lokalen Energieversorgungsunternehmen EW Walenstadt hat das Projektteam in der Stadt Walenstadt (Kanton St. Gallen) den ersten Peer-to-Peer-Energiemarkt der Schweiz auf der Basis der Blockchaintechnologie mit 37 teilnehmenden Haushalten und einem Seniorenheim realisiert. Prosumenten-Haushalte, die bereits eine Photovoltaik-Anlage besassen, konnten ihre überschüssige Solarproduktion direkt an benachbarte Haushalte verkaufen, ohne Abwicklung über bzw. Abhängigkeit von einer Drittpartei. Über eine Benutzerschnittstelle konnten sowohl Prosumenten als auch Konsumenten Preise angeben, zu denen sie bereit waren, lokal produzierten Solarstrom zu (ver)kaufen. Die Transaktionen wurden automatisch berechnet, verwaltet und auf einem Blockchainsystem in Echtzeit gespeichert. Wenn die Energienachfrage oder das -angebot nicht innerhalb der Gemeinschaft bereitgestellt bzw. abgenommen werden konnten, diente der lokale Energieversorger EW Walenstadt als Reservoir/Versicherung, um Über- bzw. Unterkapazitäten zum fixen Einspeise- bzw. Bezugspreis auszugleichen.

Das verteilte System sicherte die Datenintegrität und die Konformität mit den Regeln des lokalen Energiemarktes, ohne dass eine zentral verwaltete Datenbank erforderlich war. Dadurch wurde sichergestellt, dass die gespeicherten Daten nicht durch einen böswilligen Akteur verändert werden konnten, und sorgte für das nötige Vertrauen innerhalb eines Netzwerks von Peers, die sich nicht kennen. Eine solche konsensbasierte Vertrauensbildung ist besonders in grossen, offenen Gemeinschaften von Vorteil, in denen es keine entsprechenden rechtlichen Rahmenbedingungen oder deren Durchsetzung gibt. Darüber hinaus kann ein Destributed Ledger (Technologie zur „verteilten Buchführung“) eine höhere Sicherheit bieten, da es keinen Single Point of Failure (d.h. keine Achillesverse) gibt. Ein weiterer Vorteil der eingeführten Lösung steht im Zusammenhang mit dem Datenschutz und der Einhaltung der Allgemeinen Datenschutzverordnung (GDPR) der Europäischen Union: Es wurden keine persönlichen Daten auf der Blockchain veröffentlicht; zu keinem Zeitpunkt wurde eine Verbindung zwischen dem öffentlichen Schlüssel und der wahren Identität des Haushalts, der den privaten Schlüssel besitzt, auf der Blockkette veröffentlicht. Durch die Verwendung einer selbstbestimmten Identität, bei der die privaten Daten auf dem Gerät des jeweiligen Marktteilnehmers gespeichert bleiben und die Zugriffskontrolle über den Distributed Ledger erfolgt, werden Anonymität und das Recht auf Vergessen/Widerruf als grundlegende Funktionalitäten allen Peers innerhalb des Netzwerks zur Verfügung gestellt.

Nachdem das prototypische System von einem interdisziplinären Team von Forschenden und Mitgliedern aus der Industrie unter der Leitung des Bits to Energy Labs der ETH Zürich entworfen und implementiert worden war, haben die Teilnehmer während eines ganzen Jahres auf dem System gehandelt. So wurde das System unter saisonalen Schwankungen getestet und das Nutzerverhalten über einen Zeitraum von 12 Monaten beobachtet. Während der einjährigen Feldphase des Projekts produzierten die Solarpanels im Quartier über 250 MWh und die teilnehmenden Haushalte verbrauchten fast 470 MWh; 70 MWh wurden innerhalb der Gemeinde gehandelt.

Folgende Aspekte standen im Fokus der Untersuchung im Quartierstrom-Projekt:

A) die technische Machbarkeit eines auf Blockchain basierenden lokalen Energiemarkts mit besonderem Schwerpunkt auf der lokalen Nutzung der Solarenergie,

B) die optimale Marktgestaltung und die daraus resultierenden Preise im Laufe der Zeit,

C) Nutzerverhalten, insbesondere Interaktion mit der Benutzerschnittstelle, Preispräferenzen und die Motivation der Teilnehmer zur Teilnahme am lokalen Energiemarkt sowie

D) Datenschutzaspekte, die technische Skalierbarkeit der Lösung, das regulatorische Umfeld und potenzielle Geschäftsmodelle.

Die Ergebnisse dieses Projekts sind vielfältig, aber vor allem die Akzeptanz unter den Teilnehmern sowie das öffentliche Interesse, das dem Projekt entgegengebracht wurde, waren ausserordentlich positiv. Über das Projekt wurde in den Medien ausführlich und positiv berichtet, unter anderem im SRF, bei CNN Money, Blick und im Blog des Weltwirtschaftsforums. Die technische Umsetzung und Gestaltung des Systems stellt Pionierarbeit dar und demonstriert die technische Machbarkeit eines P2P-Energiemarktes unter Verwendung moderner intelligenter Mess- und Kommunikationsinfrastruktur. In der Konzeptionsphase des Projekts erwies sich die Identifizierung und Umsetzung eines geeigneten Marktdesigns als grundlegend für die ordnungsgemässe Funktion des P2P-Energiemarktes; folglich erwies sich dieser Aspekt als aufwendiger als ursprünglich vorgesehen. Die Marktpreise für den Energiehandel innerhalb des Quartiers (resultierend aus den Geboten der Teilnehmer in der Benutzeroberfläche) pendelten zwischen dem Einspeisetarif als Untergrenze und dem regulären Strompeis für Privathaushalte als Obergrenze. Die Interaktion der Teilnehmer mit der Benutzeroberfläche übertraf die Erwartungen des Teams, und die überwiegende Mehrheit der Teilnehmer schien die grundlegende Mechanik des implementierten Auktionsmechanismus trotz seiner Komplexität zu verstehen. Obwohl viele Teilnehmer ihre Fähigkeit zur direkten Beeinflussung des Preises, den sie für den lokalen Strom bezahlten/erhalten, zu schätzen wussten, äusserte gegen Ende des Projekts eine Mehrheit von ihnen den Wunsch nach einem System mit einem höheren Automatisierungsgrad. Das Projekt offenbarte zugleich auch operationelle Schwierigkeiten bei der Einführung eines solchen Transaktionssystems auf der bestehenden Infrastruktur für intelligente Zähler und bei der Identifizierung eines vielversprechenden Geschäftsmodells für ein blockkchain-basiertes System und im Rahmen der aktuellen Schweizer Gesetzgebung für Eigenverbrauchsgemeinschaften.

Résumé

La production décentralisée d'énergie renouvelable joue un rôle de plus en plus important pour atteindre les objectifs fixés dans la stratégie énergétique 2050 de la Suisse et pour couvrir la demande future en électricité tout en réduisant les émissions de gaz à effet de serre. Les marchés locaux de l'énergie peuvent accroître l'équilibrage local, permettre aux consommateurs d'influencer activement l'approvisionnement en énergie et fournir des incitations aux investissements dans la production d'énergie renouvelable. Les progrès réalisés dans les technologies de registres distribués ont stimulé les ambitions de créer de tels marchés de l'énergie décentralisés dans lesquels les consommateurs peuvent vendre directement l'énergie renouvelable excédentaire d'un pair à l'autre. Cependant, seul un nombre limité de projets ont été mis en œuvre avec succès dans la pratique, car les marchés de l'énergie pair à pair (P2P) sont confrontés à des défis sur de multiples fronts, notamment la complexité technique, la disponibilité d'infrastructures adaptées, les questions concernant la conception du marché, le comportement et l'acceptation des utilisateurs, la confidentialité des données, les modèles commerciaux potentiels et les obstacles réglementaires.

Le projet Quartierstrom (proposition intitulée "PowerID"), qui a été soutenu dans le cadre du programme phare par l'Office Fédéral Suisse de l'Energie, est l'un des premiers à créer et à examiner un véritable marché de l'énergie P2P. En étroite collaboration avec la société d'électricité locale EW Walenstadt, l'équipe du projet a mis en place le premier marché de l'énergie pair à pair de Suisse basé sur la technologie de la chaîne de blocs, avec 37 ménages participants et une maison de retraite dans la ville de Walenstadt (canton de Saint-Gall). Les ménages “prosommateurs”, qui possédaient déjà un système photovoltaïque, pouvaient vendre leur production solaire excédentaire directement aux ménages voisins sans interférence ou dépendance à l'égard d'un tiers de confiance. Grâce à une interface utilisateur, les prosommateurs et les consommateurs ont pu indiquer les prix auxquels ils étaient prêts à vendre/acheter l'énergie solaire produite localement. Les transactions ont été automatiquement

calculées, gérées et stockées en temps réel sur un système de chaîne de blocs. Si la demande ou l'offre d'énergie ne pouvait pas être échangée au sein de la communauté locale, le fournisseur d'électricité local, EW Walenstadt, servait de réserve pour combler les capacités excédentaires à des tarifs fixes.

Le système distribué garantissait l'intégrité des données et la conformité avec les règles du marché local de l'énergie sans nécessiter de base de données gérée de manière centralisée. Cela a permis d'éviter que les données stockées ne soient altérées par un acteur malveillant et a apporté la confiance nécessaire au sein d'un réseau de pairs qui ne se connaissent pas. Cette confiance consensuelle est particulièrement bénéfique dans les grandes communautés ouvertes, où il n'existe pas de cadre juridique correspondant ou d'application de celui-ci. En outre, un registre distribué (“distributed ledger”) peut offrir une sécurité accrue, car il n'y a pas de point de défaillance unique. Un autre avantage de la solution introduite est lié à la confidentialité des données et au respect du règlement général sur la protection des données (RGD) de l'Union européenne: Car les données personnelles n'ont pas été publiées sur la blockchain; de même, aucune association entre la clé publique et la véritable identité du ménage qui détient la clé privée n'a été publiée sur la blockchain à aucun moment. Grâce à l'utilisation de l'identité autosouveraine, dans laquelle les données privées restent stockées sur le dispositif du pair et le contrôle d'accès est assuré par un registre distribué, l'anonymat et le droit d'oubli/révocation sont fournis comme fonctionnalités de base à tous les pairs au sein du réseau.

Après que le système prototype avait été conçu et mis en œuvre par une équipe interdisciplinaire de chercheurs et de membres de l'industrie dirigée par le Bits to Energy Lab de l'ETH Zurich, les participants ont fait des transactions sur le système pendant une année entière. Le système a donc été testé sous des variations saisonnières et le comportement des utilisateurs a été observé sur une période de 12 mois. Pendant la phase de terrain d'un an du projet, les panneaux solaires du Quartier ont produit plus de 250 MWh et les ménages participants ont consommé près de 470 MWh, 70 MWh ont été vendus de ménage à ménage au sein de la communauté.

Plus en détail, le projet Quartierstrom a étudié

A) la faisabilité technique d'un système énergétique communautaire basé sur une chaîne de blocs, avec un accent particulier sur l'utilisation locale de l'énergie solaire,

B) la conception optimale du marché et les prix qui en résultent au fil du temps,

C) le comportement des utilisateurs, en particulier l'interaction avec l'interface utilisateur, les préférences de prix et la motivation des participants à participer au marché local de l'énergie, ainsi que

D) les aspects liés à la protection de la vie privée, l'évolutivité technique de la solution, l'environnement réglementaire et les modèles commerciaux potentiels.

Les conclusions de ce projet sont multiples, mais surtout, l'acceptation par les participants ainsi que l'intérêt du public pour le projet ont été remarquablement positifs. Le projet a bénéficié d'une couverture médiatique importante et positive, notamment dans des médias tels que SRF, CNN Money, Blick et le blog du Forum économique mondial. La mise en œuvre technique et la conception du système représentent un travail de pionnier et démontrent la faisabilité technique d'un marché de l'énergie P2P utilisant une infrastructure moderne de communication et de comptage intelligent. Lors de la phase de conception du projet, l'identification et la mise en œuvre d'une conception de marché appropriée se sont révélées fondamentales pour le bon fonctionnement du marché de l'énergie P2P; par conséquent, un travail bien plus important que prévu à l'origine a été consacré à ces aspects. Les prix du marché pour le commerce de l'énergie au sein du Quartier (résultant des offres des participants dans l'interface utilisateur) ont fluctué entre le tarif de rachat comme limite inférieure et le tarif de détail résidentiel comme limite supérieure. L'interaction des participants avec l'interface utilisateur a dépassé les attentes de l'équipe et la grande majorité des participants semblait comprendre les mécanismes fondamentaux du mécanisme d'enchères mis en œuvre, malgré sa complexité. Alors que de nombreux participants ont déclaré apprécier leur capacité à influencer directement le prix qu'ils payent/reçoivent pour l'électricité locale, vers la fin du projet, une majorité d'entre eux ont exprimé une préférence pour un système plus automatisé. Le projet a également révélé des difficultés opérationnelles dans le déploiement d'un tel système transactionnel sur l'infrastructure existante de compteurs intelligents et dans l'identification d'un modèle commercial prometteur pour un système basé sur une blockchain, en particulier dans le cadre de la législation suisse actuelle pour les communautés d'autoconsommation.

Take-home messages

For a more comprehensive list of the key findings of the project, please refer to the section 5.2 Key results.

Table of Contents

Abbreviations

B2E	Bits to Energy Lab
C21	Cleantech21
ETH	ETH Zurich (Swiss Federal Institute of Technology)
EnG	Energiegesetz
EnV	Energieverordnung
EVG	Eigenverbrauchsgemeinschaft
GDPR	General Data Protection Regulation of the European Union
HSG	University of St. Gallen
HSLU	Lucerne University of Applied Sciences and Arts
LVD tariff	Local voltage-dependent grid tariff
P2P	Peer-to-Peer
PoA	Proof-of-Authority
PoS	Proof-of-Stake
Pow	Proof-of-Work
PV	Photovoltaic
SCS	Supercomputing Systems
SFOE	Swiss Federal Office of Energy
SG	Canton of St. Gallen
SCR	Self-consumption rate
SSR	Self-sufficiency rate
StromVG	Stromversorgungsgesetz
StromVV	Stromversorgungsgerorsnung
std	Standard deviation
TEE	Trusted Execution Environment
WEW	Wasser und Elektrizitätswerk Walenstadt (utility company in Walenstadt)
ZEV	Zusammenschluss zum Eigenverbrauch
ZHAW	Zurich University of Applied Sciences

1 Introduction

Lead author: Verena Tiefenbeck, ETH

1.1 Background information and current situation

In the past few years, the costs for distributed renewable energy sources, such as wind and solar energy, have been falling considerably. Consequently, distributed energy sources have become key levers for transforming the electricity market from a vertical top-down structure into a decentralized, bottom-up landscape and for providing a reliable and sustainable energy supply (Green and Newman 2017, Hentschel et al. 2018, Morstyn et al. 2018). Yet, a key aspect of the electricity grid is that demand and supply need to be balanced at all times. Thus, an increasingly decentralized electricity production requires more autonomous, bottom-up coordination.

The liberalization of the electricity market in many countries and technical advances in recent years have spurred ambitions for bottom-up coordination by creating marketplaces in which renewable energy can be sold from peer to peer (Andoni et al. 2019, Mengelkamp et al. 2017). Local energy markets in particular have received a lot of attention as a promising approach for creating incentives for local balancing of demand and supply (Ketter et al. 2013, Vona & Nicolli 2014). The underlying idea of these local peer-to-peer (P2P) markets is that prosumers (owners of PV panels) are able to sell their solar power surplus directly to other consumers in the neighborhood, possibly at prices that are beneficial for both, consumers and prosumers. Thus, from the prosumers' perspective, peer-to-peer markets may be a promising alternative to existing feed-in tariff models for distributed renewable energy sources.

Technical development in blockchain/distributed ledger technology have given rise to a plethora of decentral coordination concepts for the electricity sector. Yet so far, very few of these concepts have been implemented successfully in the real world. While appealing in theory, in practice, these endeavors have to overcome a variety of challenges and open questions, including the availability of suitable infrastructure, technical complexity, market design, acceptance and user behavior, data privacy, potential business models, and regulatory hurdles. Given the variety of individual barriers involved and the challenges associated with the interdisciplinary collaboration required to meet them, empirical evidence of the feasibility and performance of P2P energy markets in the real world is still scarce.

1.2 Purpose of the project

Purpose of the Quartierstrom project was to create a prototypical P2P energy market in the real world that seeks to increase local load balancing. More specifically, the goal was to create Switzerland's first P2P market based on blockchain technology that manages the exchange and remuneration of electricity between consumers, prosumers and the local grid provider in the absence of intermediaries. Beyond the technical implementation, the project aimed at investigating the feasibility of a real-world P2P energy market from different perspectives: technical feasibility (suitable hardware and software to implement blockchain-based system), market design, acceptance and behavior of households participating in the market, privacy aspects, regulatory hurdles, and potential business models.

1.3 Objectives

More specifically, the Quartierstrom project had the following goals:

- **Technical feasibility** (modules 21, 22, 31, 32, 33, 34 and 51): The first component of the project aimed to evaluate blockchain as a technology to facilitate peer-to-peer energy markets, to identify requirements of the hardware infrastructure and the availability of suitable hardware. As part of that, the project proposed to examine energy consumption, privacy preservation and technical scalability of the identified solution to understand the ecological impact of the blockchain technology. Regarding the implementation of the prototypical system, a minimum of 20 participating households was set. Beyond that, the simulation and implementation of a battery control system was proposed that considers the current state of the community.

- **Platform and market design** (module 32 and 51): In order to create incentives that increase local balancing, the project aimed to investigate blockchain-based solutions for distributing and pricing energy on the local market, and to implement a suitable market design based on smart contracts.
- **User Behavior** (modules 33 and 41): To study acceptance and user behavior in the local P2P market, the project aimed to build a user interface for the participants that visualizes current and historic data on the community performance and which serves as basis for the billing process. To that end, the project proposed to test different options for the design and content of the user interface systematically in an iterative process including focus groups, literature reviews, interviews, and surveys
- **Regulatory environment** (module 61): One module analyzed the current state of the regulatory context and relevant regulatory developments in Switzerland and in other countries.
- **Business model** (module 61): To assess the viability of different business models in the light of technical and regulatory developments; an analysis of the current situation as well as a forward-looking perspective of future opportunities that might arise if the regulatory environment changes was proposed.
- **Communication** (module 12): The communication concept proposed various measures to ensure the national and international visibility of the project beyond the academic world, including a project website with regular blog posts, newsletters, press releases, etc.

2 Description of the facility

Lead author: Liliane Ableitner and Anselma Wörner, ETH

The system facilitating P2P energy trading for the purpose of this project consisted of three main components:

- **a blockchain infrastructure**: A permissioned Tendermint blockchain which stored transactions of the P2P market.
- **a market application running on the blockchain**: An iterative double auction which determined prices for locally produced solar energy.
- **a user interface with which the households interacted**: A web application which provided information on energy consumption in real time and allowed households to define their willingness to pay for solar energy from the neighborhood.

These three main system components were designed and developed by the project team specifically for this project and are depicted in Figure 3. Their design will be described in more detail in Chapter 4 of this report (Sections 4.1.2, 4.3.1, 4.3.2).

To facilitate the operation of the system, each of the households was equipped with prototypical smart-meters that can measure currents, voltages and frequencies on each of the phases and that come with an integrated single board computer (SBC). The SBCs act as distributed nodes for the blockchain system that is introduced in Section 4.1. Each household was equipped with a maximum of three smart meters to separately measure net consumption, production and battery power. The deployed hardware will be described in Section 4.2.

With a remarkably innovative infrastructure in place (e.g. photovoltaic systems, community battery storage), the neighborhood Schwemmiweg was identified as pilot region in the town of Walenstadt, SG. The local community for the pilot test consisted of 37 participating households. The community consists of consumers and prosumers with a total solar PV capacity of 280 kWp with a total storage capacity of 80 kWh in form of lithium ion batteries. In all, 19 households from the Schwemmiweg and another additional 22 households were invited to join the pilot test. The households therefore received an invitation letter, drafted by ETH Zurich, revised by Sprachwerk and EW Walenstadt. The letter informed participants about the planned project in their neighborhood.

The recipients of the letter had the possibility to register for the pilot project by signing a consent form, in which they declared their willingness to take part in the project and share the collected smart meter data with the project team. While a minimum of 20 households was agreed on as a requirement for the study to be implemented, we were able to recruit almost twice as many households, which reflects the popularity of the idea among the community in Walenstadt. In all, 37 household signed up for the pilot project, agreed to share their data and are willing to answer surveys. The prosumer-consumer ratio was high: Out of the 37 registered households, 27 owned photovoltaic panels and 8 out of these even owned battery storage systems. One of the consumers was a retirement home (treated as one consumer).

Figure 1 An aerial view of the neighborhood, which shows the high penetration of PV systems in Walenstadt.

3 Procedures and methodology

Lead authors: Verena Tiefenbeck and Anselma Wörner, ETH

3.1 Timeline

The timeline presented below illustrates the course of the project, highlighting the different stages of the project. The active field phase in which the Quartierstrom system was live, was launched in January 2019 and ended after one year in January 2020. In July 2018, the utility company BKW and meter-to-cash-provider SwiBi (now merged into esolva) joined as a project partners of the consortium and in Feb., 2019, SBB joined as additional partner. SBB built a PV system (9 kWp) on a transformer station, which was integrated into the market in September 2019.

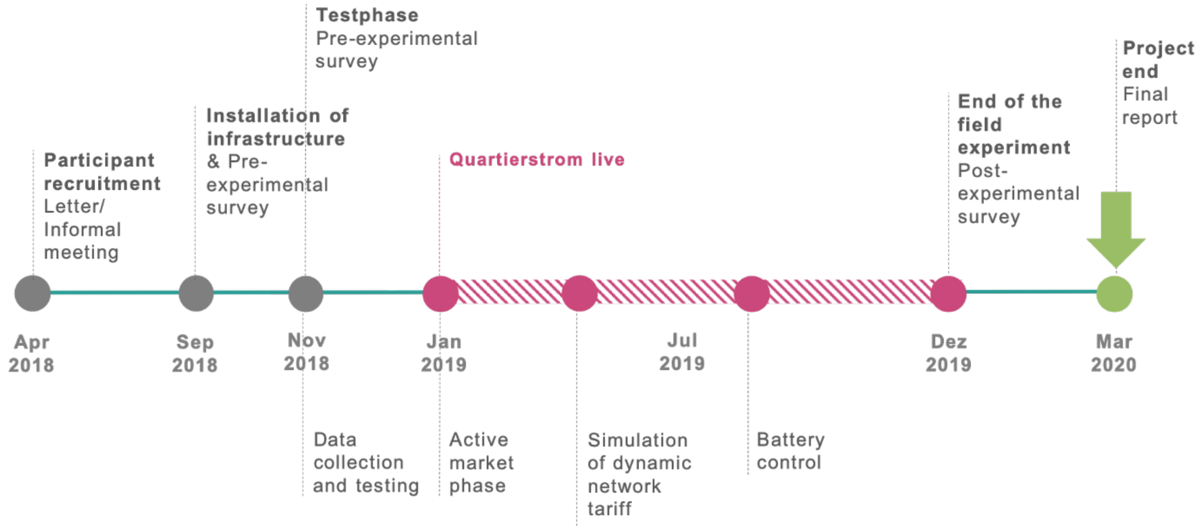

Figure 2 Structure of key tasks and responsibilities within the project consortium.

3.2 Overview of key areas and organization

To meet the goals outlined in section 1.3, the consortium led by the Bits to Energy Lab (B2E) at ETH Zurich defined five key areas, which are illustrated in Figure 3. The project was led by Sandro Schopfer (until June 2019) and by Verena Tiefenbeck, both at ETH Zurich.

System architecture (Sections 4.1 and 4.2): The Bosch IoT lab at the University of St. Gallen (HSG) and the B2E lab implemented the blockchain-based infrastructure (hardware and software) in collaboration with EW Walenstadt. Together with Supercomputing Systems (SCS) and the Lucerne University of Applied Sciences (HSLU), they evaluated different blockchain technologies to identify the most suitable architecture.

Market and mechanism design (Sections 4.3 and 4.5): The team of the B2E Lab (supported by the Bosch IoT lab at HSG and by SCS) investigated different market mechanisms, implemented the market design on the platform, defined the bidding formats and evaluated the resulting dynamics (price, self-sufficiency, self-consumption etc.) on the market. *Note: The original project proposal had not included a dedicated market design module. However, detailed analyses of these aspects at the core of the system revealed themselves to be fundamental to ensure the stable operation of the system. Therefore, the team at ETH Zurich added another researcher from own funds to conduct the necessary analyses.*

Management system (Section 4.4): The B2E team implemented the user interface, on which the participants could access consumption and production data of their household and community, as well as set their price preferences for buying and selling in the community.

Business and legal (Section 4.6): The Zurich University of Applied Sciences (until Sept. 2018: Planar AG) and Cleantech21 foundation investigated the regulatory environment and business models.

Communication/PR (Section 8): Sprachwerk led and coordinated the communication activities of the project.

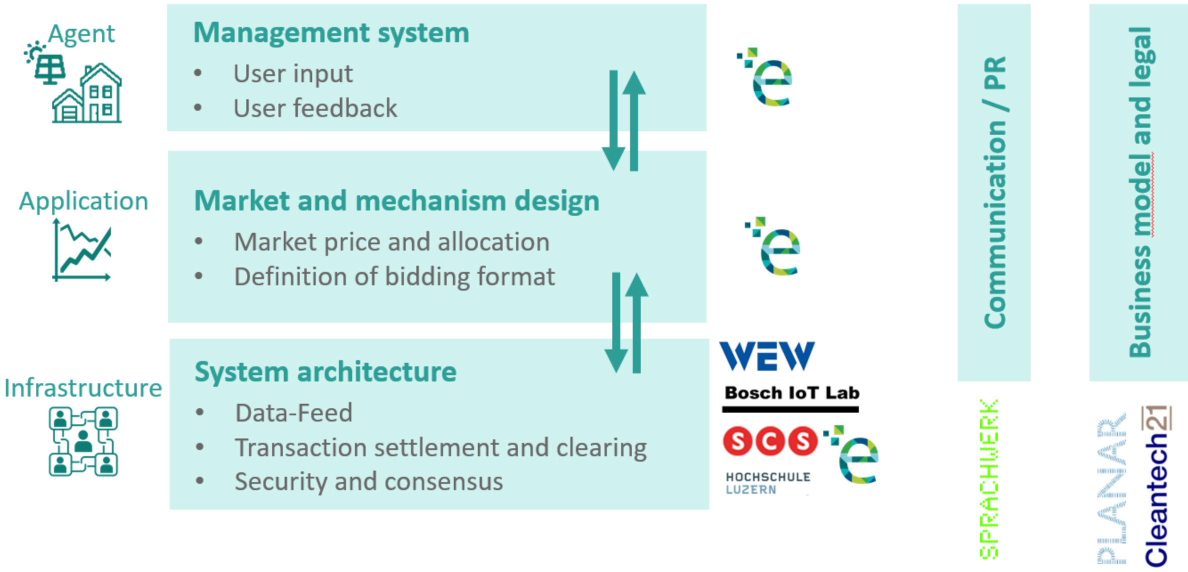

Figure 3 Structure of key tasks and responsibilities within the project consortium.

3.3 Work packages

The work packages of project are listed in Table 1 below. All packages have been completed and the results are reported in the sections indicated in column 3.

Modul	**Description**	**Status**
Modul 11	**Administrative Tasks and Project Management (Lead: ETH)**	Completed
Modul 12	**Communication (Sprachwerk)**	Completed, see summary in Section 8
Modul 21	**Metering Hardware (ETH, SCS)**	Completed, installed in Walenstadt, see description in Section 4.2
Modul 22	**Hardware Wasser- und Elektrizitätswerk Walenstadt (WEW)**	Completed, in place/installed in Walenstadt
Modul 31	**Theory and Review of Blockchain Technology (ETH, HSG, HSLU, SCS)**	Completed, see Section 4.1
Modul 32	**Software: Platform Engineering (ETH, HSG, SCS)**	Completed, see description in Section 4.3.1
Modul 33	**Software: User Interface (ETH)**	Completed, see description in Section 4.3.2
Modul 34	**Software: AI for Community Control (ETH)**	Completed, see description in Section 4.3.34.3
Modul 41	**User Behavior and Acceptance (ETH)**	Completed, see Section 4.4
Modul 51	**Data Analysis (ETH, SCS)**	Completed, see Section 4.4 / 4.5

Modul 61	**Business and Legal (Cleantech21, Planar AG/ZHAW)**	See Section 4.6

Table 1 Work packages and status of completion.

4 Results and discussion

4.1 Blockchain architecture (Module 31)

4.1.1 Role of blockchain

Lead authors: Sandro Schopfer, ETH and Arne Meeuw, HSG

A decentralized market for solar energy requires the exchange of electricity between private households, and blockchain technology is being promoted as a suitable information technology to realize this vision by many. On a blockchain-based market, transactions can be settled without the mediation of a utility company or a financial institution. Despite the ongoing hype around blockchain, there is little understanding of the usability and value proposition of this technology in practice.

The goal of module 31 ("blockchain architecture and platform evaluation") of the Quartierstrom project is the evaluation of existing blockchain protocols and their applicability to local peer-to-peer energy markets. For the selection of the blockchain, the project team formulated four requirements:

- **Requirement 1:** Lowest possible energy consumption to secure the blockchain
- **Requirement 2:** Sufficient bandwidth (throughput) to handle the local peer-to-peer (P2P) market application with a minimal time slot resolution of 15 minutes.
- **Requirement 3:** Decentralized computations to reduce the risk of single point of failure: Consensus among Quartierstrom participants is required over market prices for every time slot.
- **Requirement 4:** Lightweight blockchain architecture to allow for deployment on low-cost IoT-type hardware.

The development of a decentralized local energy market place can be realized with a variety of different blockchains. Since the inception of the bitcoin blockchain, many other types of blockchains have been proposed and were already built. In the recent months and years, other related decentralized systems without blocks have been proposed which gave rise to the term Distributed Ledger Technologies (DLTs) as overarching definition that includes also blockchains. All of these systems have different properties regarding their functionality (e.g. execution of smart contracts), degree of decentralization, bandwidth (transaction throughput), latency (time required to reach consensus), energy consumption, general maturity and accessibility for developers.

4.1.2 Selection of blockchain architecture for the project

Authors: Arne Meeuw, HSG, Sandro Schopfer, ETH, Alain Brenzikofer and Sabine Proll, SCS, Alexander Denzler, HSLU

Blockchains can be divided in public and private chains. Public chains are fully permissionless, meaning that any party can potentially validate blocks. The validation process is governed by a so-called consensus protocol. The most established and field-proven consensus protocol is Proof-of-Work (PoW), which is employed by the bitcoin blockchain (and many others) and utilizes hash functions to validate transactions in a block. So-called miners or validators spawn a network of nodes that keep track of the order and correctness of all transactions contained in the blockchain. These include double spend attacks, transaction spamming, and more generally, the broadcasting of faulty blocks. In order to validate a block, the hash function must be repeatedly evaluated with the transactions contained in a block until a pre-defined difficulty-level can be satisfied. The continuous re-evaluation or brute forcing of the hash function secures the underlying blockchain to a very high degree. However, large amounts of electricity are required to continuously validate blocks by reevaluating hashing functions using custom mining hardware. The resulting energy consumption is in conflict with requirement 1 for the Quartierstrom system as the electricity spent for running the computation is in any case irreversibly dissipated into heat, regardless if the block was accepted by the network. To overcome the known inefficiencies of PoW systems, researchers and engineers came up with another consensus protocol called Proof-of-Stake (PoS), which requires much less energy but can guarantee the same security properties as PoW systems. In PoS systems, the native currency of the blockchain is used to secure the network by requiring validators to stake (i.e. bonding or committing) their coins to a validated block. The validator earns interest on the staked amount if the block is proven to be valid by the rest of the network. The staked amount can be partially or completely removed by the network if an invalid block has been proposed. This process is referred to as slashing. Therefore, PoS blockchains do not suffer from energy inefficiencies like PoW blockchains. In the past months, many blockchain projects emerged that aim at building PoS systems, all of which operate on different assumptions and variations of this consensus protocol. However, while there are many convincing projects and different protocol variations to overcome current shortcomings of PoS systems, there is not enough data available from running PoS networks that have actually operated over a long timerange with proven reliability against various kinds of attacks, compared to the bitcoin blockchain, for instance.

Private blockchains, on the other hand, do not employ a native currency and can be thought of as PoS systems without “skin in the game”, i.e. without staking a currency with value. Instead, they rely on a proof of authority (PoA) scheme where the validators are known a priori. Thus, private blockchains do not suffer from the high energy consumption that PoW systems create. The validators of private blockchains are usually known to each other. Even if the blockchain is not secured by a cryptocurrency (for example in a private or consortium chain), digital assets can still be transferred between the parties, for example by a traditional contractual agreement between the validating parties.

Requirement 2 can be theoretically approached with public networks by utilizing scaling solutions like off-chain state channels. Such solutions keep track of changes of the account balances of the different nodes (issued transactions for example) off-chain and can be settled on a public chain whenever a channel needs to be settled, closed or opened. It is clear that such solutions reduce the number of on-chain transactions and therefore the associated transaction costs and environmental externalities. However, generalized state channels are currently under development and not mature enough to project and compute complex decentralized market structures, as applied in the Quartierstrom project into state channels. Therefore, the project team decided that state channels can currently not be used to compute arbitrary state changes off-chain to satisfy requirement 3 and 4.

The computation and determination of market prices for a given time does not have to depend on a global consensus protocol with validators distributed all over the world. Rather than requiring global consensus over local market prices and associated transactions, it is more efficient and meaningful to leave the validation function to members of the Quartierstrom community, as they need to decide market prices that reflect the value of locally generated solar energy. Therefore, the project team decided that the set of requirements 1 to 4 can be best approached with an application-specific and self-sovereign blockchain. The blockchain is application-specific because the local energy market is the only application running on this specific blockchain. Its primary purpose is A) the exchange of consumption and production data as well as bids and asks to reach consensus over current market prices and B) to define and settle trades via transactions.

In July 2018 SCS evaluated different blockchain technologies with a focus on the maturity of the implementation (note: as the field of decentralized technologies is evolving rapidly, the information in this comparison may have changed by the time of the release of this final report, for an overview of blockchain protocols employed in P2P energy projects, see also Mazzola et al. (2020)). With each technology, a full node and two wallets were set up. Then, for each platform, the same set of interactions was attempted. The table gives an overview on the functionality that could be implemented with each technology. "Signing" means the functionality of signing an arbitrary message. "Payload" means support for adding custom payloads to transactions. An ✗ means that the functionality could not be successfully tested with reasonable effort (even if the functionality might be provided by the technology):

	Setup	Signing	Payload	Consensus
Nano	Docker ✓	✗	✗	PoA/PoS
IOTA	One-liner ✓	✗	✗	Centralized
Cardano	Docker ✓	✓	✗	DPoS
EOSIO	One-liner ✗	✗	✗	DPoS
EWF	Github build ✓	✓	✓	PoA EWF
Tendermint	Github build ✓	DIY ✓	DIY ✓	PoA or PoS
Hyperledger Fabric	Docker ✓	✓	✓	PoA

Table 2 Overview of blockchain technologies evaluated by SCS.

For the use case of Quartierstrom, proof-of-work (PoW) blockchains have been categorically excluded because of their energy-intensive mining to reach consensus. In terms of energy efficiency, IOTA uses PoW as a spam prevention. This makes IOTA the most energy-intensive platform of the above selection. Proof-of-authority (PoA) and proof-of-stake (PoS) are only slightly more energy-consuming than common centralized cloud solutions. Quantifying these differences is outside of the scope of this report. Nano and IOTA are the only platforms in the selection that do not provide generalized smart contract support. From the standpoint of spring 2020, we would suggest to evaluate Corda, Hyperledger Sawtooth and Polkadot as well for use cases similar to Quartierstrom.

Tendermint implementation - After the project team discussed Ethereum, Nano, IOTA, Cardano, EOS, EWF, Tendermint and Hyperledger regarding the four requirements and decided to implement the network on the Tendermint (Buchman et al. 2018) consensus protocol. Tendermint is an open source project that is very lightweight and highly modular at the same time, which makes it an ideal candidate for IoT applications (Requirement 4). Tendermint handles the communication with peers in the network, establishes consensus and replicates the state of the blockchain automatically on other validator machines. Tendermint can be thought of as a pluggable consensus engine, which simplifies the development of a new, application-specific blockchain. Applications written in any programming language can be potentially deployed to a Tendermint blockchain thanks to the application blockchain interface (ABCI), which separates the application from the communication and consensus protocol and eases the development. Tendermint is maintained by the Cosmos project, which is currently building a hub that allows interconnecting private or public Tendermint chains. Tendermint blockchains can be set up as both, private or public chains, because the application operating on top of Tendermint can decide to add or drop validators based on certain criteria. The use of Tendermint allows the project team to react in a flexible way on future trends. As such, in the future, the Quartierstrom blockchain could be interconnected with other blockchains and allow the payment or staking mechanisms via cryptocurrencies or a potential Swiss franc stable coin. However, it is important to point out that the Quartierstrom blockchain can also operate completely in isolation as a private blockchain where only members of the community validate blocks.

4.1.3 Evaluation regarding energy consumption

Lead author: Arne Meeuw, HSG

The blockchain deployed in the Quartierstrom network is thus a private blockchain network (with the option to operate it as public network) and does not rely on the computationally expensive PoW scheme. Instead, it relies on a proof of authority (PoA) scheme. This network is realized on SmartPi meters (see section 4.2.1). Besides measuring the electric energy, the SmartPis host the blockchain and are used to settle transactions.

Thus, in the evaluation of the following results, one needs to keep in mind that the SmartPis in the project were installed in addition to the existing smart meter infrastructure. For future large-scale deployments, other hardware solutions would be preferable, namely using certified smart meters (that are deployed anyhow for keeping track of the electricity consumption). Equipping these smart meters with additional capabilities for hosting the blockchain and for settling electricity trades would probably result in a lower energy use than in the case of the Quartierstrom pilot project, where both the SmartPis and the existing smart meters consume energy. Thus, the figures reported in the following represent an upper bound of the energy consumption of the infrastructure required to operate the blockchain-based solution.

The SmartPi itself operates between 1.9W (idle) and approximately 5W (full load). During operation, we estimated an average consumption of 3.5W resulting in energy consumption of approximately 31kWh per year and annum. To participate in the Quartierstrom trading platform, each of the households needs to be equipped by at least one SmartPi that measures electricity import and export of a household. However, in the Quartierstrom project, we deliberately choose to install more SmartPis to visualize both consumption and generation profiles for the participants.

Number of SmartPis	Consumption per SmartPi per year	Total consumption of SmartPis per year	Total electricity consumption of the community per year
37	31 kWh	1’147 kWh	470’000 kWh

Table 3 Estimated energy consumption of SmartPis compared to community consumption

As shown in Table 3, the deployed SmartPis consume 1’147 kWh per year, while the entire community consumes roughly 470’000 kWh per year (estimation based on the first half year of the Quartierstrom operation). Therefore, the SmartPis consume roughly 0.24% of the annual demand of the community. Another meaningful figure is the ratio of the consumption of the SmartPis relative to the self-consumption of the entire community, which reflects the volume of trades that could be matched to other community members due to aligned load profiles and price expectations thanks to the platform. During the field phase, the trades among community amounted to roughly 14.8% of the community consumption or 69’000 kWh. In this perspective, the energy consumption of the SmartPis amounts to roughly 1.6% of the solar energy it enabled to be traded in the community (this excludes classical self-consumption within the households). As stated above, these numbers are prototype-specific, as they reflect the additional installation of SmartPis on top of the existing smart meter infrastructure and thus represent an upper bound of the energy consumption.

4.1.4 Technical evaluation of blockchain regarding scalability (HSG)

Lead author: Arne Meeuw, HSG

Overall, the stability of the blockchain system deployed hosting the Quartierstrom system was good. However, contradictory to earlier expectations, data provision and stable communication among the smart meters deployed in the participating households proved to be very challenging and required more maintenance on site than anticipated. Communication issues were mostly due to the devices losing internet connection. Additionally, special setups in apartment houses and shared PV systems provided additional complexity to the precise real-time accounting between the participating households.

The Quartierstrom platform is based on a permissioned blockchain that is executed by the prosumers' SmartPis of the field test under full process transparency. These validators of the platform reach an agreement (consensus) how to execute the market application and determine the flows of energy (who bought how much energy from whom). This process is very communication-intensive and can require up to $\mathcal{O}(n_{val}{}^2)$, where n_{val} is the number of validators in the system (27 in case of the Quartierstrom field-test).

Blockchain benchmarking is a topic very well known to the blockchain world. New consensus mechanisms and whitepapers of blockchain platforms publish performance statistics in order to provide figures of maximum expected performance. In academic literature, benchmarking of blockchain-based platforms is well represented, but has not yet offered a de-facto standard for testing procedures (e.g., Blomand & Farahmand 2018, Han et al. 2018). The common key performance metrics of a blockchain-based system are its throughput (measured in transactions per second) and its latency (seconds until a transaction is included in a block).

In order to evaluate the performance of the permissioned blockchain running on the Quartierstrom-participants' smart meters, we built a benchmarking methodology based on academic literature and tested all devices (75) of the field test (Blomand & Farahmand 2018, Han et al. 2018). In this methodology, we treat the throughput and latency of the system as dependent variables and the number of validators (degree of decentralization) and communication bandwidth (data rate in kbit/s) as independent variables.

The Quartierstrom field test offers a unique setup with a broadband communication between all of the smart meter devices that enables us to artificially limit the data rate and emulate constrained communication infrastructures, such as Zigbee, or PLC.

First, we found that the capabilities of the constrained hardware (smart meter) running in the participants' houses are limiting the maximum throughput. This is due to the implementation utilizing only a single core of the Raspberry Pi SBC's CPU. We found a six-fold decrease in performance of the running market application when compared with a simple token transfer application. The token transfer application was able to reach a maximum throughput of around 60 tps while the market application peaked at around 10 tps. In addition, we found that the blockchain-based platform requires higher data rates than comparable centralized systems. The data rates required by the field-test setup (27 validators, 75 total participating devices) saturate most modern low-bandwidth communication technologies. A minimum requirement of 250 kbit/s rules out technologies such as narrowband PLC, WPAN, or NB-IoT. However, part of the high utilization of the communication bandwidth can be traced back to the unoptimized transaction scheme of the platform, which is based on JSON. Third, we found that the ratio between consumers and prosumers (non-validators and validators) has to be chosen based on the performance requirements. While more validators in the system raise the fault-tolerance, higher coordination efforts reduce the maximum throughput. In order to sustain a local energy market of 75 participants with a clearing time of 15 minutes the platform with its 27 validators is able to sustain the required transaction throughput with a security factor of 1.8x. According to the results, the field-test setup would be able to support 500 additional consumers or batteries, if the number of validators is kept constant. A more detailed analysis of the scalability of the system considering these technical aspects is available in the journal article (Meeuw et al. 2020).

4.1.5 Evaluation of blockchain protocols regarding privacy preservation

Lead authors: Alain Brenzikofer and Sabine Proll, SCS

The power consumption of each individual household is recorded every 15 minutes and placed on the market in form of a bid. The blockchain only guarantees pseudo anonymity by representing each demand and production smart meter as a public key (the public key can be thought of as an account number in the traditional banking sense). No association between the public key and the household's true identity that holds the private key is published on the blockchain at any point in time. However, from bids and consumption values, third parties may be able to gain insights about consumer behavior, household characteristics or occupancy patterns. By using advanced data analytic tools, further social or demographic data may be derived or predicted from consumption data (Beckel et al. 2014). An open platform with no direct owner should therefore provide the basic functionality to protect the demand data of the participants.

The following approaches to preserve privacy have been investigated by SCS:

Transparent-Bid Auction with Shielded Bid Originators[1]
The idea is to have shielded addresses to hide the identity of the participants on the market. Only the participant himself knows which shielded addresses belong to him. Two approaches have been investigated:

- zk-SNARKS[2](using Zero Knowledge Proofs)
  The evaluation revealed that current implementations of zk-SNARK libraries are not mature, as they do not implement hash functions or encryption/decryption. Developing our own zk-SNARKS was beyond the scope of this project. Moreover, the computational complexity is very high for an embedded system like our blockchain smart meter.
- Linkable Ring Signatures following the CryptoNote[3] protocol.
  A first proof of concept implementation looks promising: There are libraries available that offer the needed functionality to implement linkable ring signatures (LRS). A proof-of-concept has been made but there was no implementation for the field test

Both zk-SNARKS and Linkable Ring Signatures risk leaking private information when using light clients. For both protocols, every user has to scan every block for transactions concerning himself. If a light client queries a full node for his account balance, the full node learns the user's individual public keys. For Quartierstrom, this is a drawback, as pure consumers who do not sell excess energy are equipped with cheaper light client devices.

Multiparty Computation
This approach treats the consumption value as a secret, which can be shared among a group of computers. The secret of each member can only be recovered if enough machines collaborate in the computation of the secret. Researchers have already shown that virtually every arithmetic operation can be performed over those secrets, however, at cost of higher overhead regarding communication between computer nodes. This approach has been investigated in a semester project with focus on

[1] Brenzikofer A. et al., 2019, "Privacy-Preserving P2P Energy Market on theBlockchain",
[2] As used by the privacy-oriented cryptocurrency Zcash
[3] As used by the privacy-oriented cryptocurrency Monero

privacy preserving self-consumption groups (supervised by ETH). It was shown that calculating one's own percentage of power usage within a group can be done by multiparty computation as this example involves very simple arithmetic computations. It was in general found that there are currently no tested and general purposes multiparty computation platforms and it would require the implementation of the basic primitives of multiparty computations by the project team with potentially unsure outcome.

Trusted Execution Environments
Here the logic of the blockchain is moved to trusted hardware (a Trusted Execution Environment, short TEE). The blockchain gives only the guarantee that the specific market logic has been executed in the TEE. The participants can only access the information relevant for them:

- the hash of the source-code that was executed for each transaction in the TEE (to guarantee that the logic has not been tampered with)
- their own measurements
- their own price in the specific period

Thus, the participants cannot see measurements of prices of the other parties, not even with pseudonyms.

In summary, the approach with shielded bid originators could be applied directly, as an enhancement, to the current implementation of Quartierstrom. However, the approach with TEEs has major implications on the architecture and the software and hardware design (since the logic and the persistence is moved to the TEE). Implementing these concepts in the Quartierstrom codebase is beyond the scope of the project.

Apart from the development for Quartierstrom, SCS is currently developing the integration of TEEs in the Substrate blockchain framework (https://github.com/scs/substraTEE), with a grant from the web3 foundation. With this, a future implementation of Quartierstrom would be possible, using the TEE approach to preserve privacy.

4.1.6 Conclusion regarding blockchain technology

Lead author: Arne Meeuw, HSG

Blockchain technology offers added value in case of a true bottom-up system. In other words, the actual merger of a group of private consumers and producers who want to create a group of their own consumption, independent of the energy supplier. In that case, the voting mechanism of a blockchain gives the participants the certainty that the system by definition works as intended. An advantage of a blockchain compared to an app running on a centralized backend system is only inherent if there is a lack of trust between the participants, as a centralized solution needs a responsible operator. If this operator is trusted by all participants, a centralized solution is still a good option.

A blockchain-based and decentralized energy market provides an opportunity for participation and self-determination of the participants. Mechanisms such as on-chain governance, i.e. changing rules by a majority decision of the participants in the system, involve the users and can bring proposals and opinions to a vote as in a direct democracy. However, this requires technically highly skilled participants who understand the formulation of rules and procedures by program code (in the form of smart contracts). The disadvantage of blockchain is the low possibility of abstraction to enable novices to understand and thus actively participate.

Concerning the energy consumption of the system, is important to note that the energy consumption of the blockchain implemented for this project is considerably smaller than the energy consumption of public blockchains which are often cited in the media – those global, public systems are in fact not comparable to the permissioned, local system implemented for Quartierstrom. In addition, even in a centralized solution, metering devices to conduct the measurements and provide the data in real-time in relatively high-resolution have to be installed and (centralized) computing capacity must be provided. We conjecture that there will be no considerable difference between the energy consumption of a centralized solution and a permissioned Tendermint blockchain running on new smart meters.

4.2 Hardware development and implementation (Module 21 & Module 22)

4.2.1 Metering hardware in participating households (ETH/WEW)

Lead author: Sandro Schopfer ETH and Arne Meeuw HSG

In the first quarter of 2018, the project team analyzed different options for measuring electricity consumption and related properties at the building connection points. Many of the participating households were already equipped with smart meters using remote read-out over the internet. This metering setup is already very advanced and ideal for a blockchain pilot-project. The project team managed to retrieve the current meter readings from the deployed smart meter type. However, reading additional power meter values like current and voltage (separated by phases) proved to be difficult. In order to collect as much data as possible, the project team decided to use a prototypical smart meter with an integrated single board computer, which is more suited for the highly decentralized application. The chosen smart meter, called “Smart-Pi” has an open interface and for the measurements of voltage, current, frequency and power and can host the blockchain locally. The power consumption of this device (including power-measurement) does not exceed 5 W.

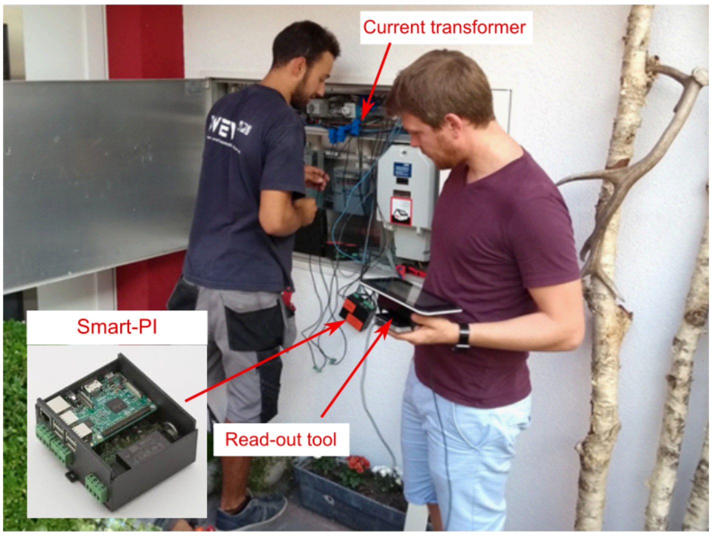

Figure 4: Installation of Smart-Pis

A separate virtual private network (VPN) has been established to connect A) the devices to the internet and B) assure a static IP address over which the blockchain nodes can establish a meshed network connection to exchange information in truly decentralized and direct way. All cable modems already deployed for smart meter infrastructure before the Quartierstrom project needed to be replaced in order to form a separate and secure network with static IP addresses. Figure 4 shows a typical Smart-Pi installation, where the voltage is measured directly and powers also the Smart-Pi single board computer.

The current is measured with current transformers (CT) and can be clipped around the phase wires of L1, L2, L3 and N. The SmartPis usually connect quite fast to the internet, however, their IP address is not directly known. This makes it difficult to connect to the device and to verify the correctness of the installation. The project team therefore developed a read-out tool based on a tablet device which connects to the SmartPis without internet connection. The read-out tool allows the electrician to install the devices without supervision of the project team. A careful preparation of the 72 devices was necessary to a) assign each household the corresponding 1-3 devices for measuring consumption, production or (dis)charging of storage unit and to b) keep track of the hardware addresses to identify the devices later over the internet.

4.2.2 Metering hardware for grid-level analyses (SCS)

Authors: Sabine Proll, SCS, Alain Brenzikofer, SCS

Two Smartboxes[4] have been deployed in the Quartierstrom grid. One Smartbox was installed at the transformer for the "Schwemmiweg" N7 grid, another at EV-charging facilities in Maienfeld. Measurement data has been recorded throughout the second half of the field test and is available for research purposes on request.

4.3 Software & platform engineering

4.3.1 Platform engineering / market application (Module 32)

Lead author: Anselma Wörner, ETH

4.3.1.1. Overview of projects or startups in the area of peer-to-peer exchanges

To get an overview of existing studies and companies engaged in building in peer-to-peer electricity markets at the beginning of our project in 2018, we conducted a review of the existing academic literature (e.g., Morstyn, 2018; Mengelkampt et al. 2017; Laszka et al. 2017) and, in addition, created an overview in which we list industry efforts relating most closely to Quartierstrom (see Table 4, updated in March 2020). This overview includes the chosen market design (if any information on it was available), and the basic blockchain infrastructure used in these projects. It is interesting to note that over the duration of the Quartierstrom project, several new initiative for P2P energy markets have started. Reviewing these projects lead us to the conclusion that except for few known exceptions, most projects were far away from implementating a system in the field in 2018, whereas today, there are a number of projects live in different countries across the world. Still, in many cases, the blockchain platform as well as the market design or pricing mechanism are described in fuzzy terms. User engagement and the user interface increasingly moved into the focus during that time, as most platforms include a real-time visualization of energy consumption and generation. However, prices and efficiency achieved by P2P trading platforms also depend on an appropriate market design and its implementation, which will be described in the next paragraphs. The user interface built on top of that will be described afterwards.

[4] Smart grid solutions, the commercial offspring of the BfE «GridBox Pilotnetz» project

Project/ Company	Basic idea	Market design	Status	Country	Blockchain protocol
elblox	P2P trading of renewable energy	Different market models possible	Development phase, first projects live	Switzerland	Unknown
HivePower	Now energy consulting, initially platform for P2P trading of solar power	Different market models possible (e.g. central optimization)	Project live in CH, further pilot demonstrators in different countries	Switzerland	Formerly: public blockchain + state channels (Ethereum, custom channels)
LO3 Energy	P2P trading of solar energy within local community	Iterative double auction	Projects live in Brooklyn and Landau	US, project in Germany	Private blockchain (Tendermint)
Lumenaza	P2P trading of renewable energy/ visualization of renewable energy generation	Different market models possible (e.g. central optimization, auction)	Different projects live	Germany	-
PowerLedger	P2P trading of renewable energy	Central pricing mechanisms	Different projects live	Australia, projects in US, Italy and India	Public-private hybrid blockchain (Ethereum, EcoChain)
WePower	P2P trading of renewable energy tokens	Auctions for token investment in renewable energy plants, not defined any further	Development phase	Gibraltar	Public blockchain (Ethereum)

Table 4: Overview of industry projects/startups for blockchain-based energy exchange, status March 2020.

4.3.1.2. Market application

The market design for a P2P market describes the way in which prices are determined and local electricity is distributed within the community and should be defined with the aim to meet these overall project goals. In order to create a successful peer-to-peer exchange for electricity in line with the overall objective of promoting sustainability, there should be incentives for local consumption of locally generated electricity, so the prices should reflect the availability of local electricity. The breakdown of the Californian electricity market in 2001, which caused unforeseen price jumps and even led to outages, is one infamous example, which illustrates the importance of appropriate market design for electricity distribution.

There are generally two alternatives to determine prices and allocation of electricity: a) Running an algorithm that calculates prices relative to the availability of local resources and distributes the available energy randomly to the community members; b) Running an auction mechanism which allows the participants to state price limits for which they are be willing to buy or sell electricity within the local grid.

Discriminative Double Auction

A key decision in the market design was to create an auction (see option b) mentioned above in which all participants have the possibility to influence the prices for which they buy or sell electricity. While we did not expect all participants to adapt their prices frequently in the long run, we consider this is a unique chance to elicit price preferences for local, renewable energy from individuals in a real setting. There exist some studies which asked individuals about their willingness to pay for green or local electricity or about their intentions to invest in renewable energies. Although today's regulatory framework would in theory allow the implementation of an auction mechanism within a self-consumption community (in German "ZEV", see Section 4.6.1 for the current regulation of self-consumption communities), this is the first study which allowed individuals to actually influence the true prices they will pay.

Based on the experiments and studies resulting from the literature research, we have identified a double auction with discriminative pricing as the most suitable market mechanism for the Quartierstrom market. For both, consumers and prosumers, the smart meters send bids containing the price limit determined by the individual household and the electricity demand or supply measured smart meters. An order book collects all bids during an interval of 15 minutes and orders them by price: Sell bids with a lower sell price are prioritized (see yellow curve in Figure 5), and buy bids with a higher price (see purple curve). Discriminative pricing means that for each trade, the price is derived as the mean between the respective buyer's and seller's price bid (see turquoise dotted line). This auction is run iteratively every 15 minutes, which means that the market is cleared and trades are allocated in this frequency.

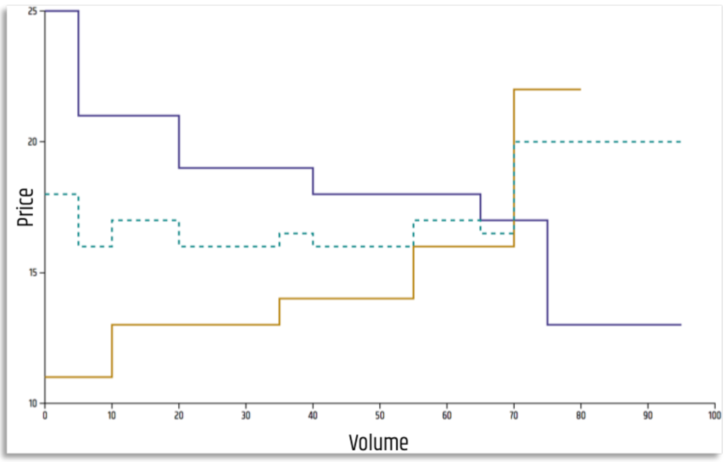

Figure 5: Double auction with discriminative pricing.

After a short test phase, we deployed the double auction described above which then ran throughout almost the entire field test, except for the month of April 2019 when we tested an automated pricing mechanism which automatically determined the same prices for all participants depending on supply and demand within the community. Both market mechanisms have been implemented in JavaScript and has been integrated into the blockchain platform. The implementation includes the EW Walenstadt into the market by assigning all excess bids which cannot be filled with local supply or demand to the utility provider at existing tariffs. All of the blockchain nodes run the auction algorithm every 15 minutes to clear the market.

Alternative: Uniform price mechanism

One of the research questions we are tackling in this project is whether participants want to actively engage in a market in this way and whether their bidding behavior results in efficient market outcomes.

For this reason, we have conducted an experiment with an alternative market mechanism ("uniform price mechanism") during one month to create a comparable baseline for the auction market. During the month of April 2019, the Quartierstrom participants were not able to change their price settings anymore and prices were determined automatically by an algorithm which was developed for this experiment. This algorithm computed the market price for each 15-minute time slot based on the available solar production in the market and the existing demand for energy during that time slot. In addition to that, the price preferences we had elicited from the participants in previous months served as input to the pricing algorithm. We call this alternative market mechanism "uniform price mechanism", as all participants faced the same uniform price and did not have the possibility to influence the price during that period.

The uniform price mechanism determined the allocation of solar energy relative to the demand of the different consumers. This means, for instance, that in any given time period in which solar production equaled 60% of the overall energy demand in the Quartier, each consumer was allocated 60% solar energy from the neighborhood and had to buy 40% of the energy they consumed from the EW Walenstadt at standard tariffs. This allocation rule is commonly employed in Virtual Power Plants to treat all participants in a fair and equal manner.

Billing based on P2P trades

The first energy bill based on the Quartierstrom system, for the billing period of January 7 to June 30 was created and sent out in August 2019. The second bill for the period of July 1 to January 6, 2020 was sent out in January 2020. Each household has benefitted from trading on the local marketplace as compared to the base scenario of the WEW tariff of 20.75 Rp/kWh and a granted feed-in-tariff of 4 Rp/kWh in both periods. Realized savings primarily result from the reduced network fee for trades on the Quartierstrom platform. The money that was saved on the network fees was mostly shared between consumers and prosumers, depending on their specific bids and supply and demand in the local market. In this way, both consumer and prosumers could benefit. However, the amount of the savings varies strongly from household to household, depending on their respective PV generation and load profile. In addition to the standard billing information, households also received a more detailed overview of their energy data: A supplementary sheet showed monthly energy consumption and production and illustrated where the household source energy from and where prosumers sold their solar generation to during the first half-year of the study. An additional diagram showed the average consumption/production profile of the household in relation to the local market price, helping interested households to identify to what times they might shift their energy consumption.

Originally, the team had planned to also integrate the Smartbox data (see section 4.2.2) in a later project stage to implement a voltage-based dynamic tariff (see section 4.5) on top of the local market price. However, communicating the price dynamics and underlying market mechanics without overwhelming the participants was already quite challenging for the local energy market as implemented. Adding a second layer of complexity with voltage-dependent prices would have required substantial additional efforts in the development of the user interface. Second, the on-site maintenance efforts for the operation of the individual smart meters were higher than anticipated, resulting in considerably higher than anticipated efforts on the side of the small team that implemented the blockchain. Due to that, the effort and risks involved in developing and testing a voltage-based dynamic tariff via smart contracts on top of the pioneering work carried with success (and much effort) would have exceeded the capacity of the team. Furthermore, location-based tariffs would further complicate the regulatory situation. Given these issues, it was agreed that a simulation-based analysis of voltage-dependent pricing would be carried out in the project. Consequently, the Smartbox data has not been integrated into the market logic as originally planned.

4.3.2 User Interface (Module 33)

Lead author: Liliane Ableitner, ETH

To understand the user needs and usage intentions for the design of the user interface which abstracts the market logic for the user, the team conducted focus groups with a sample of Swiss people who did not take part in the Quartierstrom project. Based on our findings from these focus groups we designed the user interface or webapp for the Quartierstrom market with the following main functions:

- Providing information to the participants on their electricity consumption (and production, if applicable) data (15-minute resolution)
- Providing an overview on the community market
- Empowering participants to participate in the pricing of P2P energy

Figure 6 shows a screenshot of the landing page of the user interface. It displays key metrics on the user's energy and trading data and allows users to set price bids. Figure 7 shows the "My Energy Data" page of the user interface, which informs users about their energy consumption and production profiles. It was the most popular page during the experiment.

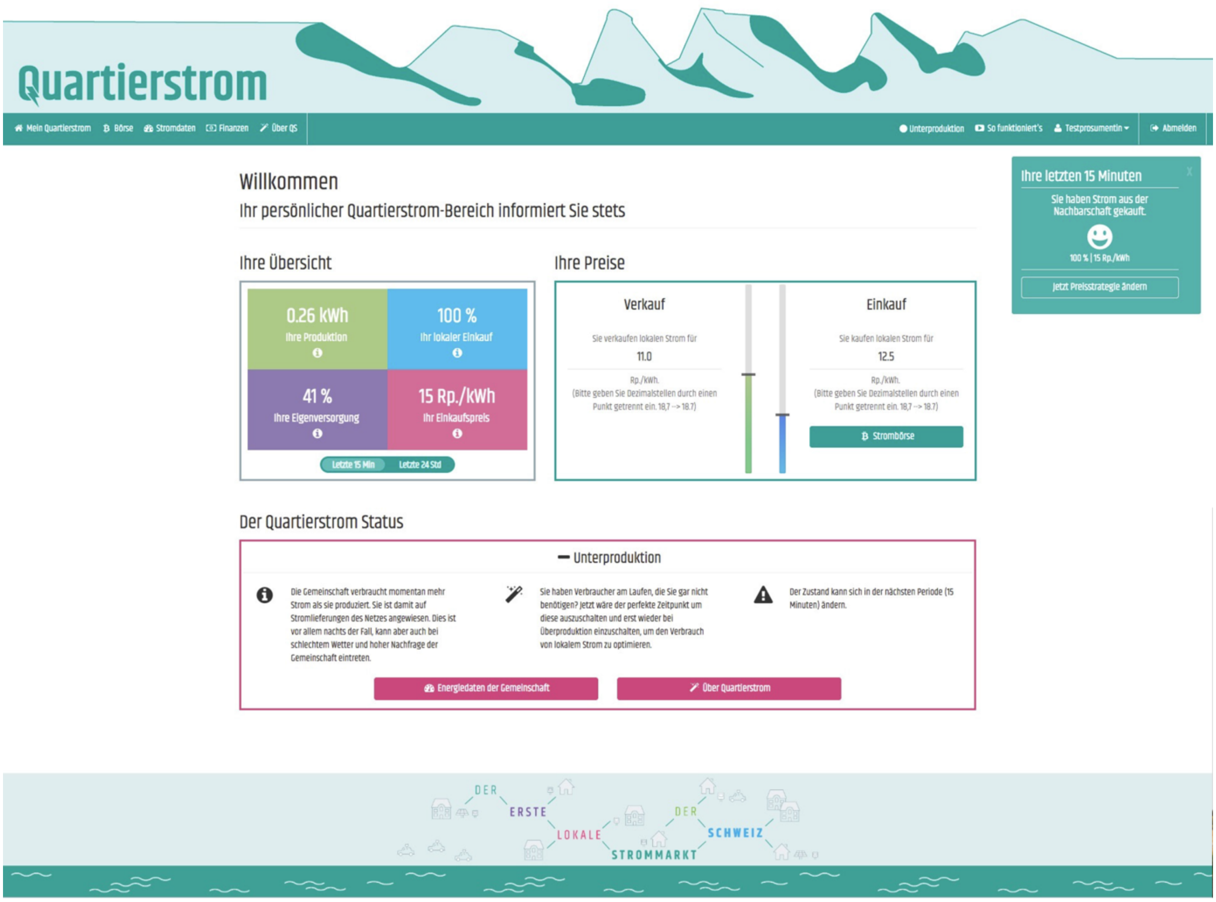

Figure 6: Landing page of the Quartierstrom web application.

Figure 7: "My Energy data" page of the Quartierstrom web application.

As part of the kickoff event at the beginning of the field phase, which 29 households attended, a demonstration and training session was organized. The remaining households received login instructions via mail. Further, the team provided participant support via telephone and email throughout the field test. In the beginning of January, we also hosted two open in-person consultation-hours for participants that needed in-depth support. Towards the beginning of the field test, the team received a couple of support requests that were of technical nature (e.g., support of different web browsers, issues related to participant's firewall interfering with the Quartierstrom webapp). From time to time, a few participants reported difficulties with understanding displayed information.

Throughout the field test, the web application was monitored actively and occurring bugs were fixed. In addition, the team developed a monitoring website in January and February for internal purposes. The monitoring website provided a quick overview of the current market state, the orderbook and user interaction with the web app. In January, the team also created the concept for sending out monthly reports to the participants and implemented it. At the beginning of every month, participants received a summary of the energy data of the previous month along with tips for setting price limits. Furthermore, the price-setting element of the webapp contained information on the probability of selling and buying locally produced electricity; this information was updated each month based on the data of the previous month. Prior to the fixed-uniform price-experiment that took place in April, the web application was adapted; during the month of April, the price setting functionality was disabled and reactivated at the end of the month.

4.3.3 Battery control (Module 34)

Lead author: Sandro Schopfer, ETH

Flexible loads like batteries, heat pumps or electric hot water heaters play a crucial role in prosumer households. Already today prosumer households retrofit their electric hot water heater to charge the hot water thank when their solar system is producing surplus energy. In addition, heat-pumps that optimize self-consumption by adding a smart-grid ready interface to the unit have entered the market. Battery systems are slowly becoming a popular choice to increase self-sufficiency and self-consumption. These are all valuable options to increase self-consumption on a household level. However, with a Quartierstrom-like system in place, self-consumption optimization can be expanded to entire communities: Even households that cannot transform to a prosumer may still retrofit their electric water heater to charge their hot water tank in order to benefit from cheap and local electricity that is incentivized by a bottom-up grid tariff and a local energy market. If battery prices continue to fall, larger battery systems may be operated where space is available but not necessarily a roof to install a PV system. The Quartierstrom market place provides the necessary data to avoid electricity exports at the community level and to increase self-sufficiency of the entire community.
Previous research at the Bits to Energy Lab has already demonstrated in simulations that less storage capacity is needed to reach a predefined level of self-sufficiency if the batteries in a community collaborate to avoid exports at the community level rather than at individual household level (Schopfer 2019). This also implies that a community with a battery system (operating at the community level) can reach higher degrees of self-consumption and self-sufficiency.
Apart from decreasing community exports and imports, flexibilities may be utilized in numerous different ways. These include peak-shaving, voltage stabilization or reserve markets, etc. While these applications are beyond the scope of the ongoing Quartierstrom project, it is worth noting that the blockchain platform could be potentially extended to transparently rent out flexibility in different households and reimburse them for the usage of batteries or other flexible loads.

Storage systems in the Quartierstrom field test
About 8 out of the 27 producers that participate in the Quartierstrom-project already have battery systems installed. The largest battery system of the Quartierstrom network, shown in Figure 8 and referred to as “B001”, has a capacity of 37 kWh and is implemented in an apartment building located in the Schwemmiweg. The system is AC-coupled and can be charged/discharged with approximately 28 kW. Both, the solar and battery system installed at the property are collectively operated by the condominium owners. The primary goal in the field test is a technical proof-of-concept of connecting the battery to the Quartierstrom system and of operating it as a community battery storage system (rather than as a storage system of an individual building). This setup prioritizes inter-community energy flows and reduces exports from the community. Operating the 37-kWh battery system in the service of the community should increase both self-sufficiency and self-consumption of the entire community. In addition to realizing the technical proof-of-concept, to goal is to get a first estimate to what extent self-sufficiency and self-consumption of the community can be increased by operating the battery based on the state of the community (surplus production vs. consumption).

In order to quantify the increase in self-sufficiency and self-consumption, the case where the battery is operating in normal self-consumption mode at the household level is simulated as a reference case. The measured self-consumption data and self-sufficiency rates will then be compared to that reference case.

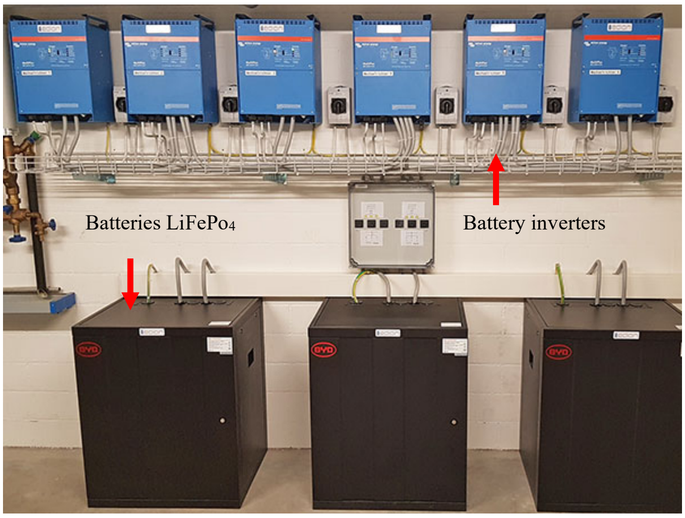

Figure 8: Battery 37 kWh system in Schwemmiweg

Battery control using the energy management system application programming interface (APi)
The heart of an AC coupled battery system is the battery inverter: Its main function is to convert DC to AC current in order to discharge the battery and vice versa. Interfacing hardware is often not a trivial task and in the case of battery inverters, some manufacturers may completely restrict access to the inverter, either to reserve flexibility for their own needs, or to avoid battery degradation from charging schedules defined by the battery owner or aggregator. Fortunately, the installed Victron battery inverters embrace a highly open interface strategy. With the help of the installation company Edion (a partner of EW Walenstadt), we have identified a straightforward way of interacting with the battery, namely via the energy management system (EMS) that supervises and controls the battery inverters. The EMS provides a simple dashboard to manage flexible assets and provides an application programming interface (APi) that can be remotely accessed from other applications via https protocol. The APi can be also reached through one of our SmartPis (via physical connection to the EMS) to conserve the decentralized nature of the project. Due the high number of SmartPi-devices in this household and limited number of ethernet ports on the routers, we have decided to interact over the cloud service of the EMS with the battery. Via the API, we can assume full control over the battery and dictate the desired charging or discharging rate in units of kW via a setpoint controller.

The Quartierstrom-integrated community battery controller
As outlined in section 4.3.1.2, the market application executes a double-auction every 15 min and results in a list of peer transactions (cashflows and volumes in kWh) between all participating households. For a community-battery controller, the market can be queried for net consumption in any period of time. We therefore extended the Quartierstrom-Blockchain by an additional smart-contract module called storage application represented in Figure 9Figure 9**Error! Reference source not found.**. The storage control module can access data on community-wide consumption and production rates. Based community-level data, the community battery can be operated by charging the battery if the community exports energy and discharging it when the community imports energy. The provision of flexibility for

more complex applications like peak-shaving, voltage regulation and others are not part of this field test, as the complexity involved in computing the schedule using weather forecasts and more sophisticated methods like model predictive control or reinforcement learning. For the battery control phase in this project, however, we had to limit ourselves to a simpler operation of the community system. Given the challenges described above involved in the technical installation and maintenance and the relatively short duration of the project, a battery control scheme of reasonable complexity had to be implemented and future research needs to evaluate the potential of more advanced algorithms in detail. The system implemented shifts self-consumption of the battery from the individual household level to the community level. The controller allows for a simple self-consumption optimization at the community level, and just requires the community level import and export rates as input to the controller. Thus, it serves as a technical proof-of-concept and provides measurement data to quantify to what extent the operation of a battery as a community storage system can increase the community's self-sufficiency and self-consumption.

Beyond that, we developed a more general concept of dealing with flexibility in the blockchain system. Based on the status of the community, the module allows for the creation of a schedule for the battery and verifies - at a later point in time - whether the battery system followed the schedule. The agent of the battery system agrees to the schedule and executes the schedule by invoking the API. In theory, any schedule could be enforced, e.g. schedules that minimizes the peak-demand or over-voltages. We see this schedule mechanism as a basic (proof-of-concept) case to pilot the general approach of community-level dispatching of flexibility. In a blockchain context, this execution of flexibility according to a schedule could be guaranteed via a staking mechanism. If a flexible asset does not follow the agreed schedule, the stake could be slashed away. If the schedule has been executed accordingly, the agent of the battery gets rewarded.

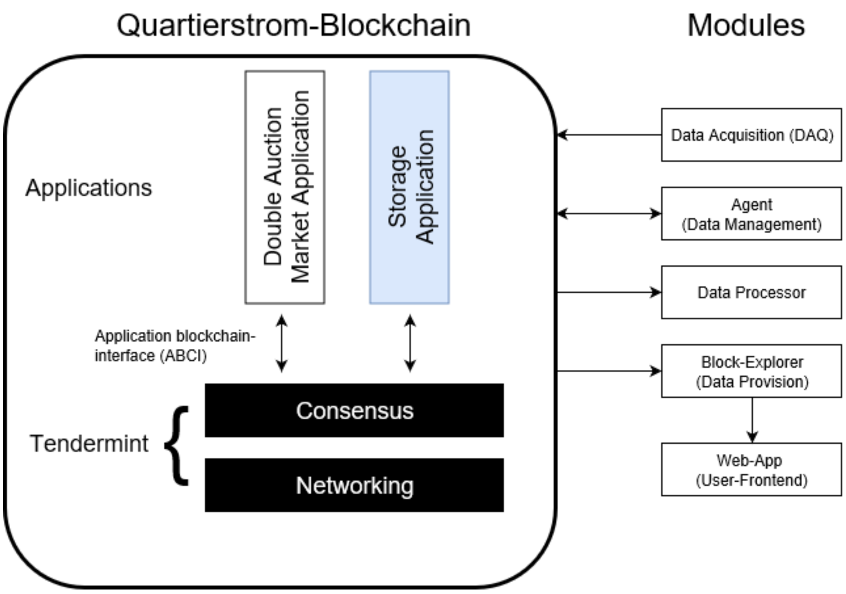

Figure 9: Extension of Quartierstrom-Blockchain with "storage application"

Controller operation

In the course of the Quartierstrom field phase, we actively interfaced the B001 battery and implemented a community controller that aims to increase self-sufficiency and self-consumption of the community by forcing the battery to charge when the community exports energy. The community-battery control system was in operation during multiple periods from July 1, 2019. Until July 17, the controller ran without interruption. Shortly after that, we noticed that the energy management system (EMS) was unavailable.

An on-site inspection revealed that the system had halted due to activation of the DC fuse. The reason for this is likely an interruption in communication with a high-power set point that could not be changed for the next hours. Another potential cause may be due to the inverter itself: The inverter is originally used in naval applications and therefore supports high-power surges above its nominal power rating. It seems that the EMS cannot control these power surges, which are a built-in feature of the inverters. Multiple activating attempts of the community controller resulted in system failure resulting in a relatively short duration of the phase with an active community controller. To avoid continued battery straining or possible damage of the installation, the controller was only reactivated in December (Dec. 7, 2019 – Jan. 3, 2020) after careful testing and investigations. This time, the controller ran successfully for the rest of the field phase. This behavior might only apply to the present installation. However, future work should also focus on operating conditions that guarantee a safe operation of the battery.

Controller evaluation

For the analysis of the battery control, we focus on two periods during which the controller has been active. Period 1 refers to July (01.7.19 – 17.7.19), and Period 2 refers to December (7.12.19 - 3.1.20). To estimate the effect of the community controller, we simulate the "B001" battery in normal self-consumption mode and compare the self-consumption rate (SCR) and self-sufficiency rate (SSR) to the measured battery response with the active community controller.

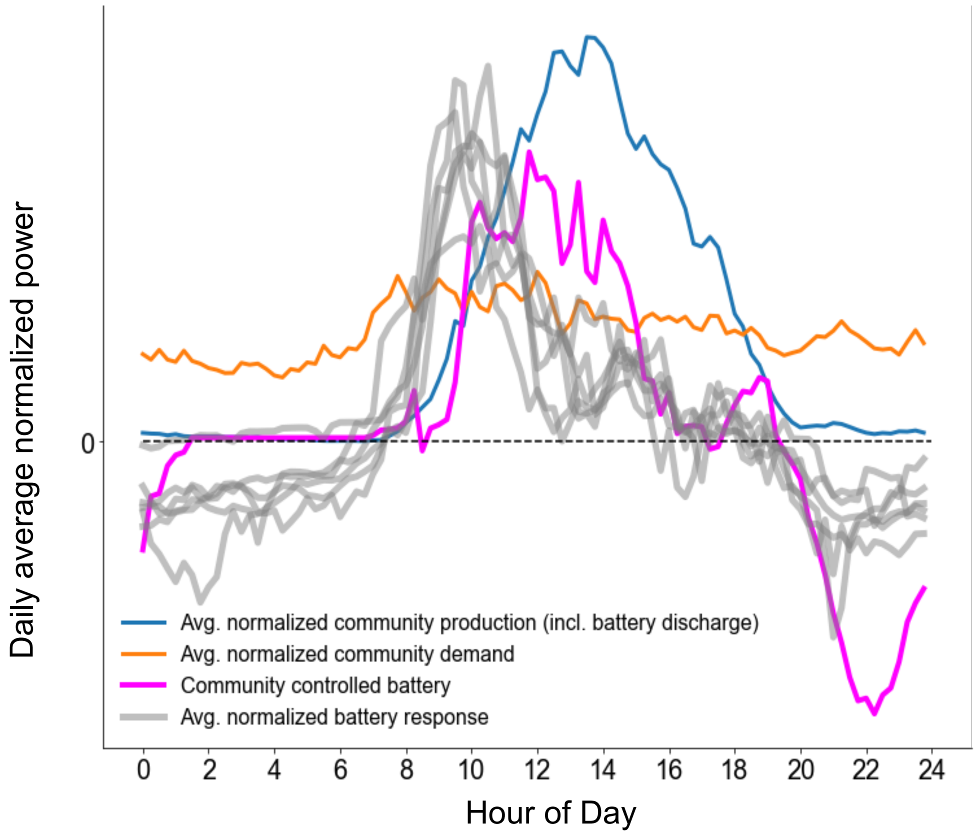

Figure 10: Average normalized battery response in normal self-consumption mode (gray, simulated) compared to the measured behavior of the community-controlled battery "B001" (in magenta) for the July period.

Figure 10 displays typical battery behavior over the course of the day. The gray curves represent battery operation under normal (i.e., household-level) self-consumption mode. Under normal self-consumption mode, batteries charge when the household exports energy to the grid and discharge when the household imports energy (provided the batteries have capacity left). Consequently, the charging process typically occurs in the morning hours. The average normalized charging curves (gray curves) are fairly aligned with each other: On average, most batteries start to charge already shortly after 7 in the morning. From a community perspective, this operation mode is not optimal, because the community as a whole still imports energy. Therefore, it the community controller needs to make sure that the produced energy is first sold within the community and that later in the day, surplus energy is stored, when the community (otherwise) exports energy. Storing a unit of energy in Lithium-Ion battery costs on the order of 20 Rp/kWh, whereas transporting it over the community grid costs only 6 Rp/kWh (grid costs, voltage-level 7). As Figure 10 shows, the charging cycle is noticeably shifted to the hour 9 forcing the battery to charge when the community exports energy. Thus, the community-controlled operation of the battery makes it possible to increase the overlap of battery charging cycles and community exports by distributing the charging cycles of the battery over time, which increases the self-consumption of the community.

To estimate the effect of this controller, we simulated the B001 battery as if it were operating in normal self-consumption mode at the household level. The comparison of the simulated and measured battery power over time is shown in Figure 11.

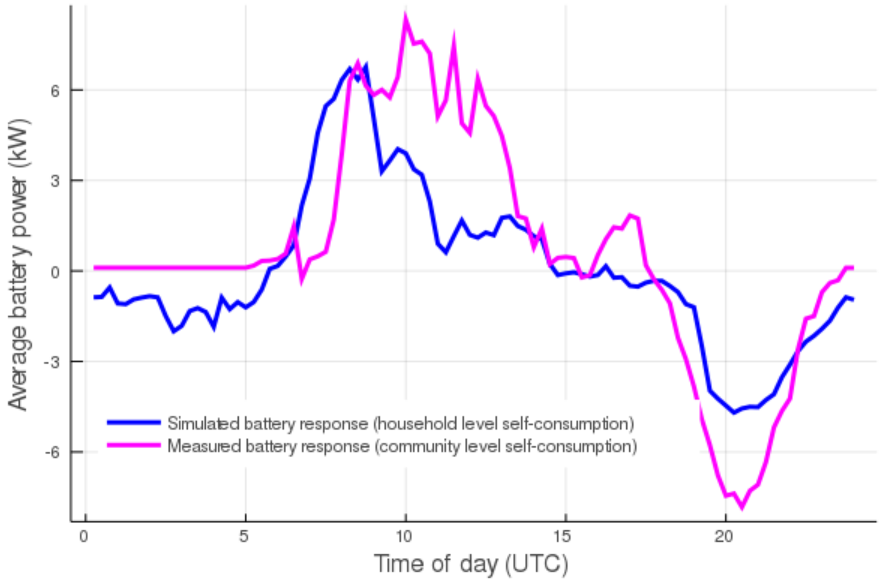

Figure 11: Measured community battery in magenta (same as in Figure 10) compared to simulated battery response in normal self-consumption mode in blue

As Figure 11 illustrates, the simulated battery response follows a more typical battery response, as shown by the gray curves in Figure 10. We carefully analyzed and cross-compared the battery response with other batteries in the community and in different time periods to verify that the battery behavior displayed in Figure 10 and Figure 11 is not result of random variations.

Results

With the simulated battery response, the SCR and SSR for July and December periods can be evaluated when the battery operates either in community self-consumption mode (as measured for July and December periods) or in normal self-consumption mode (household level self-consumption). In addition, as a reference point for both periods, we added the calculation of the SCR and SSR for the case without the B001 battery.

	Measured scores with B001 in community control		**Simulated scores in classical self-consumption**		**Baseline scores in classical self-consumption without B001 battery**	
	SCR	**SSR**	**SCR**	**SSR**	**SCR**	**SSR**
July Period 1.7 - 17.7.2019	44.2% (+6.3%)	39.2% (+4.5%)	41.2% (+3.3%)	37.6% (+2.9%)	37.9% (+0%)	34.7% (+0%)
Dec. Period 12.12 - 3.1.2020	92.7% (+4.0%)	6.4% (+0.4%)	91.4% (+1.7%)	6.4% (+0.4%)	89.7% (+0%)	6.1% (+0%)

Table 5: Comparison of self-consumption/sufficiency in community operating mode and normal household level self-consumption (SCR=self-consumption ratio, SSR=self-sufficiency ratio)

The values for SCR and SSR for both periods are reported in Table 5. The first column represents the measured values with active community control. An SCR of 44.2% for the July period and 92.7% for the December period could be reached. Without the B001 battery, the SCR would have been between 6.3% and 37.9% lower. If the battery had operated in normal self-consumption mode (at the household level), the battery would have increased the SCR of the community by only 3.3% from 37.9% to 41.2%. Therefore, the community-controlled battery increased the SCR for the July period by 3 percentage points, from 41.2% to 44.2%. While the effects in absolute numbers may appear small, relative to the contribution of the entire battery, they are in fact rather considerable: in normal self-consumption (at the household level), the battery increases the SCR of the community by only 3.3%. If operated in community mode, the battery increases the SCR of the entire community by 6.3%. Thus, the community-control almost doubles the effect of the battery, compared to normal self-consumption.

It is generally speaking more difficult to increase the SSR of solar installations. This holds also true for the effects of the community controller on the SSR. Without the B001 battery, the achieved SSR of the community would be 34.7%. With the active community controller, an increase of 4.5% to 39.2% can be achieved. If the B001 battery had operated in normal self-consumption mode (at the household level), the battery would have increased the SSR by only 2.9% (roughly half as much as with the community controller) from 34.7% to 37.6%.

For the December period, the effects of the community controller on the SCR are noticeably lower mainly due to the lower production rates in winter and less periods where the community exports energy. The B001 battery contributes to the community SCR by 3% (from 89.7 to 92.7%) with active community controller. Without community controller, the SCR would increase only by 1.7% (roughly half as much as with the community controller. For the December period, the B001 battery only contributed to 0.4% increase in SSR in both cases.

Remarks and summary

The operation of the community controller demonstrates that we successfully increased SCR and SSR for the summer period (July) and the SCR for the winter period (December) at the community level. Three main aspects deserve special attention regarding interpretation, extrapolation and practicability:

- **Interpretation of the results**
  The marginal effects of the community controller (Table 5) may appear small at first when

comparing the community controller with the classical self-consumption controller that operates at the household level. However, the effects must be interpreted relative the contribution of the B001 battery to the SCR and SSR to the community and not directly to the values of the entire community. In fact, in July, the B001 battery almost doubled the contribution of the battery to the SCR/SSR if the controller operates at the community level and not at the household level. Due to the increased demand in winter months and lower battery charging cycles, no changes in SSR could be reported in the December period and effects on the SCR were also smaller.

While these numbers may not directly fuel novel business models, it is important to note that batteries should be operated as efficiently as possible and deployed where they can maximize SCR/SSR or other grid-related benefits to offset the resource intensive manufacturing processes of batteries. Community structures may incentivize such smart placement/operation of batteries because the increased SCR/SSR rates achieved could be also used in favor of fewer battery capacity deployed or one large (and therefore cheaper) installation instead of many small costly ones.

- **Extrapolation to the entire calendar year and different communities**
  The results reported above are strongly linked to the configuration of the Quartierstrom network and may change considerably in other settings. To develop a sense for the expected increase in SCR/SSR for the calendar year 2019, the samples of the two periods investigated correspond to extreme months (high production in July, low in December). Taking the average gain in SCR and SSR in these two extreme months resulting from the operation of the B001 battery in community mode, the average increase in SCR amounts to **2.8%** and the average increase in SSR amounts to **0.8%**. The controller may show similar effects in communities that have similar production/consumption ratio as the Quartierstrom Network. Communities with small production-to demand-ratio may not benefit at all for community operated batteries (due to absence of community exports).
- **Operation, safety and warrantees**
  The operation of the battery installation remained quite challenging and required on-site manipulation. Future teams should perform prior tests to confine the operation space of such batteries to guarantee safe and uninterrupted operation. The setup should also be used to integrate the other batteries to test out different control strategies. However, due to their high inertia, the integration of thermal loads might be even more valuable.
-

4.4 User Behavior and Acceptance

4.4.1 Analysis of Bidding & Trading Data (Module 51)

Lead author: Anselma Wörner, ETH

We have collected data on energy consumption, production and the resulting trading in 15-min resolution between December 2018 and January 2020. In addition to the trading data, we have also conducted a pre-experimental survey to gather supplementary information on participants' preferences and their socio-demographics.

During the field phase of the project, the solar panels in the Quartier have produced over 250 MWh and the participating households have consumed almost 470 MWh. The time-discrete, discriminative double auction was cleared 35,000 times during this time, of which all resulting transactions were stored on the blockchain system.

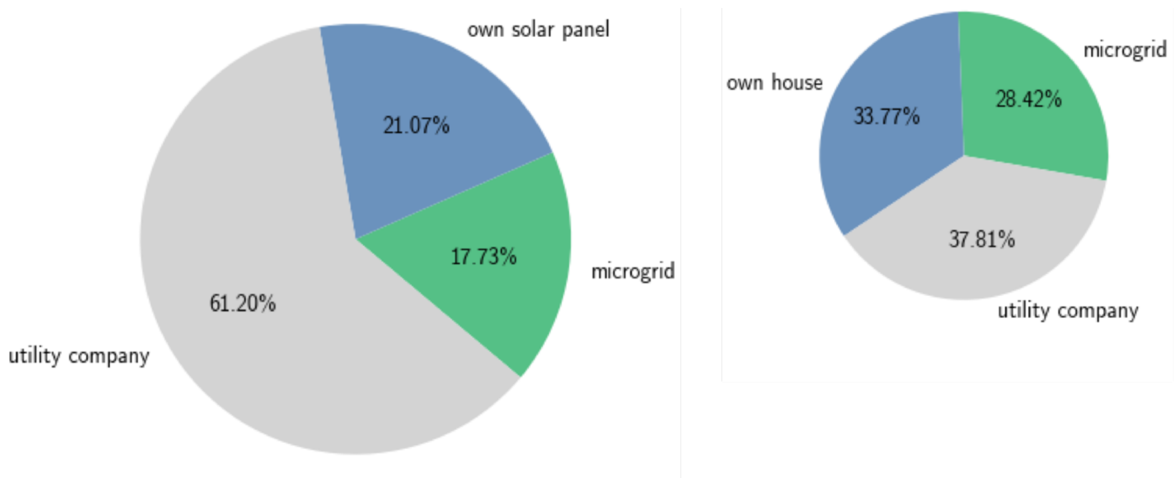

Figure 12 Energy allocation within the Quartier during 2019. The pie chart on the left shows the average self-consumption ratio at the individual household level (in blue) and the additional self-consumption ratio at the community level (in green). The chart on the right shows self-sufficiency rate (in blue and green, respectively). Both the self-sufficiency rate and the self-consumption rate were increased substantially by enabling local trade on the Quartierstrom platform.

Local energy trading boosted the community's self-sufficiency rate by 84.1% (from a self-sufficiency rate of 21.1% to 38.8%) during the field experiment (Figure 12). Likewise, the self-consumption rate also increased substantially by 84.2% (from 33.8% to 62.2%). The fact that there is still a substantial among of solar energy sold to the utility company illustrates that a higher share of consumers – or active control of more flexible loads – would be desirable in future implementations of P2P markets to fully reap the benefits and sell an even higher share of the solar generation locally.

The market design emerged as one of the key factors in the Quartierstrom project, as the market application processes the measured smart meter data to derive the transactions that are finally visible to the participants and are being charged in their electricity bills. The market application as component of a P2P market had received less attention in other P2P projects, which often focused on the blockchain infrastructure with less focus on the price determination or on the user. The double auction mechanism chosen for the Quartierstrom research project granted a particularly active role to participants which sets this market design apart from other approaches in which users cannot actively engage in the price determination on the market. Letting consumers bid a price per kWh of solar energy allowed us to elicit consumer preferences and to observe the heterogeneity of preference profiles in a real market environment, which may differ from stated intentions made in surveys.

In fact, our findings on the preferences displayed by the participants of our field study challenge the findings of existing research regarding individuals' willingness to pay for renewable energy. In line with prior survey-based research, in the pre-experimental survey, the Quartierstrom participants had stated a high willingness to pay for local electricity from the P2P market. However, their subsequent actual bids on the web portal were substantially lower and did not reflect strong preferences (in form of a price premium) for local solar energy over energy supplied by local utility company WEW.

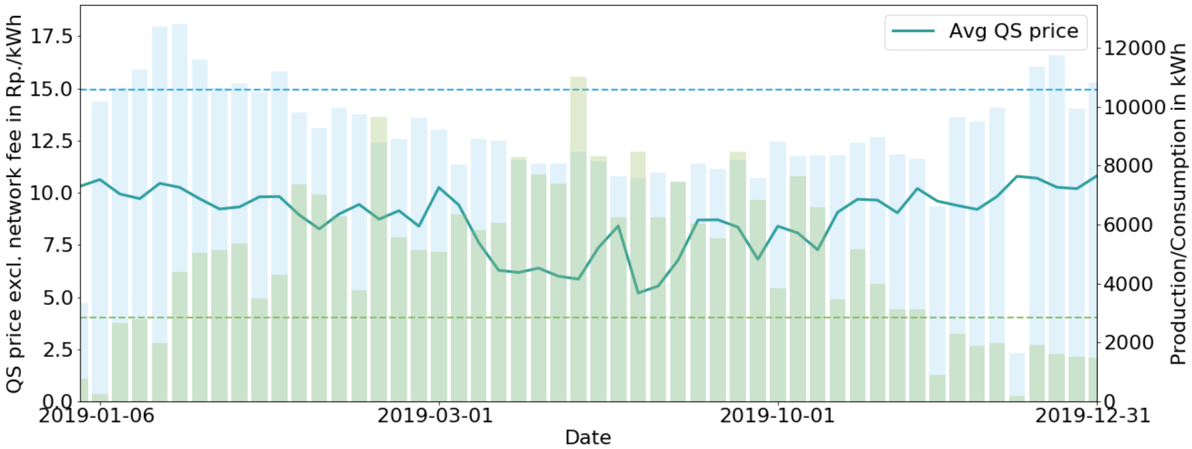

Figure 13 Quartierstrom price over time. The line chart shows the evolution of the average Quartierstrom price for trading within the community (excluding the grid fee of 5.79 Rp/kWh for network level 1-6). Green and blue bars represent weekly energy production and consumption in kWh, respectively. With increasing supply of energy within the Quartier, the market price decreases.

On average, the sellers asked for 7.37 Rp/kWh (std = 3.52) as compared to the basic feed-in-tariff of 4 Rp/kWh. This shows that prosumers would like to earn more on the local market than they were granted by the utility provider. The buyers were willing to pay an average of 18.9 Rp/kWh. (std = 2.84) as compared to the WEW residential retail tariff of 20.75 Rp/kWh. Participants are hence not willing to pay more for locally produced solar energy, but would rather save on their energy expenses. It is worth mentioning that participants were aware that network tariffs for trading in the Quartier were lower than the network tariffs included in their standard tariff of 20.75 Rp/kWh. This may have influenced their bidding behavior in the sense that they knew prosumers were already earning more than the standard feed-in-tariff plus network tariff if the trading price was above 9.79 Rp/kWh. Overall, only 7.6% of the buy bids were above the WEW tariff, hence bidding an additional price premium for local energy.

These results illustrate that the behavior of individuals in a market context where bidding behavior is reflected in actual payments may differ from the survey results on renewable energy preferences. Furthermore, the collected data provide interesting insights from a behavioral economics perspective. If one examines bidding behavior over time, the prices offered show learning effects from previous periods and reactions to seasonal changes during the year. Individuals changed their price bids relatively often in the first months of the study, but from the beginning on this varied strongly across individuals. Some individuals adjusted their bids weekly (or more), likely to follow weather changes, whereas others changed their prices only once or twice. This strong variation across households is also reflected in the activity on the web app which is described in the following section on user behavior. The Quartierstrom system accommodates these different user types, but this aspect could be given more thought in a larger-scale implementation, for instance by offering additional services or recommendations for "power users".

Overall, the market prices for trading energy within the Quartier fluctuated between the feed-in tariff as the lower bound and the residential retail tariff as the upper tariff, resulting from the participants' bids. Figure 13 illustrates the price evolution, which is correlated to the supply of solar energy within the community. The market price hence reflects the availability of solar energy and increases when little local supply is available.

The real-time pricing achieved by the auction mechanism thus provides a monetary incentive for shifting consumption loads to periods in which local solar energy is available. Interviews with the participants suggest that many participants engaged in load-shifting activities. For instance, some households claimed that they now used their laundry machines during hours of sun rather than at nighttime. However, the experiment does not allow for quantitative analyses on this matter due to a lack of baseline data and as we do not collect data from a control group that does not face real-time pricing incentives. However, given that manual demand response programs have shown limited success in existing research studies, we conjecture that the potential for autonomous load control to shift flexible loads (e.g. from heat pumps, EVs, home storage) is more promising to reap the benefits of real-time pricing. We discuss a possibility for dynamic battery control in Section 4.3.3.

One aspect that influences the economic attractiveness of local energy markets is the controversial question whether electricity traded within the community could benefit from lower grid fees (considering only the lower grid levels used, rather than all grid levels). In the absence of that, the participants in the Quartierstrom project would not have been able to incur monetary benefits from trading. Yet, the current Swiss regulartory setting does not allow for such scemes. To comply with the regulartory setting, the Quartierstrom project has compensated the fees for the higher grid levels.

4.4.2 User Behavior (Module 41)

Lead author: Liliane Ableitner, ETH

For the evaluation of user interaction on the Quartierstrom platform, we consider the following three aspects, according to which this section is organized:

A) interaction with the P2P energy market or web app usage statistics

B) user preferences regarding pricing mechanisms of locally exchanged electricity, and

C) perceived user benefits.[5]

A) Interaction with the P2P energy market

Over the duration of the active field phase of the study, we recorded a total of 2450 logins to the Quartierstrom web application. While logins decreased in the final months of the year, there were 20 monthly active users on the application on average. This level of activity is surprisingly high for an energy-related context. The usage data also shows that activity on the Quartierstrom web app varies strongly among the participants. A small subset of users (7 participants) used the application very frequently, often several times per week. A second group (13 participants) used the application with more or less regular usage patterns, depending on the household. The least active group used the app only on occasionally. Nevertheless, most of them have logged in at least once over the course of the year (28 participants).

In addition to the access to the web app, participants received monthly summary reports via email on the first day of each month. Remarkably, there was no increase in the activity on the web app subsequent to the delivery of the report. Interviewed households generally showed high appreciation for the reports, as they provide a concise overview and remind the participants about the project.

B) Results to the experiment on uniform price mechanisms

With respect to user preferences regarding pricing mechanisms, we examine two different roles of the households in P2P energy pricing: agency (active participation in the pricing) vs. the convenience of

[5] Note that several paragraphs in this chapter have been adapted from the journal article Ableitner et al. 2020

automation (when the price is defined by a third party, e.g., the utility company). Generally, pricing of P2P energy is a delicate question, as the P2P concept does not comprise a central institution that defines a global price for P2P energy; instead, prices result from bilateral negotiations of prices between market participants. From the user perspective, however, this implies an extensive effort if price preferences need to be adjusted manually by the participants, as is the case in the Quartierstrom project. For most participants, the opportunity costs of the time invested are likely to exceed the financial benefits from an optimized bidding behavior in the P2P energy market. On the other hand, the possibility of setting price preferences grants participants a more active role and, from a research perspective, a possibility to elicit price preferences and the participants' willingness to take a more active role in the market.

Therefore, we conducted a within-subject experiment that manipulates participants' ability to set prices (yes/no) as independent variable. During the first three months of the study, participants could set price limits in the UI. In month four, we deliberately disabled the feature, preventing households from setting their preferences for P2P prices (participants were informed about the change upfront). For all P2P trades during that phase, a dynamic (based on supply and demand), yet uniform price was defined for all participants that ranged between the feed-in tariff and retail price. The main dependent variable is user preference for one or the other pricing mode.

Based on user preferences and their interaction with the web app, we identified different user segments: After the experiment, 11 out of the 28 users (i.e. households that had created an account) stated they wanted to participate actively in the pricing of P2P energy and set their own price limits. The interview data suggest that this group values the gamification character, the idea of a free market, and the fact that they don't have to trust a third party in determining prices for their surplus (resp. locally purchased) electricity.

By contrast, 13 households preferred automated pricing, i.e. uniform market prices defined by the system (based on current demand and supply in the community). They seem to value automated prices for convenience and simplicity reasons. Remarkably, the correlation of user preference and usage frequency is rather counterintuitive: those who used the portal more often tend to prefer automated prices. Regression analysis with pricing mechanisms preference as the dependent variable shows that usage explains 16% of variance in the preference for the pricing mechanism (marginally significant effect of $b = 49.85$ at $p = .057$). User type (consumer/prosumer) or the frequency of previous price changes do not affect the preference for one or the other pricing mechanisms. As a result, we segment our study participants into the following categories: individuals who use the portal for data exploration and who prefer to set their own prices (30%), individuals who use the portal for read-only purposes and who prefer to rely to externally defined prices (35%), and non-users (24%) or households that have not responded to our surveys (11%). Figure 14 visualizes the different user clusters.

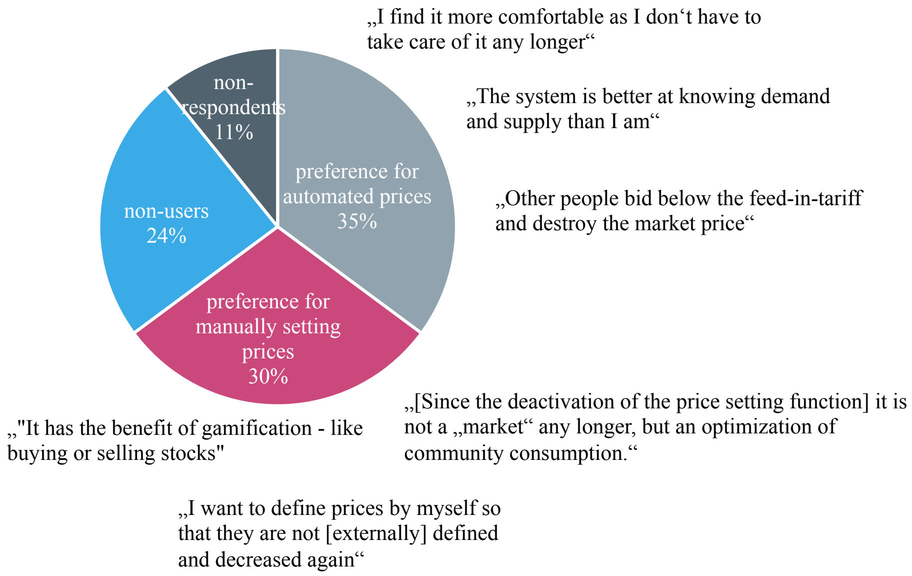

Figure 14: User segmentation by activity level (price-setting preference and system usage) in the P2P energy market

The usage data further suggests that the different pricing mechanisms did not affect participants' usage of the web application. The general acceptance of the P2P energy market, however, had decreased significantly after the period with automated pricing, as indicated by a paired sample t-test: At the end of the three-month period with manual price setting, the general acceptance of the market was 4.71 (SD=.59), measured on a 5-point Likert scale, translating into *good acceptance* to *very good acceptance* on average. By contrast, the acceptance indicator dropped to 3.53 (SD=1.01) translating into *undecided* to *good,* $t(16)=4.78$, $p=.0002$ after the automated pricing phase. However, this result might also be an artefact of the within-subject study design (a study design with crossed treatments was not feasible for technical reasons and due to the small sample size). In other words, we cannot rule out that the decrease in the general acceptance rating is due to general time trends (e.g., fatigue of participants over time). With regard to usability evaluations, participants' rating after the automated pricing phase was 5.35 on a 7-point Likert scale; thus, it was similar and not significantly different from the usability rating in the manual price-setting mode, where it had received a score of 5.41.

In a post-experimental survey in January 2020, we asked participants again about their preferences for the pricing mechanisms. Interestingly, in this survey, a larger proportion of users (15/19 survey respondents) stated they preferred the automated pricing mechanism, so the interest in bidding prices manually decreased.

C) Perceived benefits for users

The third research aim regarding user behavior was to gather advantages of P2P energy markets perceived by the study participants. Based on these, value propositions of P2P energy markets may be derived and be compared to P2P energy market benefits identified in literature (Reuter and Loock 2017, Mengelkamp et al. 2017, Morstyn et al. 2018).We structure our findings of the in-depth analysis of the semi-structured interviews with nine households according to Reuter and Loock (2017) who found that individuals would be willing to join P2P energy markets for the following reasons: environmental, economic, technological/ infrastructural, political/ independence, and social/ community motivation. Households perceived strongest advantages on the environmental, economic and political/independence dimension – or it short, households perceived P2P energy markets as green, local, and fair.

4.5 Local Voltage-Dependent Grid Tariff[6]

Authors: Sabine Proll, SCS, Alain Brenzikofer, SCS

Motivation

If several power plants feed into the distribution grid at the same time with little consumption, the grid can get congested and undesirable overvoltages can occur. On the other hand, many electric vehicles that charge with high power during the same time of day can cause congestion and undervoltages. As shown in Brenzikofer et al. (2017) and Stocker et al. (2018), voltage deviations can be mitigated by shifting flexible load and generation in time. Electric boilers and other flexible loads can draw power when the sun shines. Grid-attached batteries can soften both consumption and production peaks. However, one may not assume that improving the power balance in a community automatically improves voltage stability in any case, as shown in Figure 15**Error! Reference source not found.**. A battery system A installed on branch A may choose to charge because there is a lot of cheap PV energy produced on branch B, potentially causing an undervoltage on branch B while not improving the overvoltage on branch A by much. A pure energy market neglecting grid topology would risk to put additional strain on the grid.

The proposed local voltage-dependent grid tariff (LVD tariff) factors voltage stability into the market prices to incentivize grid-stabilizing behavior and improve profitability of well-placed storage systems. Our tariff design rewards battery B for charging while it puts a penalty on battery A for doing so.

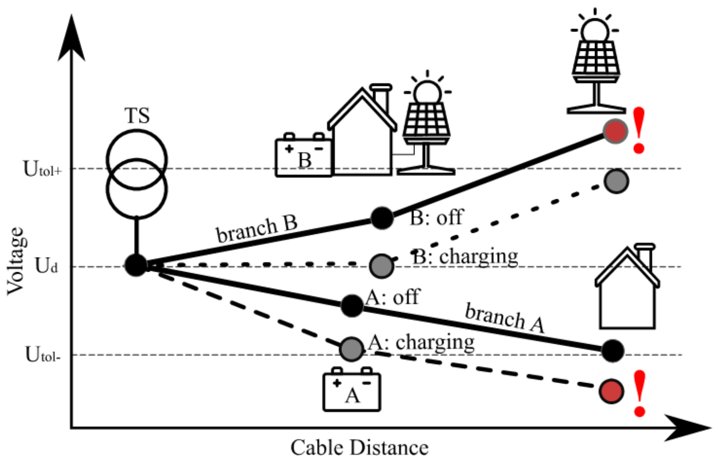

Figure 15: Voltage on different branches

Price Composition

In Quartierstrom, a consumer pays a price that is calculated as:

grid tariff + trading price

The trading price is explained in detail in section 4.3.1.2. The grid tariff depends on the origin of the consumed energy:

Origin	Grid Tariff
Same household	0 Rp/kWh
Within community Quartier	5.79 Rp/kWh

[6] The complete report concerning the LVD tariff can be found in Appendix 11.1.

From utility (WEW)	13.03 Rp/kWh

On top of this, here we evaluate a dynamic grid tariff that depends on the local voltage. The idea is to keep the trading price as it is and only change the grid tariff. For the evaluation we focus solely on the grid tariff and neglect the trading price for energy.

Underlying Data

The plots used to explain and evaluate the LVD tariff are obtained from the actual measurements during the field test.

- Household: All plots and calculations are based on one measurement point belonging to a household with a PV plant. The node was chosen because it has periods where energy is injected into the grid and periods where energy is consumed from the grid, varying throughout the day.
- Time resolution: Measurements were available with a resolution of 5 minutes. For simplicity, we assume that the grid tariff and the resulting costs are also calculated every 5 minutes.

Calculation of the LVD Tariff

In the LVD tariff every phase of every measurement point has its own tariff. The tariff depends on the histogram of the voltages (in a 5-minute resolution) that were measured at the same measurement point and the same phase on the day before. The upper and lower 5% and 1% percentiles are calculated where a change in tariff occurs according to Figure 16**Error! Reference source not found.**. To calculate the LVD tariff, the current voltage is compared to the histogram. If it is within the normal range of the histogram, the standard tariff of 9.65 Rp/kWh is used. When the voltage is beyond the 5% percentiles, a penalty or reward is added to the tariff. We chose a linear curve that ends at a maximum penalty/reward of 50Rp/kWh at the 1% percentiles. The penalty is charged when the voltage is low (to incentivize less consumption) and the reward is given when voltage is high (to incentivize consumption). The standard tariff was chosen to be 9.65 Rp/kWh because this is the overall average for the grid tariff that was payed during the Quartierstrom field test.

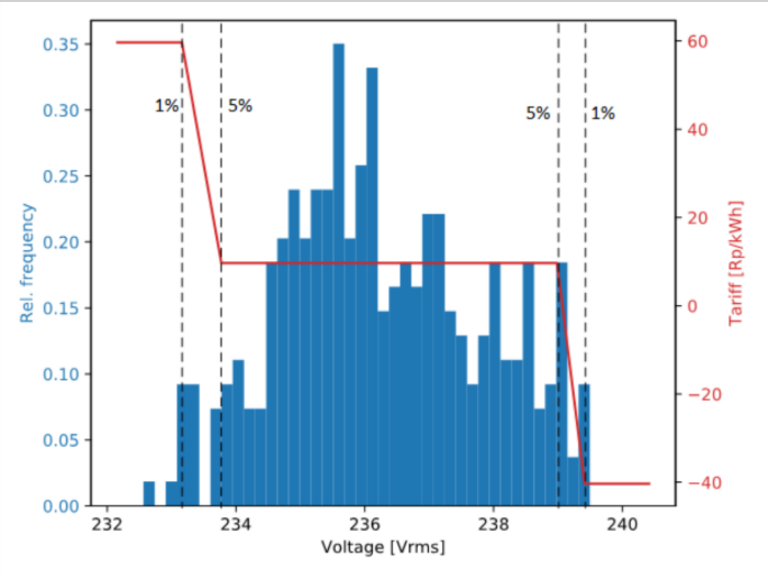

Figure 16: Calculation of LVD tariff for phase L1 of one measurement points on October 23rd 2019

Behavior of Battery Simulation

We assume that charging and discharging of the battery follows the LVD tariff curve. Depending on the percentile we are in, we charge/discharge the battery: with a peak power of 1kW (for one phase). The battery's state of charge is ignored, as it is assumed that typically charging and discharging balances each other out due to the rules of the LVD tariff. Furthermore, the (desired) effects on the local grid voltage are not simulated.

Potential of Cost Savings for Load-Balancing

We calculated the overall savings that can be achieved in the above household if a battery would be installed and controlled to follow the LVD tariff. For this, the above described battery simulation is used. The costs for all 3 phases are calculated and summed up.

The plot shows 4 curves:

Curve	Underlying consumption	Tariff
blue	actual consumption	LVD tariff
yellow	actual consumption	fix tariff of 5.79 Rp
green	actual consumption	fix tariff of 13.03 Rp
red	actual consumption + simulated battery	LVD tariff

Cost Comparison for March-December 2019

When applied to almost the whole year of the Quartierstrom field test, savings with a battery would have been at 423 CHF. (There was no data available for January and February)

Remark: There is one big outlier on December 25th. The tariff on this day is extremely low, because the voltage was much higher than the day before. To mitigate these outliers, one could try to make better predictions on the voltage distribution of the day in future projects (e. g. by taking holidays and weekday/weekends or weather forecasts into account).

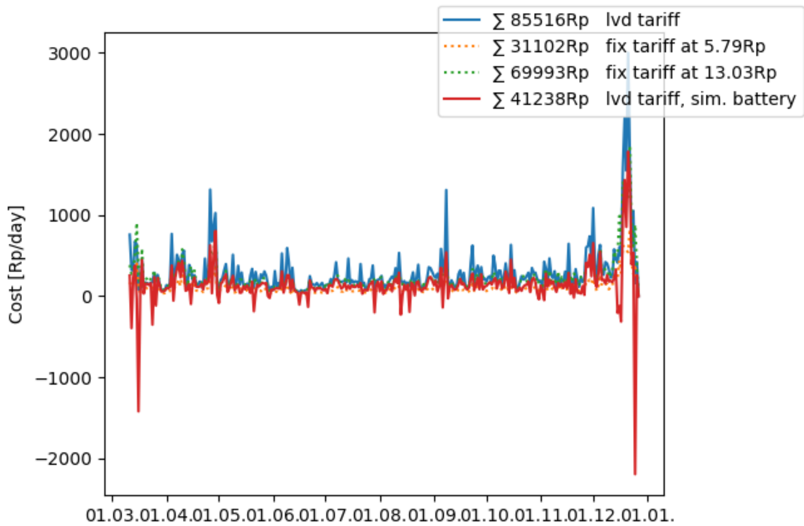

Figure 17: Locational grid pricing simulation: Total grid tariff costs 2019

Further Remarks

- Installation costs for load-balancing devices:
  Installation costs can be financed by the savings made, when the LVD tariff is applied. The savings are financed by those who do not contribute to load-balance and/or by the grid operator, as these households contribute to the voltage stability.
- As the tariff is per phase, it incentivizes
  - rewiring to correct imbalances
  - taking specific measures for single-phase prosumers
- Solidarity: The following measures contribute to a fair price for all:
  - The tariff depends on the voltages of the same node of the day before. Thereby it is almost independent of the grid topology: if voltage is usually low at my node, my tariff will take this into account.
  - For most time intervals, the tariff is fixed without reward or penalty. Therefore, the negative effects of not doing load-balancing should still result in a reasonable price.

While the simulations are based on empirical data measuered during the Quartierstrom project, in dialogue with with ElCom and SFOE, the LVD tariff was not implemented in the field. The tariff would not only have increased the already high pricing complexity for the participants, but also have created difficulties given the regulatory restrictions on grid pricing (non-discrimination rule). While it is hard to predict the effects of the proposed LVD tariff in the real world, the results give an idea on the savings one sole participant could realize when installing a load-balancing battery. The effects on the savings, when a high percentage of households have a load-balancing device, however, are unclear and should be investigated in the future. One can imagine the resulting tariff to be stricter and therefore make it harder to achieve high savings. On the other hand, when many households participate in load-balancing, the grid operator could use these as load-balancers for the higher-level grid. In this case the LVD tariff would ensure that theses households are rewarded and thereby implicitly be paid by their grid operator.

4.6 Business Model & Legal (Module 61)

4.6.1 Regulatory analysis: Current situation

Lead author: Gian Carle, ZHAW

Current situation in Switzerland

A self-consumption community is a contractual union between landowners as final consumers for the purpose of a self-consumption community of locally produced electricity (Art. 17 (1) EnG). The landowners can also let tenants participate in the self-consumption community as end consumers on their properties (Art. 17 para. 2 EnG). Landowners can themselves be the owners and operators of renewable energy generation plants (RES). There are several requirements for a self-consumption community which the landowners must fulfil. The place of production has to be on contiguous land plots, of which at least one borders on the land on which the production facility is located. Only electricity that has not used the distribution grid of the grid operator between the production and the point of consumption is deemed to be consumed at the point of production itself (Art. 14 (3) EnV). A physical connection between the production site and the various consumers within the self-consumption community is therefore necessary under current law, and virtual self-consumption is excluded. All participants in a self-consumption community must therefore be connected behind the same "private" network connection. As a result, the establishment of self-consumption community in existing properties leads to adjustments to the network connection depending on the situation. These costs, as well as any investments that cannot be amortized by the grid operator, must be borne by the property owners (art. 17 para. 4 Energy Act; art. 3 para. 2bis Electricity Ordinance (EnV)).

Self-consumption (EVG) at the place of production is also possible without the creation of a self-consumption community. This applies not only to end consumers with their own production, but also to producers who make the electricity produced locally available to several end consumers. The place of production and self-consumption must be on the same plot. Since not all buildings in the Quartierstrom project are located plot by plot as it is required for a self-consumption community and as the Wasser- und Elektrizitätswerk Walenstadt (WEW) distribution network is used to exchange energy, it is not a real self-consumption community under current Swiss federal law.

Under the current legislation, peer-to-peer communities are currently only possible if they meet the following conditions:

(1) All plots are adjacent to each other or separated only by a road, railway line or river or the peer to peer community is located on an area network.

(2) Self-consumption community must have a separate grid network, since such communities may not use the distribution network of the electrical power utility.

(3) If several landowners are end-users at the place of production, they may join forces for their own self-consumption, provided that the total production capacity of the installation is at least 10 percent of the connected load at the measuring point of the self-consumption community.

(4) The integration of properties that are not adjacent is not possible.

Relationship of the individual participants:

The following section examines the relationship and legal consequences of a self-consumption community on the basis of the current Swiss legislation. The contractual relationships must be structured differently depending on whether the trading-platform is owned by a third party, such as the network operator or another contracting partner, or whether the community itself is the owner of the trading platform and also operates it itself. Grid operators must note that they are subject to informational unbundling under Art. 10 Par. 2 StromVG[7]. They may not use information they obtain from the operation of the electricity grids for other areas of activity. In this context, a grid operator may be forced to establish a subsidiary if he wishes to operate trading platforms for consumer associations in the sense of a service.

Relationship of the self-consumption community with the utility company:
According to Art. 17 para. 1 EnG[8], the landowners participating in a self-consumption community must enter into an agreement with the plant operator and among themselves. While the self-consumption community is governed by private law internally, the external relationship with the grid operator is governed by the StromVG. The relationship between the landowner and the grid operator is specified in Art. 18 EnG and Art. 18 EnV[9]. Art. 18 (1) EnG states that after building the self-consumption community, the end consumers will have a single metering point at their disposal vis-à-vis the grid operator, just like an end-consumer. The self-consumption community is thus considered to be a final consumer with the

[7] Bundesgesetz über die Stromversorgung (StromVG), https://www.admin.ch/opc/de/classified-compilation/20042411/index.html
[8] Energiegesetz, https://www.admin.ch/opc/de/classified-compilation/20121295/index.html
[9] Energieverordnung, https://www.admin.ch/opc/de/classified-compilation/20162945/index.html

corresponding rights and obligations. The grid operator is thus subject to a connection obligation under Art. 5 StromVG. In addition, the self-consumption community (as a final consumer) is entitled to basic supply by the grid operator under Art. 6 (1) StromVG and to purchase the surplus production offered after deduction of the self-consumption.

Relationship of the participating landowners of a self-consumption community:
According to art. 17 par. 1 EnG, the landowners involved in a self-consumption community must reach an agreement not only with the grid operator but also among themselves. This agreement must be made in the forms of private law, but the law does not specify the nature of this agreement.

Position of tenants and lease holders in Switzerland:
Tenants and lease holders are in principle also part of a self-consumption community, they can only refuse to participate to a very limited extent. Since the landowners are in a similar position towards them as the network grid operator is towards the end customers, the law imposes certain obligations on the landowners and sets relatively detailed requirements for the calculation of costs towards the tenants and leaseholders. In order to secure their rights and within the framework of the self-consumption community, Art. 16 (4) EnV stipulates certain elements which must at least be recorded in writing at the time of setting up the self-consumption community.

The main differences between the community created in the Quartierstrom project and the traditional self-consumption community recognized by Swiss regulation, is the trading platform described above and the use of the public grid infrastructure within the self-consumption community. The trading platform creates a local electricity market within the self-consumption community. A very basic distinction is whether the platform is owned and operated by the self-consumption community itself or whether the self-consumption community assigns provision and operation to a third party, for example in the form of a so-called contracting service. A number of energy supply companies also offer contracting services. However, Art. 10 (2) StromVG now prohibits network operators from using information obtained from the operation of electricity grid network department for other areas of activity. Whether this provision also covers the operation of the internal network of a self-consumption community, however, does not seem to be clarified. Federal law leaves self-consumption communities a great deal of freedom to regulate the contractual relationships between the landowners involved. Thus, the integration of a trading platform into the self-consumption community, which uses so-called smart contracts and thus automatically executes and terminates transactions, does not appear to be subject to any specific obstacles under energy law.

Current legislation in the EU

With the Clean Energy Package Directive 2018/2001[10] of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, citizens and energy communities in the EU now have a number of rights to use and distribute the energy they produce themselves.

In Germany, this newly created European definition of self-consumption meets the existing definition in § 3 No. 19 EEG 2017. According to this definition, self-consumption[11] is "the consumption of electricity consumed by a natural or legal person in direct spatial connection with the electricity generation plant itself, if the electricity is not routed through a grid and this person operates the electricity generation plant itself". However, since all grid fees and taxes are incurred when electricity is fed into a public grid

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001
[11] Auf Deutsch Energiegemeinschaft, wörtlich übersetzt als "Bürgergemeinschaft"

and the relatively low remuneration under EEG 2017 is paid for the generator, there is hardly any potential for the German tenant electricity[12] models.

In Austria, the implementation of self-consumption community models is not yet known because their economic profitability is not given. In Italy and Spain, self-consumption communities do not exist because they are not legally permissible.

In France, since 2017, an implementing decree (Decree 2016-1019[13]) has authorized groups of persons (co-owners, associations or cooperatives) to consume their own energy. The new "décret d'application" (article 43 until 11 April 2019[14] and l'arrêté du 21 November 2019[15]) will extend the scope of self-consumption communities to a range of 2 km but this law is limited to 5 years.

Conclusions on the current legal situation

The legislation in Switzerland is currently more progressive than in the EU. With the introduction of the Clean Energy Package and the forthcoming Electricity Market Act, the EU is adapting the law for an upcoming decentralized production, with which the remaining EU countries will also have to legalize self-consumption community and neighborhood electricity models in about 2 - 3 years. However, every country has the right to define self-consumption and self-consumption communities themselves and won't be coordinated by the European Union.

From an economic and technical point of view, self-consumption communities have a number of advantages compared to traditional grid architectures. However, the design and scope of such communities are controversial not only from a political but also from a legal perspective. At the moment, the main obstacle to the further expansion of such self-consumption communities is the restrictive regulation that such plots of land must in principle be adjacent and a self-consumption community may not use the public distribution network of the network operator.

4.6.2 Regulatory analysis: Medium- to long-term outlook toward prosumer-centric energy markets

Lead author: Nick Beglinger, Cleantech21

The Quartierstrom project provided valuable lessons on advanced, prosumer-centric energy markets – on the regulatory and business model front. In the opinion of the author of this study, one of the key insights of the analysis is that the technology is largely available, but that the right regulatory framework is not. Regulatory innovation must thus be regarded as the key challenge for the rapid emergence of distributed renewable energies. Regulatory progress must also be regarded as key for the competitiveness of energy market players, as only with such progress, scalable and sustainable new business models will emerge.

The specific objectives of the medium- to long-term regulatory Quartierstrom pilot analysis was to:

1. Acknowledge the current state of regulation and identify innovation needs with respect to prosumer-centric energy markets;
2. Estimate the likelihood and timeline of the needed regulatory innovation;
3. Provide a preliminary analysis of what type of regulatory framework would lead to rapid prosumer-centric development (i.e. the fast emergence of distributed renewable energies).

[12] Mieterstrommodell
[13]https://www.legifrance.gouv.fr/eli/decret/2017/4/28/DEVR1707686D/jo/texte
[14] https://www.legifrance.gouv.fr/eli/decret/2017/4/28/DEVR1707686D/jo/texte
15https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000039417566&categorieLien=id

The summary findings for these three main objective-themes, according to the author of this study, are as follows:

1. Currently, prosumer energy communities operating over public networks are not accommodated in the regulatory framework of any major market (incl. Switzerland). Networks are largely regulated in a top-down logic. This presents several substantial regulatory innovation challenges as part of the transition to a prosumer-centric network management approach. The need for innovation, however, is increasingly recognized. Both technological innovation in the core energy domains (PV panels, batteries, etc.) as well as innovation in the digital domain (identification, payment, internet of things, distributed ledgers, artificial intelligence), works towards a disruption of current energy markets. This innovation makes it apparent that distributed renewable sources will be the key driver of future energy markets - mainly because their economic feasibility rapidly improves.
2. For distributed renewable energy to fully emerge, however, energy framework policies need to change. Even though these changes are substantial, the likelihood of rapid regulatory innovation taking place is growing. The key driver of this is the pressure to address the climate crisis with vigor, and the fact that renewable energies must be considered as the 'low hanging fruit' in the climate fight. As a consequence, the timeline for substantial Swiss bottom-up innovation to be fully enacted could be as short as 3-5 years, with Sandbox-type frameworks emerging within 1-2 years. Already today there are parliamentary proposition for this.
3. As the energy infrastructure investment decision in a market driven by distributed renewables is with the prosumer, being the 'underlying asset owner' (e.g. home/building owner), he must be at the center of network management (optimizing local production, consumption, storage, purchase or sales decisions). In this 'bottom-up' network logic, all prosumers should be incentivized and enabled to interact over the public network – under the condition that they comply with certain quality- and data sharing standards. This improves their own energy performance, and it contributes to overall network performance (security of supply, etc.). In order to correctly incentivize prosumers, public network tariffs should dynamically reflect the true network usage costs, and they should be fair in the sense of treating all market participants on equal terms, regardless of their size.

As experienced firsthand by the Quartierstrom pilot, **Swiss regulations** are not yet ready for bottom-up energy trading. Quartierstrom itself was exposed to regulatory uncertainty. A key regulatory conclusion is thus to **fast setup of a sandbox policy framework that allows prosumers to trade energy over the public grid.**

The graphic and explanatory comments on 'Regulatory Dynamics of Prosumer-centric Energy Networks' following below, summarize the main findings of the Quartierstrom study with respect to the key drivers of prosumer-centric energy provision from a regulatory point of view.

In order to fully address the regulatory questions asked at outset of the Quartierstrom project, answers to each of these questions (and selected additional key questions) are provided in Appendix **Error! Reference source not found.** (Regulatory FAQ). More in depth regulatory analysis is provided in the Appendix **Error! Reference source not found.** (Background Review on Regulatory Developments Relating to the Emergence of Distributed Renewable Energies).

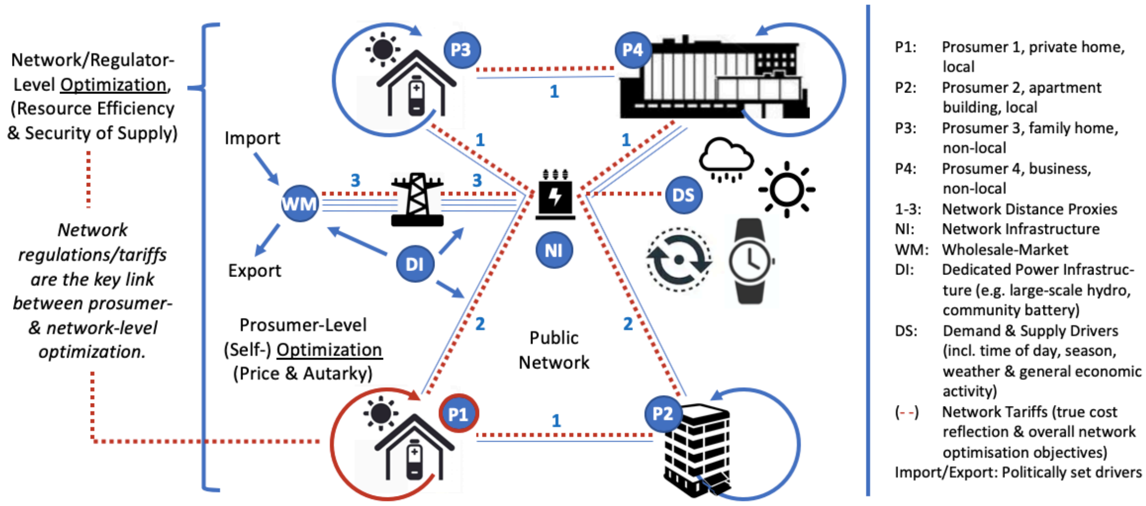

Figure 18: The Regulatory Dynamics of Prosumer-centric Energy Networks

Comments to Figure 18:

- The emerging energy market is called ‘bottom-up’ as the key/driving investment and operating decisions are taken by many distributed market participants, the prosumers (P1-P4). They are the owners of assets (e.g. houses) with which energy can be generated (e.g. with solar roofs/facades), stored (e.g. in cellar batteries), and traded (with smart meters).
- Bottom-up energy assumes fully liberalized energy markets – allowing each participant to choose from whom to buy and to whom to sell power (e.g. P1 to P2, or P1 to P4).
- Overall network optimization/management works such that it starts from the distributed decisions of prosumers (at the ‘bottom’/distributed edge of the network) and coordinates/optimizes them ‘upwards’ (for overall network management/governance).
- With the right rules governing how the network can be used, prosumers can be incentivized correctly, and overall network performance can be optimized according to the political targets set.
- P1 primarily makes her energy investment decision based on her demand, the generation and storage potential of her infrastructure/house, and the prevailing network usage conditions (policy framework/tariffs). This is the same for P3 (also a private household), as well as P2 (an apartment building – with the owner acting as the prosumer, selling power to tenants) and P4 (a business prosumer – with greater energy needs than what the business may produce/store locally).
- In the author's view, the objective of the regulator should be, for any politically agreed upon level of imports and exports (‘foreign dependence’), to maximize security of supply (at competitive price levels) as well as resource efficiency, and at the same time reflect the true costs of network usage in the form of dynamic tariffs.
- Network usage costs are made up of the costs of the network infrastructure (NI) engaged (transformers, etc., distance/network meters) as well as the current network usage demand (DS), which in turn is driven by economic activity, the weather, season, time of the day, etc.
- Other things equal, network tariffs for P1 selling to P2 (at distance 1, and no NI) should be lower than P1 selling to P3 (distance 2+1, incl. NI).
- The policy framework setting out the rules and tariffs for using the grid (incl. its NI components) is the key link between the optimization/investment decision by the prosumer, and that by the

regulator. If, for example, prosumers cannot trade energy at competitive rates, they make sub-optimal infrastructure decisions. Instead of covering their entire roof with PV panels, they may only cover half (resulting in valuable renewable energy generation capacity being lost in the market). Or, they may invest excessively in local storage solutions, aiming for autarky and maybe even defecting from the grid. While a high degree of autarky carries value to certain prosumers, it also implies suboptimal resource efficiency (meaning that there may be constraints on raw materials and/or excessive exploitation of nature if everyone pursues such a strategy).

- Prosumers should be enabled to transact over the public grid based on fair and transparent commercial conditions. These should also be fair relative to the providers of dedicated energy infrastructure (DI) and electricity sourced from wholesale markets (WM, e.g. at distance 3, incl. NI).
- Conditions should apply for energy and for capacity/storage markets (which will likely develop to be one and the same).
- It is clear that a bottom-up energy system will need time to emerge and will do so in phases. It is important, however, to allow for sufficient network usage from the outset (i.e. asap, in order to increase renewable energy disposition). For example, private prosumers (e.g. P1 or P3) should be able to sell power to commercial ones (e.g. P2 or P4) – even if this means, in the current logic, selling from network level 7 to network level 5 (e.g. P1 to P4). This is because it represents a sustainable way to supply peak commercial demand during daytime, when household demand is low (many people are at work or at school), but household production is high (the sun is up).
- The more local energy trading happens, the better (cheaper/safer given less infrastructure is used). During the emergence of bottom-up energy, the organization through prosumer/consumer communities at a local level (such as the local level 7 grid run by the local utility), appears to be a sensible way forward. Long-term, it seems likely that all the network is essentially an 'open community', and for prosumer to interact directly with the regulator (through their smart meters).
- The smart meter takes a key role in the development of bottom-up energy networks. At present, smart meters are not prosumer-centric (purchased by the utility and installed as part of the network participant's infrastructure). But prosumers should be free to choose standard-/quality-compliant hard- and software to share data, and trade energy/capacity with the service providers, communities, or selected individual prosumers. For this reason, the smart meter market may be expected to move from B2B to B2C in prosumer-centric energy markets.

Smart meters can also be expected to take a key role in network status monitoring – measuring network performance in a distributed way and sharing it with the regulator.

4.6.3 Business models with short- to medium-term applicability

Lead author: Gian Carle, ZHAW

This chapter examines whether a profitable business model for a self-consumption community (in German called ZEV) with a decentralized energy exchange market - similar to Quartierstrom - can be developed and thus, whether the concept is scalable from an economic point of view under the current regulatory conditions. The analysis is conducted from the perspective of a start-up company (and not an incumbent in the utility sector). The analysis is subject to a high degree of uncertainty due to the following boundary conditions:

- The business model must be legally feasible in the regulated market where self-consumption communities are limited by law (see Section 4.6.1).

- Furthermore, the business model is dependent on a functioning electricity grid, which is, however, in the hands of the grid operator. The grid situation will not be affected by the liberalization of the electricity market, as the grid will remain a monopoly.

Obviously, in order to assess the scalability of the project, one must not take the costs of the Quartierstrom project as a benchmark, as they include considerable research and development costs due to the pioneering stage of the project.

In the subsequent analysis, the costs for hardware were excluded from the calculation. For example, the smart meter "Smart power" by Evulution (www.evulution.com) could be used, which meets all the requirements of a blockchain smart meter. Additional hardware costs would make the business case less attractive. However, the software integration costs have to be covered by the start-up company if the software covers more than an intelligent control and regulation system for safe, powerful and efficient grid operation as mentioned in the StromVV (see Art. 8c StromVV).

In order to be able to quantify possible revenues, the fees for a self-consumption community (ZEV) were used as an analogy, since these concepts also use a decentralized energy exchange as in Quartierstrom. The analysis is based on existing self-consumption community solutions, among others Ormera[16], a blockchain-based self-consumption community and SEL[17], which also integrates boilers, batteries and heat pumps into the self-consumption community. Ormera, and esolva charge a yearly fee, SEL a yearly and a one-time fee. ewz, ewl and iwb charge a fee per total self-consumed kWh (from rooftop and neighbors, excluding energy form the electrical power utility) (see Table 6. Parameters used to calculate a possible business case

).

	Parameter	Calculated on the basis of information from the following companies
Revenue of a start-up:	Fee per kWh and/or one-off fee	SEL[18], ewz[19], ewl[20], iwb[21], esolva[22], Ormera[23]
Costs/expenses of a start-up:	Wages, marketing, IT infrastructure	Start-up from the Blockchain-ZEV scene

Table 6. Parameters used to calculate a possible business case

The presented calculations assess how much revenue would be generated if a self-consumption community with the same energy consumption, same PV-production, same amount of households (37) as in Quartierstrom (see Table 8: Quartierstrom-Parameters, based on the set-up in Walenstadt

) had to pay the fees for the various self-consumption community solutions (SEL, Ormera, ewz, ewl) and how long it would take for the system to reach break-even. The cost estimates were derived from an existing blockchain start-up (see Table 7). The detailed analyses can be found in Appendix 11.3.

Cost factors	Swiss Francs

[1616] www.ormera.com
[17] https://smartenergylink.ch/
[18] https://smartenergylink.ch/
[19] https://www.ewz.ch/de/geschaeftskunden/solarenergie/solarenergie-fuer-eigentuemer/eigenverbrauchsgemeinschaft.html
[20] https://www.ewl-luzern.ch/privatkunden/energie/strom/produzieren/eigenverbrauch/
[21] https://www.iwb.ch/Fuer-Zuhause/Solarenergie/Solarstrom-nutzen.html
[22] https://www.esolva.ch/angebot/zev-b2b
[23] http://ormera.ch/

Wage costs (Assumption of average wage is 100'000 CHF of the 7 employees) and occupational benefits (21.6 % of wage for AHV, ALV, NBU, BVK)	851'000
External software programming (blockchain)	150'000
Office costs 250 CHF per workplace and month[24]	21'000
Marketing budget	59'000
IT costs 200 CHF per employee and month[25]	17'000
bookkeeping (150 CHF per month) [26]	2'000
Total per year	1'100'000

Table 7 Assumption of yearly cost of an existing blockchain start-up providing self-consumption community

Quartierstrom-Parameters	Values January 2019 to January 2020
Number of measuring points/households	32/37
Total energy consumption (in kWh)	469'467
Production volume of PV traded in the community (in kWh)	152'669
PV electricity fed-in into the grid (in kWh)	100'418
Self-consumption (in percent)	32 %
Payment for PV energy feed-in in the Quartierstrom project (cent/kWh)	4
Payment for PV energy feed-in for all other districts of Walenstadt (cent/kWh)	9
Grid costs for electricity purchases from WEW (in centimes/kWh, without KEV, "Abgaben" and swissgrid fees), "Arbeitspreis"	10.08
Grid costs for electricity purchases within Quartierstrom (in centimes/kWh), "Arbeitspreis"	5.79

Table 8: Quartierstrom-Parameters, based on the set-up in Walenstadt

24 http://www.derhauptsitz.ch/#patenschaft
25 https://www.runmyaccounts.ch/2013/07/wie-viel-kostet-ein-mitarbeiter-wirklich/
26 https://www.startups.ch/de/services/buchhaltung

	ZEV/ Block-chain-solution	revenue per kWh (cent-imes)	revenue per smart meter	fixed fee	Annual income for a ZEV-Quartierstrom -solution	Number of solutions implemente d to cover start-up costs	Number of years to reach break-even point
iwb	ZEV	5.0	0		7'746[27]	1'421	10
ewz	ZEV	4.0	0		6196	1'776	10
ewl		3.0			4'647	2'367	10
esolva	ZEV		95 CHF per metering Point and year		7'030[28]	838	9
Ormera	ZEV with Block-chain-billing	0	118 CHF per meter and one-time fee of 5000 CHF		13'732	953	9
SEL SMART ENERGY LINK	ZEV	0		110'780 CHF in the first year, subsequent years 5,920 CHF	110'780 CHF in the first year, subsequent years 5,920 CHF	62	4

Table 9: Company-earnings for ZEV solutions (ewz, ewl, iwb, SEL and esolva) and a ZEV-blockchain solution (Ormera)

Unfortunately, no exact figures are available for the current number of self-consumption houses or self-consumption communities (ZEVs) in Switzerland in order to classify the needed amount of self-consumption communities to cover the start-up costs (see Table 9). According to VESE[29] there are currently around 500 self-consumption communities in Switzerland. Since no predictions can be made about the number of new buildings or self-consumption communities, the approach taken here is to determine how many buildings with several consumption points in an apartment building already have a PV potential. The company Geoimpact has - based on its Swiss Energy Planning Tool - made some calculations for the author to provide information on the potential for self-consumption communities compliant with the current legislation.

In Switzerland, there are 66'575 plots with more than 10 consumption points and at least 3 kWp PV potential, of which 62'162 are multi-family houses with more than 10 apartments. There are also 356'337 buildings with a PV potential of at least 30 kWp, which could also be a nucleus for a possible self-consumption community solution.

[27] 154920 kWh * 5 cents/kWh

[28] =95 CHF per metering point*37 housolds*2 meters per household

[29] VESE – Verband unabhängiger Energieerzeuger – eine Fachgruppe der SSES

Results

Almost all examined solutions presented in Table 9 require at least 9 years with 838 to 2'367 Quartierstrom self-consumption communities served before the business model pays off (see Table 9). Only SEL's solution, which is the one with the highest revenue for the start-up, would lead to the break-even point being reached within approx. 4 years, with 62 Quartierstrom self-consumption communities. On this basis, self-consumption communities of this setup do not seem to be a realistic business model given the current legislation, unless high fees (over 100 CHF/per month and households) are charged to the self-consumption community members. The earnings mechanism considered in this calculation is the "internal trading". However, there are regulatory limits. In addition, the current grid usage model prevents incentives for local optimization except within self-consumption community solutions. The current self-consumption community framework conditions prevent high scalability within Switzerland. However, scaling must be very high in order to reduce costs for hardware, software, installation and operation, since savings for prosumers are too low today and customers' willingness to pay for local and renewable electricity is limited (no willingness to pay)[30].

The opportunities for a realistic business model of this kind would increase if the legal framework for self-consumption communities, would be expanded. Today's conditions for self-consumption communities (especially with regard to the grid entry point and the ban on shared use of the distribution grid) are deliberately restrictive in order to counteract excessive grid fee losses; there are calls for these conditions to be softened so that in future "virtual ZEV", e.g. behind a transformer, would also be possible to incentivize local consumption of distributed generation. According to Daniel Büchel (SFOE)[31], there are considerations to adapt the grid usage model in Switzerland in order to legally enable self-consumption communities similar to the Quartierstrom setup.

Concerning the customer side, self-consumption communities are mainly targeting distributed producers who need to optimize their self-consumption. One challenge will be to win the corresponding consumers. A neighborhood electricity model primarily addresses technology and green-power-affine customers and probably less the customers who want cheap electricity as the energy bill savings are too small.

4.6.4 Business model analysis: Medium- to long-term outlook toward prosumer-centric energy markets

Lead author: Nick Beglinger, Cleantech21

The rapid emergence of distributed renewable energies taking place now, majorly disrupts the energy market. This presents opportunities – for new types of energy value propositions, and for climate action. If energy market participants are incentivized with the right regulatory framework, it is the author's thoughts that many different distributed infrastructure owners will initiate projects. Collectively, these will represent significant capacity. As concluded in the medium- to long-term regulatory analysis in Section 4.6.2, prosumer-centric energy markets are almost ready in terms of technology, but not with respect to regulations. As no energy trading is generally permitted over the public grid, all types of scalable prosumer-centric business models will face regulatory uncertainty. It also means that only with the right policy framework renewables can be implemented at climate-compatible speed.

In most markets, including Switzerland, regulatory innovation will likely take place in stages, whereby two fundamental business model approaches with respect to regulatory risk can be differentiated:

1. A business model likely compatible with near-term regulatory innovation, but with limited reach and scalability potential (consulting or data services provided to utilities, serving niche opportunities with solutions that cater to current market processes, etc.);

[30] https://quartier-strom.ch/wp-content/uploads/2020/02/MM-Quartierstrom_Februar2020_Langversion-1.pdf
[31] SF, Kassensturz,10.12.2019, https://www.srf.ch/sendungen/kassensturz-espresso/warum-es-mit-dem-solarstrom-harzt#

2. A business model tailored to fully leverage the prosumer-centric/bottom-up energy future, very scalable, but dependent on wide-ranging regulatory innovation

In terms of markets being served, it is important to differentiate between:

1. Developed markets – where the main challenge is to enter a space cluttered with incumbents, and existing rules as well as infrastructure not yet adapted to prosumer-centric approaches;
2. Developing markets – where there is limited local competition, few regulations, limited network infrastructure, but significant uncertainty beyond the energy domain (country risk, skill levels, etc).

In the author's opinion, the current **smart meter roll-out plans need revision**. In his view, smart meters, and the data generated by them, **should be owned and controlled by prosumers**. They are key to the prosumer-centric value proposition and thus the rapid deployment of renewable energies.

When analyzing the specific value proposition options for bottom-up/prosumer-centric energy provision, the following factors were identified as being of importance:

- Distributed energy provision, including local storage, and optimized usage of grid infrastructure, has many fundamental advantages over the status quo. A large number of small distributed sources is more secure and resilient than small number of large plants. In addition, the primary energy investments are made by many individual market participants (not the government). Provided true cost accounting regarding network tariffs, as the author suggests, there is unlikely a more competitive energy option. In other words, with the right regulatory incentives set, bottom-up energy could emerge rapidly, driven by market forces and private sector investment. The right business models can facilitate implementation/scaling, but the key competitive lever is clearly with regulations.
- Bottom-up energy needs to be price-competitive, otherwise the deployment of renewables will not happen fast enough to meet climate targets. 'Green' and 'local' soft factors can mobilize niche markets only. Factors such as 'gamification' may play a role in the introduction of a new system. But it is the bottom-line that counts, also with bottom-up energy.
- Prosumer-centric markets will need to function in an automated way. Despite being at the center, only very few prosumers will want to frequently interact with their energy infrastructure and related decisions (during normal operations, following an initial period of high interest).
- A bottom-up energy strategy makes sense, whether there still is a central entity taking charge of certain coordination and service roles, or whether a fully decentralized setup is at work. The overall system gains in value with growing numbers of distributed market participants, and diverse interaction options between them being permitted over the public grid. The journey towards bottom-up energy will likely continue with further pilots such as Quartierstrom, including a strong role by a utility. It may then see communities that legally represent their prosumer members without a central authority, but with still offer limited reach and interaction options. Eventually, energy will likely transit to a fully open market on which all participants are able to interact freely across the entire grid (enabled by an automated 'data hub' or 'marketplace').
- The main objective is not to apply a particular technology (such as DLT/'blockchain') to the energy market, but rather to offer a competitive bottom-up value proposition independent of the technologies engaged. Many real-world use cases demonstrate that the application of DLT is generally complemented with other technologies (e.g. dynamic web applications, smart contracts, IoT, AI). The choice of technology is influenced by process- and positioning-parameters relating to the business model. For a project such as Quartierstrom, the relevant 'market' is not 'energy-blockchain' but 'prosumer-centric energy'.
- Distributed energy is mainly driven by digital technologies and is all about data. Therefore, analyzing dataflows, data ownership, sharing prerequisites and options, as well as identification, security and privacy challenges is relevant for defining bottom-up value propositions.

5 Conclusions

Lead author: Verena Tiefenbeck, ETH

5.1 General conclusions

Despite multiple challenges on various fronts, the Quartierstrom project has successfully implemented Switzerland's first blockchain-based P2P energy market, with national and international visibility. The technical implementation and design of the system represents pioneering work and demonstrates the technical feasibility of a P2P energy market using modern smart metering and communication infrastructure.

Local energy trading almost doubled the community's self-sufficiency rate (from a 21% to 39%) and self-consumption rate (from 34% to 62%). Real-time prices in the local market reflect the availability of solar energy in the community and increase when little local supply is available, thus providing a monetary incentive for shifting consumption to periods in which local solar energy is available.

Overall, the developed decentral solution has proven to work in a stable and reliable manner in the field prototype. However, certified off-the shelf hardware is required for a reliable and energy-efficient operation and for a reliable implementation on a larger scale. Given the complexity involved, centralized solutions should also be considered as a potential alternative approach. While the prototype implementation in Walenstadt proved the technical feasibility of a blockchain-based P2P market, it revealed technical challenges due to the immaturity of the blockchain ecosystem and related scalability and privacy concerns. As independence from a central mediator is likely not a major concern in the Swiss energy market, the operation of a P2P market on a centralized server infrastructure by a grid operator or utility provider seems like a viable option – in particular given the technical hurdles arising from the nascent status of blockchain technology and relevant technical know-how. Beyond that, however, the project emphasized the importance of high granular energy data on household level, not only for implementing P2P markets, but, more generally, for optimizing the use of renewable resources and visualizing consumption patterns for users. Herein, the (mandatory planned) smart meter rollout together with reliable communication infrastructure for the metered energy data is crucial.

The project participants have received the project very positively. Despite the complex underlying market mechanisms, the majority of participants have interacted with the Quartierstrom user interface (web application) on a regular basis and have actively participated in the pricing by adjusting their buying/selling price limits. The real-world bidding data thus collected represent a unique dataset of price preferences in a local energy market. Nevertheless, in the long run, P2P energy markets need to provide solutions with a higher degree of automation.

A key barrier for the rapid success and scalability of P2P energy markets clearly is the current regulatory framework, which does not accommodate P2P energy markets operating over public networks. A fast setup of a sandbox policy framework, legislative progress, and regulatory certainty are vital for scalable and sustainable business models such as the those proposed to emerge.

Many members of the consortium and additional partners have contributed to the project with valuable input, from the inception of the project to its completion. In hindsight, two factors were particularly vital to the success of the project:
A) The interdisciplinary composition, good team spirit, creativity, and relentless joint efforts of the team that jointly developed and implemented the technical infrastructure, privacy evaluation, market design, and user interface, and
B) The excellent collaboration with an innovative and extremely supportive main implementation partner, the EW Walenstadt (Christian Dürr in particular).

5.2 Key project results

Technical implementation (modules hardware, software, blockchain, battery control)

- The Quartierstrom project has successfully implemented Switzerland's first blockchain-based P2P energy market. The technical implementation and design of the system represents pioneering work and demonstrates the technical feasibility of a P2P energy market using modern smart metering and communication infrastructure.
- As no suitable off-the shelf hardware solution could be identified for hosting the Quartierstrom system, the team realized a self-developed prototypical hardware solution. It consisted of smart meters with an integrated single board computer that were installed in addition to the existing metering infrastructure.
- Blockchain selection: Four key requirements were defined (energy consumption, bandwidth, consensus, low-cost hardware); after thorough evaluation of various protocols, the Tendermint consensus protocol was selected for the project implementation.
- The blockchain system hosting the Quartierstrom system proved to be stable.
- Despite the advanced existing metering infrastructure in Walenstadt, substantial efforts were necessary to ensure data provision and maintain stable communication among the smart meters deployed. Overall, the level of effort required for on-site maintenance was considerably higher than anticipated.
- The energy consumption of the blockchain implemented for this project is considerably smaller than the energy consumption of public blockchains. The energy consumption of a permissioned Tendermint blockchain running on new smart meters is not expected to differ significantly from the energy consumption of a centralized solution.
- Still, given the complexity involved in blockchain-based peer-to-peer markets, centralized solutions may be a good alternative in environments where participants have sufficient trust in the operator.
- Privacy aspects of decentralized P2P markets have been investigated and potential solutions have been proposed that might outperform current centralized solutions in their ability to protect personal data.
- A control system for a community battery was implemented that prioritizes inter-community energy flows and reduces exports from the community (technical proof-of-concept). A 37-kWh battery was connected to the Quartierstrom system and an agent of the battery system was developed to control its charging or discharging rates based on the availability of energy in the community.
- The community battery controller produced a noticeable shift in the charging pattern: It increased the overlap of battery charging cycles and community exports by distributing the charging cycles of the battery over time, which increases the self-consumption and self-sufficiency rate of the community.

Market design

- A double auction with discriminative pricing was identified as the most suitable market mechanism for the Quartierstrom market.
- An auction was run to clear the market every 15 minutes based on the bids sent by the participants' smart meters. They contained the price limits set by the households as well as the electricity consumption and production measured smart meters.
- The time-discrete, discriminative double auction was cleared 35,000 times during this time, of which all resulting transactions were stored on the blockchain system.
- Local energy trading almost doubled the community's self-sufficiency rate (from 21% to 39%) and self-consumption rate (from 34% to 62%).
- Real-time prices in the local market reflect the availability of solar energy in the community and increase when little local supply is available. It thus provides a monetary incentive for shifting consumption to periods in which local solar energy is available.
- A local voltage-dependent grid tariff has been proposed and evaluated that adds a penalty or reward to the standard grid tariff in periods of particular low and high voltage, respectively. A simulation explored the price effects of the local-dependent grid tariff, when a battery is used for load balancing.

User behavior

- Overall, the participants have received the project very positively. Despite the complex underlying market mechanisms, the majority of participants have interacted with the Quartierstrom user interface on a regular basis and have actively participated in the pricing by adjusting their buying/selling price limits. Nevertheless, P2P energy markets need to provide solutions with a higher degree of automation.
- Participants' self-reported willingness to pay a price premium for local energy is not reflected in their actual price bids on the web portal, which were substantially lower. The real-world bidding behavior observed and the price preferences thus elicited are unique and valuable.
- The P2P energy market was well received among its users, indicated by comparably high and stable usage activity of the web application throughout the year, although activity in the first quarter of the active field phase was highest.
- An alternative market mechanism was tested with automated, uniform pricing. About half of the participants preferred the system that allow them to set their own price limits and thus to participate actively in the pricing of P2P energy after the mini-experiment in April, whereas the other half preferred automated pricing. However, after the end of the one-year field, a majority of participants stated that they preferred an automatic pricing mechanism.

Regulatory aspects and business model

- The current legislation in Switzerland does not allow self-consumption communities spanning across non-adjacent plots of land using the public grid infrastructure. While this legislation is still more progressive than currently in the EU. The Clean Energy Package Directive 2018/2001 mandates European countries to grant a stronger role to end-consumers and prosumers within the next 2-3 years, which may result in a more open regulation for energy communities in EU countries.
- A fast setup of a sandbox policy framework, legislative progress, and regulatory certainty are vital for scalable and sustainable business models to emerge.

Communication

- 4 press releases and 39 blogposts have been published from May 2018 to Feb. 2020
- The website quartier-strom.ch attracted 400-600 monthly visitors on average.
- At least 246 media publications on the project have appeared in various media outlets across the world, including TV broadcasts on SRF and CNN Money, a cover story in Blick (“Hier ist jeder Bewohner ein Strombaron”), and an article on the blog of the World Economic Forum.

6 Outlook

Lead authors: Verena Tiefenbeck and Anselma Wörner, ETH

The Quartierstrom provides a proof-of-concept for the feasibility of a P2P energy market using modern smart metering and communication infrastructure. The results indicate that local energy markets could serve as a valuable vehicle for the integration of decentral renewable energy sources and the project has been received very positively not only among the participants, but also among, practitioners, academic researchers, and the general public. The flagship project was covered in the Swiss and international media (e.g., in SRF aktuell, CNN Money Switzerland, World Economic Forum Blog, interview in SRF Kassensturz), and resulted in several invited talks for members of the project consortium (e.g., Crypto Valley Conference, Event Horizon, please see Chapters 7 and 8 for references on the (inter)national exchange and media coverage).

At the same time, the prototypical installation developed in relatively short time and tested with 37 participating households is only a first step for creating P2P energy markets at scale. For reaping their full potential, much remains to be done on various fronts. This includes the identification of a suitable governance structure of a potential large-scale solution, further refinement of the described business model, as well as adjustment to the proposed technical solution. More specifically, it is necessary to implement a fully-fledged self-sovereign identity solution for managing identities and data from smart meters and customers, while at the same time ensuring a high level of data security and privacy. Furthermore, as the transition from PoW to PoS on many public blockchains is still in its early stages, an in-depth evaluation of “layer 2” solutions like the lightning network should be considered carefully. Mainly, as they manage to harness the benefits from both worlds, public and private blockchains, while mitigating the downsides. In case of a centralized infrastructure, appropriate smart metering devices and communication infrastructure still also needs to be tested on the larger scale, as the communication infrastructure in the Quartierstrom project was not representative for most distribution grids. Beyond that, the generalizability of the findings on user behavior needs to be re-evaluated with a larger and more diverse sample of participants, including a larger share of consumers, for instance. Furthermore, while the project has implemented and analyzed a first prototype of a battery controlled by the availability of local electricity at the community level, it would be interesting to include a larger number of flexible loads (batteries, heat pumps, electric vehicles etc.) and to empirically evaluate their impact on diverse parameters including price, SCR, and SSR. To actually unlock the potential of those flexible loads, it is necessary to develop and to empirically assess smart algorithms that control those loads in line with the individual households’ preferences regarding flexibility, risk, cost, etc. To that end, it is not only necessary to better understand the variance in these preferences (both between households, but also over time), but at the same time to develop and evaluate different market mechanisms and strategies to ensure that diverse preferences can be elicited, updated, and be reflected in the design of the intelligent algorithms.

The current regulatory framework does not accommodate P2P energy markets operating over public networks. The fast creation of a sandbox policy framework, legislative progress, and regulatory certainty are vital to foster innovation and for scalable and sustainable business models such as those proposed to emerge. From a technical point of view, for any rollout at larger scale, it is necessary to develop a system that relies on certified and reliable hardware solutions. More advanced control algorithms to integrate flexible loads like storage systems, heat pumps, water heaters, or electric vehicles need to be developed and tested in real-world applications. Furthermore, future projects need to identify strategies to accommodate the needs of a broader spectrum of participants. In particular, it will be crucial to develop solutions that strike a good balance between active user involvement and a higher degree of automation. Future work should also assess the acceptance and impact of different incentive schemes for maximizing local self-sufficiency and self-consumption or for fostering grid-friendly behavior in real-world applications and evaluate the impact of a growing number of P2P communities on the macro-level.

7 National and international cooperation

7.1 National exchange and collaborations

7.1.1 National exchange with industry

The Quartierstrom project enjoyed considerable attention, both nationally and internationally, from the industry and led to numerous exchanges with utilities and service providers from both the energy and financial industry. At the national level, formal and informal meetings were held with the following companies:

- Repower: Exchange concerning Smart Power device (Arne Meeuw, Sandro Schopfer, Gian Carle, Markus Herger), June 2019
- Postfinance & EWB (utility provider of the city of Bern)
  - Meeting regarding business models (Fabian Bärlocher und Gian Carle), July 2019
  - Meeting regarding project updates (Fabian Bärlocher, Gian Carle, Matthias Egli), July 2019
  - Meeting regarding technological approaches (Matthias Egli, Alain Brenzikofer), Sept. 2018
- Goldstörm: Industry exchange with commercial provider of solar systems (Nick Beglinger)
- Smart Energy Link: Mutual exchange (Sabine Proll, SCS)

In addition, members of the consortium have (re)presented the project at the following events and workshops to third parties:

- Science Brunch (Sandro Schopfer), Zurich, June 2018
- Elcom-Forum (Gian Carle, Alain Brenzikofer), July 2018
- Swiss Green Economy Symposium (Liliane Ableitner, Anselma Wörner, Christian Dürr), Winterthur, September 2018
- Data Service Alliance (Alain Brenzikofer), September 2018
- DSV Forum (Sandro Schopfer), Olten, November 2018
- Alpenforce (Gian Carle), Disentis, January 2019
- VTE/ESA Tagung (Christian Dürr), Altstätten/Weinfelden, March 2019
- Nationale PV-Tagung (Arne Meeuw), Berne, March 2019
- Electrosuisse Netzimpuls (Alain Brenzikofer), Aarau, March 2019
- Energy-Network-Lunch by SCS, Zurich, March 2019
- Die Blockchain-Initiative Energie+ im edna (Gian Carle), Mannheim, März 2019
- Strommarkttreffen (Gian Carle, Alain Brenzikofer), Basel, April 2019
- HSLU's CAS on Blockchain, lecturing on Blockchain & Energy (on 5 occasions, 2017-2019)
- Energy Blockchain Talks (Alain Brenzikofer), Zurich, March 2019
- Vereon Innovationsforum (Alain Brenzikofer, Christian Dürr), Zurich, April 2019
- Strommarkttreffen (Gian Carle, Alain Brenzikofer), Basel, April 2019
- Swiss Green Power Trader meeting (Gian Carle), Bern, April 2019

- EnergyCom (Christian Dürr), May 2019
- IEA Task IPVS Montreux (Sandro Schopfer), Montreux, April 2019
- ReMaP Launch Event (Christian Dürr), Zurich, June 2019
- Crypto Valley Conference on Blockchain Technologies (Anselma Wörner & Arne Meeuw), Zug, June 2019
- Betriebsleiter-Tagung (Sandro Schopfer, Gian Carle), Brunnen, September 2019
- St. Gallen Technology Forum (Anselma Wörner), Lenzerheide, September 2019
- Swissmig Fachtagung «Blockchain im Energiebereich» (Alain Brenzikofer), November 2019
- The Selber team of developers looking to deploy the Quartierstrom pilot, initiated discussions for follow-on projects with a large Swiss bank as well as a Swiss utility as cooperation partner for an additional pilot project.
- The startup Exnaton is building on the learnings from the Quartierstrom project to create a software solution for utility providers to enable P2P energy trading
- Preliminary cooperation discussions with a smart meter manufacturer (Liliane Ableitner, Arne Meeuw)

7.1.2 National exchange with academia

- University of Geneva (Dr. Ulf Hahnel and Dr. David Parra Mendoza): regular meetings and discussions on user behavior and peer-to-peer markets (Verena Tiefenbeck)
- University of Applied Sciences and Arts of Southern Switzerland (Dr. Roman Rudel, Institute for Applied Sustainability to the Built Environment; Davide Rivolta, Institute for Applied Sustainability for the Built Environment): mutual update about projects, sale of grid in microgrid Lugaggia, learnings from previous projects, role of the user, type of market (Sandro Schopfer), increase of self-consumption rate in the community, discussion of results, expectations regarding future regulatory situation and Hive Power
- ZHAW (Michele Aggeler, Regina Betz): input for Master thesis on peer-to-peer markets using blockchain (Verena Tiefenbeck)
- Teaching blockchain and energy at HSLU's CAS course (Nick Beglinger, Cleantech21), exchange with attendees on their startup plans, the distributed energy efforts of their employers, etc.
- Presentation at ETH's Blockchain Summer School (BETH, by Nick Beglinger, 11/02/2019), exchange with Dr. Stefan Klauser, Prof. Dirk Helbling, as well as different attendees.

7.2 International exchange and collaborations

7.2.1 International exchange with industry

- Regular exchange with members of the Tendermint / cosmos / lotion-js team members regarding technical developments of the blockchain protocol, support and testing reports (Arne Meeuw)
- Exchange with Sonnen GmbH (Germany) regarding applications of blockchain for energy storage systems and especially re-dispatching (Sandro Schopfer)
- Presentation to different industry representative as part of the 'Sustainable Innovation Forum', held during COP24 (Nick Beglinger), Katowice, December 2019

- Exchange with PowerLedger (David Martin, Jemma Green, Vinod Tiwari and Nick Beglinger), a prominent Australia-based energy blockchain company, on legal developments, business models, and also cooperation options in Europe
- Exchange with the European Association of Smart Energy Manufacturers (ESMIG, Willem Strabing and Nick Beglinger), on EU regulatory developments, distributed energy revenue models, cooperation approaches with smart meter manufacturers, etc. Included presentation at 2 ESMIG yearly events - Brussels, 04/06/2018 & 20/03/2019
- Event Horizon 2018, The global Summit on Blockchain Technology in the Energy Sector (Nick Beglinger), Berlin, Germany, April 2018
- Sustainable Innovation Forum 2018 (Nick Beglinger), Katowice/COP24, December 2018
- World Web Forum (Timo Gessmann, Bosch IoT Lab), Zurich, January 2019
- „Deutsche Blockchain-Initiative Energie" (Gian Carle), Mannheim, Germany, April 2019
- Visit of the Austrian trading chamber (Gian Carle & Sandro Schopfer), Zurich, April, 2019
- IEA DSM DAY: Policy and Business Models for the Digital Customer centered Energy Transition (BFE) (Verena Tiefenbeck), Berne, April 2019
- Frühjahrstreffen der österr. Technologieplattformen Smart Grids und Photovoltaik (Sabine Proll), Innsbruck, Austria, May 2019
- ETG Kongress (Alain Brenzikofer), Stuttgart, May 2019
- Event Horizon 2019, The global Summit on Blockchain Technology in the Energy Sector (Sandro Schopfer, Alain Brenzikofer), Berlin, Germany, June 2019
- International Student Energy Summit 2019 (Nick Beglinger), London, June 2019
- Paper published at CIRED, Madrid, Spain, June 2019 (publication: Brenzikofer et al. 2019)
- Fachkongress Innovative Stromanwendungen im Wohnbau (Christian Dürr), Feldkirch, Austria, June 2019
- International Blockchain Forum (Alain Brenzikofer), Rotkreuz, February 2020
- Preliminary cooperation discussions with a large smart meter manufacturer (Nick Beglinger)

7.2.2 International exchange with academia

- Scientific exchange with researchers and industry representatives of 9 local energy market projects at the 2nd Digital Workshop on Local Energy Markets at the Karlsruhe Institute of Technology (Anselma Wörner, Verena Tiefenbeck) and publication of a joint overview paper on local electricity markets in the DACH+ region published at the ACM e-Energy Workshop on Market Engineering (publication: Weinhardt et al. 2019)
- Regular scientific exchange with Dr. Ulf Hahnel, Dr. David Parra, and Alejandro Pena-Bello from the University of Geneva. Alejandro Pena-Bello came for a 3-month research visit to the Bits to Energy Lab in March 2020 (suspended due to the corona situation)
- Regular scientific exchange with Prof. Wolf Ketter, professor of Information Systems at the University of Cologne and director of the Institute of Energy Economics at the University of Cologne (EWI) and the Erasmus Centre for Future Energy Business at the Rotterdam School of Management, Erasmus University, Rotterdam, the Netherlands regarding peer-to-peer trading platforms (Anselma Wörner, Verena Tiefenbeck)

- Regular scientific exchange with Prof. Inês Azevedo, professor of Energy Resources Engineering at Stanford University regarding bidding behavior in P2P markets and generalizability aspects (Anselma Wörner, Verena Tiefenbeck)
- Scientific exchange with researchers at the Cologne International Energy Summer School (Anselma Wörner, June 2019)
- Presentation at the Research Colloquium of the Institute of Energy Economics, University of Cologne (Verena Tiefenbeck and Anselma Wörner, May 2019)
- Presentation of the paper (Ableitner et al. 2018) at 4h European Conference on Behaviour and Energy Efficiency (BEHAVE 2020), Zurich (Liliane Ableitner, Sept. 2018)
- Presentation at the 8th DACH+ Conference on Energy Informatics, Salzburg, Austria (Anselma Wörner, Sept. 2019)
- Presentation at the International Conference on Information Systems, Munich, Germany (Dec. 2019, Verena Tiefenbeck)
- Presentation at the ISDEB Workshop at the Conference "Wirtschaftsinformatik", Potsdam, Germany (March 2020, Verena Tiefenbeck)

8 Communication

Lead authors: Irene Bättig and Christa Rosatzin, Sprachwerk

8.1 Project website

The website quartier-strom.ch gives extensive insights into the project, in German and English. It provides real-time information on production, consumption, self-consumption and self-sufficiency of the community. The News section (in German only) provides background information on various topics, ranging from the local market and the web portal to blockchain technology. Monthly reviews put the numbers of production and consumption into context and user portraits show the people involved and their motivation to participate in the project. 39 blogposts were published between May 2018 and February 2020. These were also shared on LinkedIn, where Quartierstrom gathers 213 followers.

An average of 400 to 600 people visited the website every month between the official start and the official end of the project. Roughly 20 % were returning visitors and 80 % new visitors. The press release published in February 2020, informing on the results of the project, received great attention and let the number of visitors and visits soar considerably.

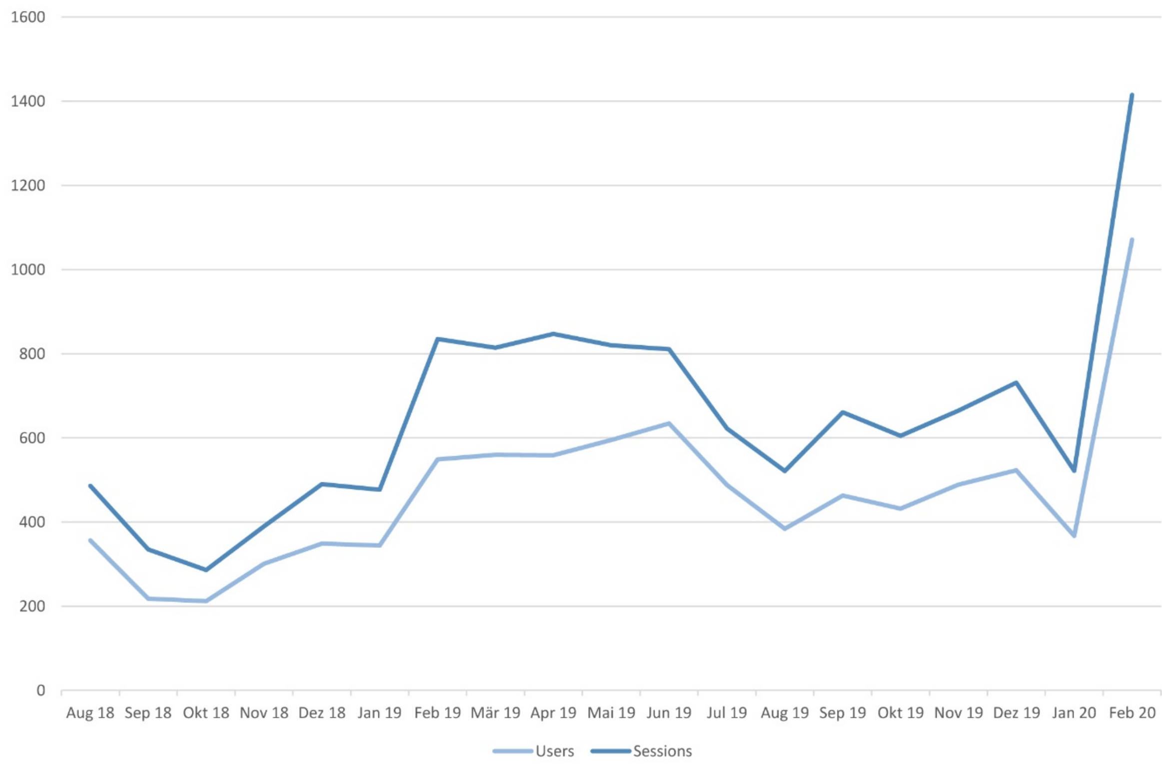

Figure 19: Evolution of monthly website visits

8.2 Press releases and newsletters

Four press releases were sent out to raise attention to the project. The first was published in July 2018 to inform the public on the project in general. In February 2019, the second release announced the official start. The third release was published in July 2019 to show the milestones and the development of production and consumption in the first half year of the project. And the fourth release informed on the results and further proceedings.

The number of publications is high. Especially the English version of the fourth press release found great attention and was published 191 times, mostly in the United States, but also in the United Kingdom, Canada, Spain, Germany, France, Portugal, Nigeria, Romania, India and Singapore.

Four newsletters were sent out, at the same time as the press releases, to 250 subscribers who have all opted in by themselves.

8.3 Media coverage and non-academic publications

8.3.1 Publications written by Sprachwerk

- April 2019, „Quartierstrom“ – eine Schweizer Premiere, Bulletin
- März 2019, Verhandlungssache Strompreis, HK Gebäudetechnik
- November 2018, Lokal handeln, Faktor „Eigenstrom“, Themenheft Nr. 49, Faktor Verlag
- November 2018, Strom vom Dach der Nachbarn, Schweizer Energiefachbuch 2019
- August 2018, Strom vom Dach der Nachbarn, Energeia plus

8.3.2 Media coverage based on press releases or journalistic research

Overall, at least 246 media publications have appeared in media outlets across the world:

- 197 publications in English (US media if not stated otherwise)
- 42 publications in German (7 of which in German media; 1 in Liechtenstein)
- 6 TV/video features
- 1 publication in Italian

The detailed list of publications in the media is avaible in Appendix Section 11.6 and on the project website https://quartier-strom.ch/index.php/homepages/fur-medien-2/ (on the website, links to the individual articles are also available).

8.4 Public perception of the project

The project was positively received by the media and the public. As a flagship project, Quartierstrom included many aspects that were of great interest for a broad public, in particular the local electricity market, the new role of prosumers as “electricity traders”, the benefits of local energy markets for the energy transition and the changing role of energy suppliers. The energy industry was initially rather sceptical about the project, but developed great interest in the course of the project and sees potential in its development. Neighbourhood electricity also triggered controversial discussions in specialist circles, especially concerning the regulatory framework for local neighborhood electricity markets. These aspects were included in the discussion on the revision of the Energy Legislation. Due to its high societal relevance, the flagship project was further covered extensively in the Swiss and international media (e.g., in SRF aktuell, CNN Money Switzerland, World Economic Forum Blog, interview in SRF Kassensturz), and resulted in several invited talks for members of the project consortium (e.g., Crypto Valley Conference, Event Horizon) as described above.

9 Academic publications

9.1 Peer reviewed academic outlets

Peer-reviewed journal articles published

- Ableitner, L., Tiefenbeck, V., Meeuw, A., Wörner, A., Fleisch, E., Wortmann, F. (2020). User Behavior in a Real-World Peer-to-Peer Electricity Market. Applied Energy.
- Meeuw, A., Schopfer, S., Wörner, A., Ableitner, L., Tiefenbeck, V., Fleisch, E., Wortmann, F. (2020), Implementing a blockchain-based local energy market: Insights on communication and scalability. Computer Communications.
- Wörner, A., Meeuw, A., Ableitner, L., Wortmann, F., Tiefenbeck, V. (2019a), Trading Solar Energy within the Neighborhood: Field Implementation of a Blockchain-Based Electricity Market. Energy Informatics *2*(1), 11.

Conference proceedings published

- Brenzikofer, A., Meeuw, A., Schopfer, S., Wörner, A., Dürr, C. (2019), Quartierstrom: A decentralized local P2P energy market pilot on a self-governed blockchain. 25th International Conference on Electricity Distribution (CIRED, June, 2019)
- Weinhardt, C., Mengelkamp, E., Cramer, W., Hambridge, S., Hobert, A., Kremers, E., Otter, W., Pinson, P., Tiefenbeck, V., Zade, M., (2019), *How far along are Local Energy Markets in the DACH+ Region? A Comparative Market Engineering Approach*. Proceedings of 2019 ACM e-Energy Workshop on Market Engineering (2019 e-Energy EME Workshop), New York, USA.
- Wörner, A., Meeuw, A., Ableitner, L., Tiefenbeck, V. (2019b) “Peer-to-Peer Energy Trading in the Real World: Market Design and Evaluation of the User Value Proposition”. Proceeding of the International Conference on Information Systems (ICIS 2019)

9.2 Not peer-reviewed academic outlets and whitepapers

- Ableitner, L., Meeuw, A., Schopfer, S., Tiefenbeck, V., Wortmann, F., Wörner, A. (2019) Quartierstrom - Implementation of a Real World Prosumer Centric Local Energy Energy Market in Walenstadt, Switzerland. Whitepaper available on arXiv (http://arxiv.org/abs/1905.07242)
- Ableitner, L. (2019). Information Systems to Empower Individuals in Realizing the Energy Transition: Design, Engagement, and Impact. Dissertation, ETH Zurich
- Beglinger, N. (2018), A climate innovation perspective on the Fouth Industrial Revolution, whitepaper available at http://cleantech21.org/fileadmin/content/NBE/C21_WP_Climate4IRDigitalMRV_102018f.pdf
- Brenzikofer A., Melchior N. Privacy-Preserving P2P Energy Market on the Blockchain (2019), whitepaper available at https://arxiv.org/abs/1905.07940
- Brenzikofer, A., Meeuw, A., Schopfer, S., Wörner, A., Dürr, C. (2019), Quartierstrom: A decentralized local P2P energy market pilot on a self-governed blockchain. 25th International Conference on Electricity Distribution (CIRED, June, 2019)
- Meeuw, A. (2019), Design, Implementation, and Evaluation of a Blockchain-based Microgrid Platform - Enabling Local Energy Markets. Dissertation, University of St. Gallen
- Schopfer, S. (2019), Assessment of the consumer-prosumer transition and local peer to peer energy networks, Dissertation, ETH Zurich.
- Another doctoral thesis on the project (by Anselma Wörner) is still in progress.

Academic papers currently under review

Two more manuscripts are still in progress; one has been submitted to a peer-reviewed journal, the other one is being prepared for submission to another peer-reviewed journal.

- Ableitner, L., Tiefenbeck, V., Wörner, A., Fleisch, E., Designing a Peer-to-peer Energy Market from the User Perspective.
- Wörner, A., Ableitner, L., Meeuw, A., Fleisch, E., Wortmann, F., Azevedo, I., Tiefenbeck, V., Trading Behavior on a Peer-to-Peer Energy Market - a Field Study.

10 Other References

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., Peacock, A.: Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renewable and Sustainable Energy Reviews 100, 143–174 (2019)

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F. Blomand H. Farahmand, “On the Scalability of Blockchain-Supported Local Energy Markets,” in 2018 International Conference on Smart Energy Systems and Technologies (SEST), Sep. 2018, pp. 1–6.

Brenzikofer, A., Müller, F., Ketsetzis, A., Kienzle, F., Mangani, M., Eisenreich, M., Farhat, Y., Bacher, R. (2017). GridBox pilot project. Computer Science-Research and Development, 32(1-2), 79-92.

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R. Han, V. Gramoli, and X. Xu, “Evaluating Blockchains for IoT,” in 2018 9th IFIP International Conference on New Technologies, Mobility and Security (NTMS), Feb. 2018, pp. 1–5.

Laszka, A., Dubey, A., Walker, M., and Schmidt, D. (2017). Providing Privacy, Safety,and Security in IoT-Based Transactive Energy Systems using Distributed Ledgers.In-ternational Conference on the Internet of Things (IoT).

Loock, M., Reuter, E., & von der Tann, C. (2016). Ideal-type business models in local smart grids.

Mazzola, L., Denzler, A., Ramon, C. (2020) "Towards Peer-to-Peer Energy Market: an Overview." arXiv preprint arXiv:2003.07940

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Morstyn, T., Farrell, N., Darby, S. J., & McCulloch, M. D. (2018). Using peer-to-peer energy- trading platforms to incentivize prosumers to form federated power plants. Nature Energy, 3, 94–101.

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Reuter, E., and Loock, M. 2017. “Empowering Local Electricity Markets : A Survey Study from Switzerland, Norway, Spain and Germany,” Institute for Economy and the Environment, University of St. Gallen. (https://www.alexandria.unisg.ch/252125/).

Schopfer, S. (2019). Assessment of the consumer-prosumer transition and peer-to-peer energy networks (Doctoral dissertation, ETH Zurich).

Stocker, N., Ulbig, A., & Toffanin, D. (2018). Results of the Sologrid Pilot Project–Decentralized Load Management to Increase the Efficiency of Local Energy Communities.

11 Appendix

11.1 Local Voltage-Dependent Grid Tariff

Authors: *Sabine Proll, Alain Brenzikofer, Supercomputing Systems AG*

Motivation

If several power plants feed into the distribution grid at the same time with little consumption, the grid can get congested and undesirable overvoltages can occur. On the other hand, many electric vehicles that charge with high power during the same time of day can cause congestion and undervoltages. As shown in Brenzikofer et al. (2017) and Stocker et al. (2018), voltage deviations can be mitigated by shifting flexible load and generation in time. Electric boilers and other flexible loads can draw power when the sun shines. Grid-attached batteries can soften both consumption and production peaks. However, one may not assume that improving the power balance in a community automatically improves voltage stability in any case, as shown in Figure 20**Error! Reference source not found.**. A battery system A installed on branch A may choose to charge because there is a lot of cheap PV energy produced on branch B, potentially causing an undervoltage on branch B while not improving the overvoltage on branch A by much. A pure energy market neglecting grid topology would risk to put additional strain on the grid.

The proposed local voltage-dependent grid tariff (short: LVD tariff) factors voltage stability into the market prices to incentivize grid-stabilizing behavior and improve profitability of well-placed storage systems. Our tariff design rewards battery B for charging while it puts a penalty on battery A for doing so.

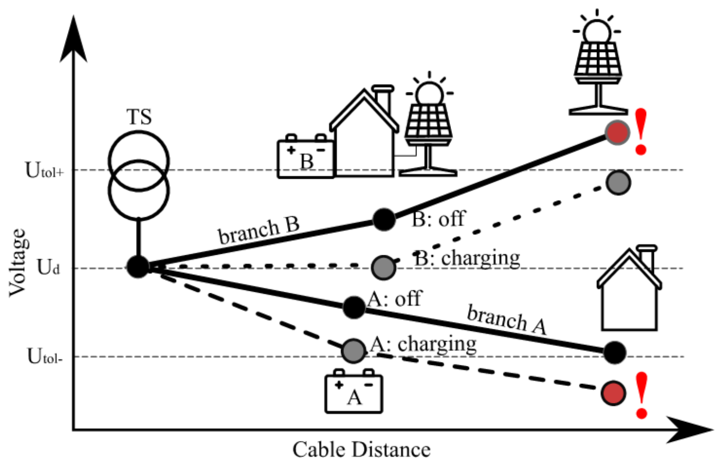

Figure 20: Voltages on different branches

Price Composition

In Quartierstrom, a consumer pays a price that is calculated as

grid tariff + trading price

The trading price is explained in detail in section 4.3.1.2. The grid tariff depends on the origin of the consumed energy:

Origin	Grid Tariff
same household	0 Rp/kWh
same Quartier	5.79 Rp/kWh
from utility (WEW)	13.03 Rp/kWh

On top of this, here we evaluate a dynamic grid tariff that depends on the local voltage. The idea is to keep the trading price as it is and only change the grid tariff. For the evaluation we focus solely on the grid tariff and neglect the trading price for energy.

Underlying Data

The plots used to explain and evaluate the LVD tariff are obtained from the actual measurements during the field test.

- Household
  All plots and calculations are based on one measurement point belonging to a household with a PV plant. The node was chosen because it has periods where energy is injected into the grid and periods where energy is consumed from the grid, varying throughout the day.
- Day
  For the day-specific analysis Wednesday, October 23rd 2019 was chosen. The day has an interesting profile, because it is mid-season, with cloudy and sunny phases. It is a normal weekday; therefore, the consumption is assumed to be representative.
- Phase
  The detailed analysis of one day is done for phase L1. For the cost-analysis of a whole month and the whole year, the costs for all 3 phases were summed up.
- Time-base
  Measurements were available with a resolution of 5 minutes. For simplicity, we assume that the grid tariff and the resulting costs are also calculated every 5 minutes.

Calculation of the LVD Tariff

In the LVD tariff every phase of every measurement point has its own tariff. The tariff depends on the Histogram of the voltages (in a 5-minute resolution) that were measured at the same measurement point and the same phase on the day before. The upper and lower 5% and 1% percentiles are calculated where a change in tariff occurs according to **Error! Reference source not found.**. To calculate the LVD tariff, the current voltage is compared to the histogram. If it is within the normal range of the histogram, the standard tariff of 9.65 Rp/kWh is used. When the voltage is beyond the 5% percentiles, a penalty or reward is added to the tariff. We chose a linear curve that ends at a maximum penalty/reward of 50Rp/kWh at the 1% percentiles. The penalty is charged when the voltage is low (to incentivize less consumption) and the reward is given when voltage is high (to incentivize consumption). The standard tariff was chosen to be 9.65 Rp/kWh because this is the overall average for the grid tariff, that was payed during the Quartierstrom field test.

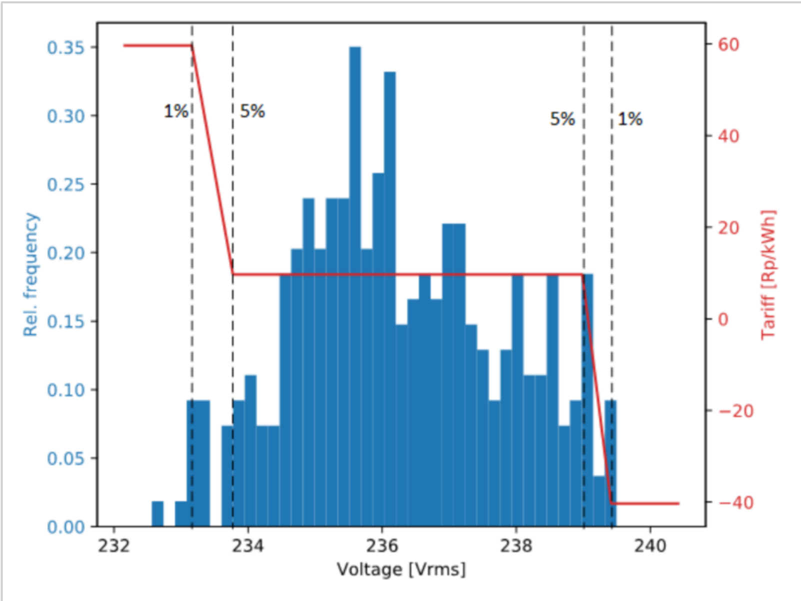

Figure 21: Calculation of LVD tariff for phase L1 of one measurement points on October 23rd 2019

Analysis for One Day

Below we explore the resulting LVD tariff for phase L1 of one measurement point, throughout one day. The plots show how the actual costs for the grid usage vary throughout the day for the tariff. We compare the LVD tariff to two constant grid tariffs at 5.79 Rp/kWh and 13.03 Rp/kWh, which provide a lower and upper bound for the actual grid tariff applied in Quartierstrom:

- Plot 1: Voltage measurement for phase L1
  The voltage determines in which percentile of the above histogram we are and therefore determines the LVD tariff of that moment.
- Plot 2: Resulting grid tariff
  - blue: LVD tariff
  - yellow: fix tariff at 5.79 Rp
  - green: fix tariff at 13.03 Rp
- Plot 3: Power demand for phase L1.
  To calculate the cost, the power demand is multiplied with the corresponding tariff of that moment. Negative demand (when power is injected to the grid) results in 0 cost here.
- Plot 4: Resulting costs per 5min (kWh x tariff)

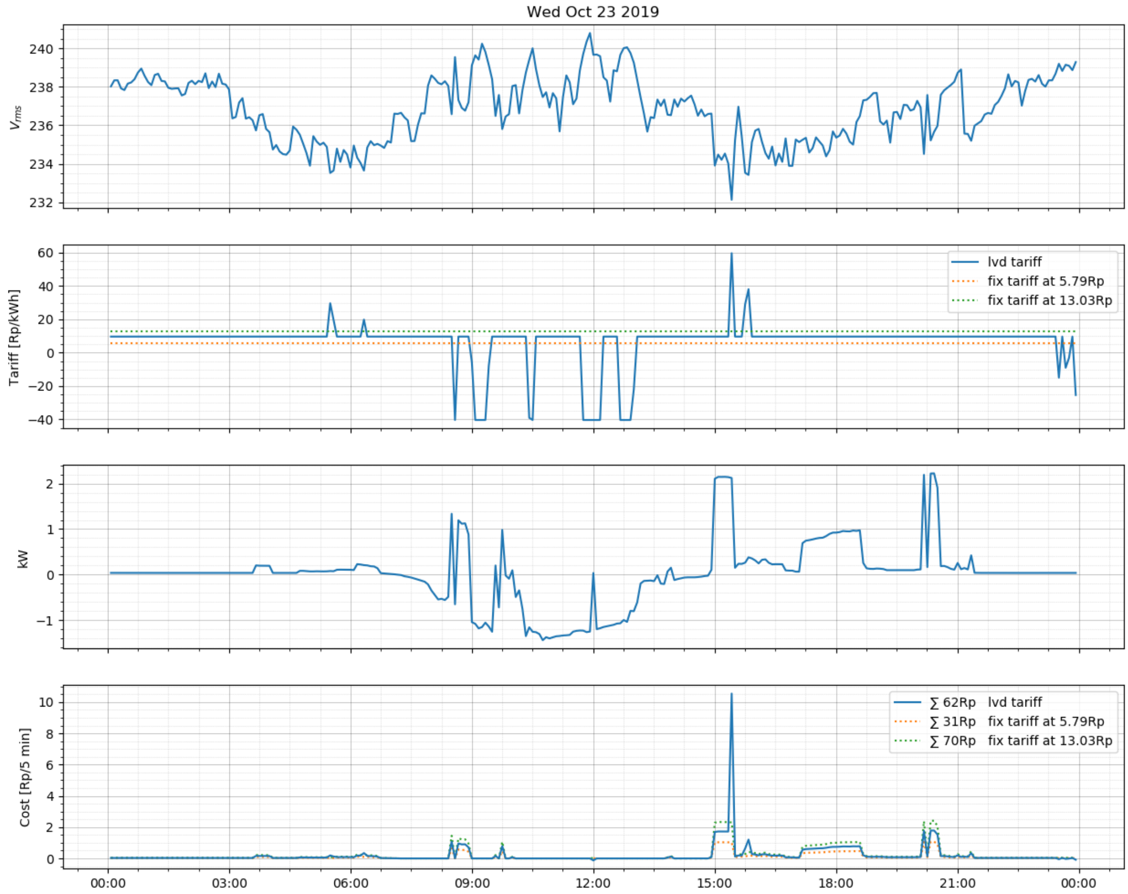

Figure 22: Cost calculation for one day

One can see that between 8:00-13:00 there are several voltage peaks resulting in a negative LVD tariff. On the other hand, there are two voltage drops after 15:00, resulting in a high LVD tariff. This is exactly what we aim for with the LVD tariff: We want to incentivize grid-stabilizing behavior within a short time-frame. The last plot shows how the costs of the LVD tariff relate to fix tariffs of 5.79 Rp/kWh and 13.03 Rp/kWh.

Analysis for One Day - with Battery Simulation

The LVD tariff is supposed to incentivize grid stabilizing behavior in the grid. This could be achieved by installing a battery that charges during voltage peaks and injects power during voltage drops. With this simulation we show the effects that such a battery would have on the costs, given the LVD tariff.

Behavior of Battery Simulation

We assume that charging and discharging of the battery follows the LVD tariff curve. Depending on the percentile we are in, we charge/discharge the battery: with a peak power of 1kW (for one phase):

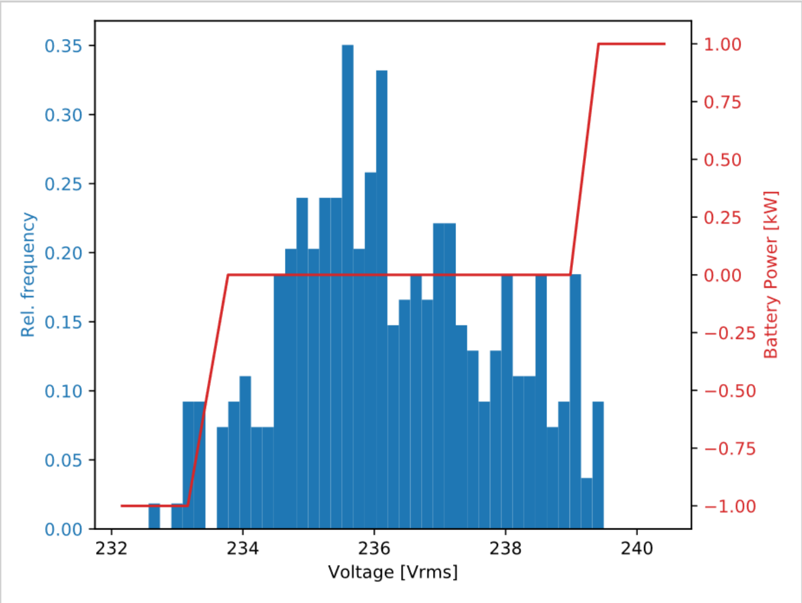

Figure 23: Battery charging/discharging for simulation

The battery's state of charge is ignored, as it is assumed that typically charging and discharging balances each other out due to the rules of the LVD tariff. Furthermore, the (desired) effects on the local grid voltage are not simulated.

Analysis

The following plots show the same data, as for the "Analysis for One Day", but extended by simulated data in red.

- Plot 3, in red: simulated consumption = actual consumption + simulated battery power
- Plot 4 in red: costs for simulated consumption under LVD tariff = simulated kWh x LVD tariff

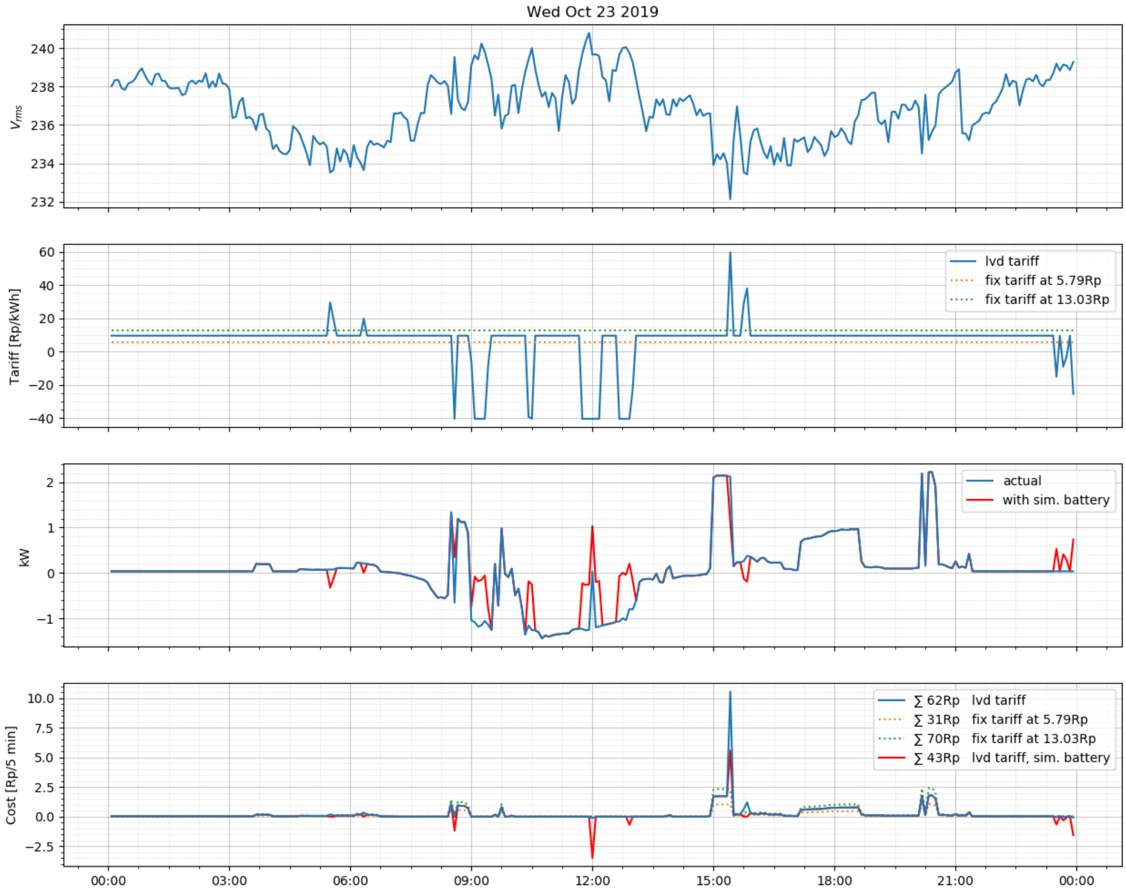

Figure 24: Cost calculation with simulated battery

As can be seen in Figure 23, the battery charges when the tariff is low and injects power when the tariff is high, which corresponds to periods of high and low voltages. So, the battery makes the desired contributions to the grid stability. Figure 24 shows that this has a positive effect on the costs. For this particular day, the usage of a grid-stabilizing battery would result in savings of 19 Rp for phase L1.

Potential of Cost Savings for Load-Balancing

We calculated the overall savings that can be achieved in the above household if a battery would be installed and controlled to follow the LVD tariff. For this, the same battery simulation as above is used. The costs for all 3 phases are calculated and summed up.

The plots show 4 curves

Curve	Underlying consumption	Tariff
blue	actual consumption	LVD tariff
yellow	actual consumption	fix tariff of 5.79 Rp
green	actual consumption	fix tariff of 13.03 Rp
red	actual consumption + simulated battery	LVD tariff

Cost Comparison for October 2019

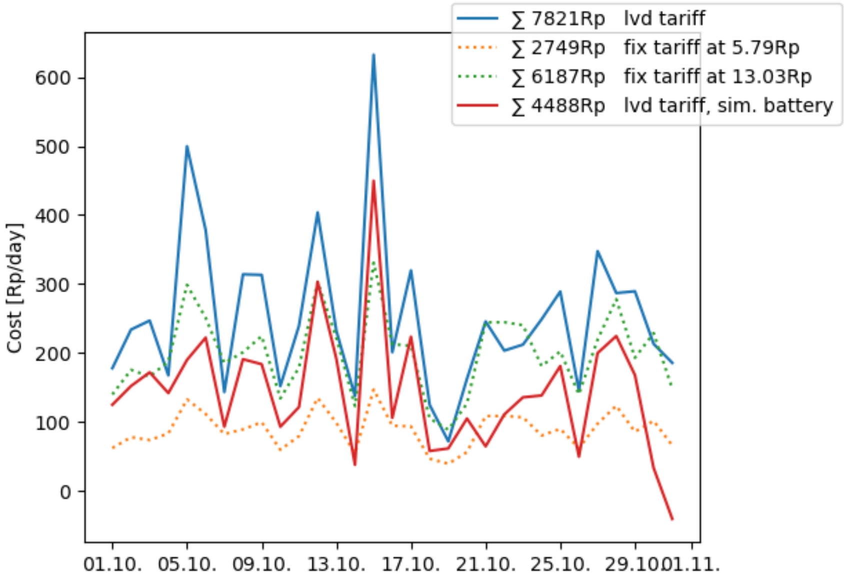

Figure 25: Total grid tariff costs October 2019

As Figure 25 shows: Assuming we had the LVD tariff in place, this household could have saved 33 CHF for the month of October if they'd had a load-balancing battery.

Cost Comparison for March-December 2019

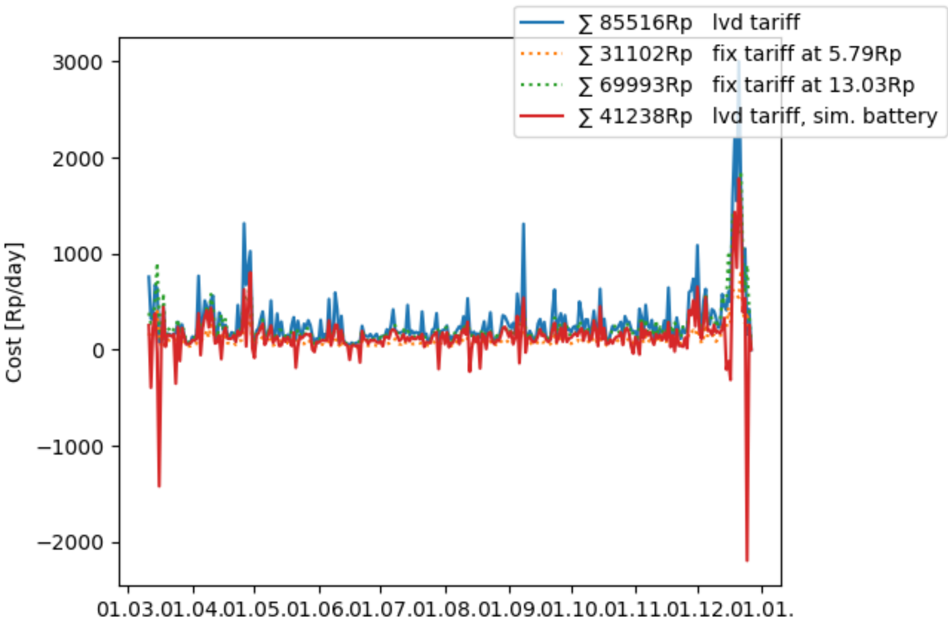

Figure 26: Total grid tariff costs 2019

When applied to almost the whole year of the Quartierstrom field test, savings with a battery would have been at 423 CHF. (There was no data available for January and February)

Remark: There is one big outlier on December 25th. The tariff on this day is extremely low, because the voltage was much higher, than the day before. To mitigate these outliers, one could try to make better predictions on the voltage distribution of the day (e. g. by taking holidays and weekday/weekends into account).

Further Remarks

- Installation costs for load-balancing devices
  Installation costs can be financed by the savings made, when the LVD tariff is applied. The savings are financed by those who do not contribute to load-balance and/or by the grid operator, as these households contribute to the voltage stability.
- As the tariff is per phase it incentivizes
  - rewiring to correct imbalances
  - taking specific measures for single-phase prosumers
- Solidarity
  - The following measures contribute to a fair price for all:
    - The tariff depends on the voltages of the same node of the day before. Thereby it is almost independent of the grid topology: if voltage is usually low at my node, my tariff will take this into account.
    - The tariff only rewards/penalizes when the voltage is outside the 5% percent percentiles. If the reference day is similar to the current day the price should only fluctuate at 10% of the time.

Future Research

It is hard to predict the effects of the proposed LVD tariff in the real world. The results give a good idea on the savings one sole participant will get when installing a load-balancing battery. The effects on the savings, when a high percentage of households have a load-balancing device, are unclear however. One can imagine the resulting tariff to be stricter and therefore make it harder to achieve high savings. On the other hand, when many households participate in load-balancing, the grid operator could use these as load-balancers for the higher-level grid. In this case the LVD tariff would ensure that theses households are rewarded and thereby implicitly be paid by their grid operator.

11.2 Aktuelle rechtliche Situation

Lead author: Andreas Abegg Gian Carle, Goran Seferovic ZHAW

Im Folgenden wird aufgezeigt, wie die rechtliche Seite in Bezug auf den Zusammenschluss zum Eigenverbrauch (ZEV) in der Schweiz und in der EU aussieht.

Rechtliche Aspekte in der Schweiz

Da nicht alle Gebäude im Quartierstrom-Projekt Parzelle an Parzelle liegen, wie das bei einem ZEV vorgeschrieben ist und das Verteilnetz von Wasser- und Elektrizitätswerk Walenstadt (WEW) genutzt wird, handelt es sich bei diesem Verbund nicht um einen ZEV nach geltendem Recht. Gleichwohl ist der unmittelbare Eigenverbrauch der einzelnen Teilnehmer ohne weiteres möglich (Art. 16 Abs. 1 Satz 1 EnG) und auch der Bezug von Elektrizität vom Netzbetreiber erfolgt nach den Grundlagen des Stromversorgungsrechts. Der innovative Aspekt des Projekts besteht nun aber darin, dass die Teilnehmenden überschüssige Energie nicht direkt dem Netzbetreiber veräussern, sondern in erster Linie im Quartierverbund handeln. Da dieser Handel aber über das Verteilnetz erfolgt, hat der Bezug nach Stromversorgungsrecht zu erfolgen und damit Netznutzungstarife für alle Netzebenen zu enthalten (Art. 16 StromVV). Da dies die Kosten des im Quartier gehandelten Stroms erhöht, «verfälscht» ein solches Netznutzungsentgelt die mögliche Wirtschaftlichkeit eines ZEV über ein Quartier hinweg, was die Verallgemeinerung der Erkenntnisse verhindern würde. Um diesem Problem zu begegnen, haben sich die Projektbetreiber in Abstimmung mit dem BFE dazu entschlossen, diese Netznutzungsentgelte zwar zu entrichten, die Kosten den Teilnehmern daraufhin aber aus den Projektgeldern zu erstatten.

Ein solch lokaler Verbund über das Verteilnetz hinweg stellt ausserdem ein Problem im Hinblick auf den diskriminierungsfreien Zugang zum Verteilnetz dar, da die Quartierstrom-Teilnehmer den Strom günstiger vom Quartier beziehen können, was andere Haushalte aus einem anderen Quartier nicht dürfen. Zwar hat das Fachsekretariat der ElCom in einigen Fällen die Frage bejaht, ob der Netzbetreiber Endverbrauchern mit weniger als 100 MWh Verbrauch den Netzzugang auf vertraglicher Basis einräumen dürfen, doch hat ein solcher Zugang diskriminierungsfrei zu erfolgen (Art. 13 Abs. 1 StromVG). Im Projekt Quartierstrom wird nicht allen Teilnehmern der Netzzugang gewährt, was einen sachlichen Grund für die Ungleichbehandlung erfordert. Die Teilnahme an diesem Leuchtturmprojekt stellt einen solchen sachlichen Grund dar.

Zusammenschlüsse zum Eigenverbrauch nach geltendem Recht

Einführung und Umsetzung der Regelung zum Eigenverbrauch

Der Eigenverbrauch wurde 2014 gesetzlich ***verankert***[32] und 2016 einer Revision unterzogen. Er ist heute in Art. 15-18 EnG und Art. 14-18 EnV geregelt.[33] Gemäss Art. 16 Abs. 1 EnG dürfen die Anlagenbetreiber die selbst produzierte Energie am Ort der Produktion ganz oder teilweise selber ***verbrauchen*** (Selbstverbrauch). Sie dürfen die selbst produzierte Energie auch zum Verbrauch am Ort der Produktion ganz oder teilweise ***veräussern.*** Der erste Satz regelt ausdrücklich das klassische Recht auf Eigenverbrauch und entspricht materiell weitgehend der bisherigen Regelung.[34] Der neue zweite Satz bringt die Veräusserung zum Verbrauch mittels Zusammenschluss der Grundeigentümerinnen zum Eigenverbrauch ***(ZEV)***[35] ***sowie der Beteiligung der Mieter und Pächter am ZEV***[36] zum Ausdruck. Der Gesetzgeber hält ausdrücklich fest, dass beides als Eigenverbrauch gilt.[37]

Gegenstand des Eigenverbrauchs ist die ***«selbst produzierte Energie»***. Diese darf «ganz oder teilweise» aber nur «am Ort der Produktion»[38] selbst verbraucht oder Dritten zum Verbrauch überlassen werden. Reicht die selbst produzierte Energie nicht aus, um den Energiebedarf am Ort der Produktion zu decken, hat die Anlagenbetreiberin Anspruch auf ***Grundversorgung***.[39]

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32 Art.7 Abs. 2^{bis} und Art. 7a Abs. 4^{bis} aEnG (Energiegesetz vom 26. Juni 1998 in der Fassung der Änderung vom 21. Juni 2013, eingefügt durch Ziff. I des Bundesgesetzes vom 21. Juni 2013, in Kraft seit 1. Januar 2014 (AS 2013 4505; BBl 2013 1669 1925). Beide Versionen sind inhaltlich deckungsgleich.

33 Vgl. zur parlamentarischen Debatte parlamentarische Initiative 12.400.

34 Art. 7 Abs. 2^{bis} und Art. 7a Abs. 4^{bis} EnG/2014.

35 Art. 16 Abs. 1 Satz 2 i.V.m. Art. Art. 17 Abs. 1 EnG i.V.m. Art. 15 EnV.

36 Art. 16 Abs. 1 Satz 2 i.V.m. Art. Art. 17 Abs. 2 EnG i.V.m. Art. 16 EnV.

37 Art. 16 Abs. 1 Satz 3 EnG.

38 Art. 16 Abs. 1 Satz 4 EnG i.V.m. Art 14 EnV;

39 Art. 6 Abs. 1 und 6 StromVG i.V.m. Art. 17 Abs. 2 und 3 sowie Art. 18 Abs. 1 EnG.

Produziert die Anlage über den am Ort der Produktion bestehenden Eigenbedarf hinaus Energie, hat sie Anspruch auf ***Abnahme und Vergütung*** ihrer Überschussproduktion durch den Netzbetreiber.[40]

Voraussetzungen eines Zusammenschlusses zum Eigenverbrauch (ZEV)

Der Bund erachtet Zusammenschlüsse zum Eigenverbrauch im Rahmen der Energiestrategie 2050 als ein sinnvolles Element und hat deren Rahmenbedingungen in Art. 17 und 18 EnG ausdrücklich geregelt. Mit einer Revision der Energieverordnung (EnV)[41], welche im April 2019 in Kraft getreten ist, hat der Verordnungsgeber die Möglichkeiten des Zusammenschlusses ausserdem etwas erweitert sowie die Kostenverrechnung präzisiert.[42] Zusammenschliessen können sich Grundstücke, welche zusammenhängen und von welchen mindestens eines an das Grundstück grenzt, auf dem sich die Produktionsanlage befindet (Art. 14 Abs. 1 EnG). Die letzte Revision der EnV erweiterte diese Möglichkeit nun immerhin dadurch, dass zwischen solchen Grundstücken eine Strasse, ein Eisenbahntrassee oder ein Fliessgewässer liegen darf, wobei der entsprechende Grundeigentümer diesfalls zustimmen muss (Art. 14 Abs. 2 EnV). Gleichwohl werden solche Zusammenschlüsse aber nach wie vor behindert durch die Tatsache, dass Zusammenschlüsse das Netz des Verteilnetzbetreibers nicht beanspruchen dürfen (Art. 14 Abs. 3 EnV). In der Praxis bedeutet diese Einschränkung, dass die Zusammenschlüsse ihre Grundstücke mit eigenen Elektrizitätsleitungen erschliessen müssen, womit sich ZEV für gewöhnlich nur innerhalb eines einzelnen Grundstücks oder für den Fall von Arealnetzen[43] wirtschaftlich verwirklichen lassen. Ob, wie in der Lehre diskutiert, ganze Quartiere oder Gemeindegebiete ihre Verteilnetze in einen ZEV einbringen werden, wird abzuwarten sein.[44] Auch das Fachsekretariat der ElCom erachtet es immerhin als möglich, dass Stromkabel im Zuge eines Zusammenschlusses zum Eigenverbrauch aus dem öffentlichen Netz an einen ZEV übertragen werden könnte (Art. 3 Abs. 2bis StromVV). Müssen Grundstücke nämlich nachträglich mit eigenen Leitungen erschlossen werden, obwohl diese über das Verteilnetz bereits erschlossen wären, macht dies einen Zusammenschluss wirtschaftlich unattraktiv.[45]

Auch das UVEK war sich bei der Revision der EnV bewusst, dass die konkrete Ausgestaltung der Verteilnetze Zusammenschlüsse verhindern kann. Es stellte denn auch klar, dass Stromversorger Leitungen nicht nur deshalb auf eine bestimmte Weise bauen dürfen, um Zusammenschlüsse zu verhindern.[46] Ganz grundsätzlich besteht hier ein Spannungsverhältnis zwischen Energie- und Stromversorgungsrecht.[47]

Als am Ort der Produktion selber verbraucht, gilt entsprechend auch nur die Elektrizität, die zwischen der Produktionsanlage und dem Verbraucher das Verteilnetz des Netzbetreibers nicht in Anspruch nimmt (Art. 14 Abs. 3 EnV). Das Verteilnetz ist in Art. 4 Abs. 1 StromVG definiert als: «Elektrizitätsnetz hoher, mittlerer oder niederer Spannung zum Zwecke der Belieferung von Endverbrauchern oder EVU». Ob der Verteilnetzbetreiber die Nutzung des Verteilnetzes gegen Netznutzungsentgelt genehmigen könnte, ist unter dem neuen Recht eher zu verneinen.[48] Der ZEV bildet gegenüber dem Verteilnetz einen einzelnen Endverbraucher mit einem einzigen Anschluss (Art. 18 Abs. 1 EnG), was auch für die Messeinrichtung, die Messung oder den Anspruch auf Netzzugang nach Art. 6 und 13 StromVG gilt. Die Lehre erachtet solche Netze hinter einem Zugangspunkt zum Verteilnetz mitunter als neue lokale Gebietsmonopole.[49]

Das EnG setzt ausserdem voraus, dass die Produktionsleistung eines ZEV mindestens zehn Prozent der Anschlussleistung am Messpunkt des Zusammenschlusses beträgt, wobei Anlagen nicht miteingerechnet werden, die nur bis zu 500 Stunden pro Jahr betrieben werden (Art. 17 Abs. 1 EnG i.V.m. 15 Abs. 1 und 2 EnV). So verfügt beispielsweise ein 10-Familienhaus, welches mit einer 100 Ampère Anschlusssicherung ausgestattet ist bei einer Spannung von 400 Volt über eine Anschlussleistung von 70

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40 Art. 15 Abs. 2 EnG i.V.m. Art. 11 Abs. 1 lit. a EnV.

41 Energieverordnung vom 1. November 2017 (EnV), SR 730.01.

42 Energieverordnung (EnV), Änderung vom 27. Februar 2019, AS 2019 913; vgl. auch Isabelle Häner, Entwicklungen im Raumplanungs-, Bau- und Umweltrecht, in: SJZ 115 (2019), S. 622, 622

43 Der Begriff Arealnetz kommt im StromVG nicht ausdrücklich vor, ergibt sich aber aus Art. 4 Abs. 1 lit. a StromVG: «Elektrizitätsleitungen mit kleiner räumlicher Ausdehnung zur Feinverteilung, wie auf Industriearealen oder innerhalb von Gebäuden, gelten nicht als Elektrizitätsnetze».

44 Vgl. Walther (FN 4) S. 57.

45 Allein die Kosten für die Verlegung von Stromleitungen belaufen sich auf CHF 500–1000 pro Meter.

46 UVEK, Erläuternder Bericht (FN 3), S. 14 f.

47 UVEK, Erläuternder Bericht (FN 3), S. 15.

48 So wohl auch Martin Föhse, Eigenverbrauch und Rückliefertarife – Eckpfeiler und Problemzonen des neuen Energierechts, in: Rechtsfragen der Energiewirtschaft Schriften zum Energierecht Nr. 10, 2019, S. 1–22 (N. 22).

49 Walther (FN 4), S. 57; tendenziell kritisch zu Parallelnetzen Föhse (FN 48), N. 20.

Kilowatt. Ein solches Haus müsste, sofern sich alle Parteien beteiligen, über eine Photovoltaikanlage von mindestens sieben Kilowatt Leistung verfügen. Dies entspricht etwa einer Fläche von 50 m^2.[50]

Entwicklung Gesetzgebung in der Schweiz

Es wird sich in den nächsten 3 – 5 Jahren gesetzgeberisch in Bezug auf eine mögliche Erweiterung von ZEV nicht viel ändern, da der gesetzgeberische Anpassungsprozess mindestens so lange dauern wird, obwohl im Rahmen der Energiewende mittel- bis langfristig der Eigenverbrauch und damit auch ZEV-Modelle weiter an Bedeutung gewinnen werden.

Der weitere Spielraum auf Verordnungsebene ist nach der jüngsten Revision vom April 2019 beschränkt. Denkbar wäre auf Verordnungsebene noch zu regeln, dass auch ZEV möglich werden, die zwischen Verbraucher und Produktion beispielsweise ein Grundstücks-Eigentümer haben, der selber nicht an der ZEV beteiligt ist, aber mit der Durchleitung einverstanden ist. Bevor eine weitergehende Aufweichung der ZEV ins Auge gefasst wird, müssten die Umwälzung der Netzkosten neu geregelt werden.

Das Fachsekretariat der ElCom hat explizit darauf hingewiesen, dass eine Eigentumsübertragung eines Kabels aus dem öffentlichen Netz an einen ZEV gemäss StromVV Art. 3 Abs. 2^{bis} möglich bzw. vorgesehen ist. Bei einer gemeinsamen Nutzung des Kabels durch ZEV und VNB ist die ElCom hingegen zurückhaltender.

Rechtssituation in der EU

Clean Energy Package

Mit dem Clean Energy Package (Richtlinie (EU) 2018/2001 des Europäischen Parlaments und des Rates vom 11. Dezember 2018 zur Förderung der Nutzung von Energie aus erneuerbaren Quellen), haben die Bürgerinnen und Energie-Gemeinschaften in der EU mittlerweile eine Reihe von Rechten zur Nutzung und Verteilung der selber produzierten Energie. Die Anerkennung der Rolle der Bürgerinnen, die erneuerbare Energie erzeugen, verbrauchen, handeln und speichern, ist jetzt auch in der EU gesetzlich verankert.

Die Mitgliedstaaten sorgen dafür, dass Eigenversorger im Bereich erneuerbare Elektrizität individuell oder über Aggregatoren berechtigt sind, erneuerbare Energie zu verkaufen. Endkunden dürfen Strom, der von ihnen an Ort und Stelle innerhalb bestimmter Grenzen erzeugt wurde, verbrauchen, speichern und verkaufen sowie an Flexibilitäts- oder Energieeffizienzsystemen teilnehmen. Die Richtlinie sieht die Möglichkeit zum „kollektiven Eigenverbrauch" in Mehrparteiengebäuden und Gebäudekomplexen vor.

Aktive Kunden dürfen keinen unverhältnismässigen oder diskriminierenden, technischen oder verfahrensrechtlichen Erfordernissen, Verfahren und Gebühren und nicht kostenorientierten Netzentgelten unterworfen sein. Ab 2026 sollen sogar alle Entgelte für den Eigenverbrauch wegfallen, solange die Anlage eine geringere Leistung als 25 Kilowatt aufweist.

Die aktuelle gesetzgeberische Situation der EU und das blockierte Stromabkommen werden in den nächsten Jahren (noch) keinen Druck auf eine Erweiterung des gesetzgeberischen ZEV-Rahmens in der Schweiz ausüben.

Elektrizitätsmarkt-Gesetz der EU

Die Renewable Energy Directive (Directive (EU) 2018/2001)[51] definiert auch 'gemeinsam handelnde erneuerbare Selbstverbraucher' als eine „gemeinsam handelnde Eigenversorger im Bereich erneuerbare Elektrizität" eine Gruppe von zumindest zwei gemeinsam handelnden Eigenversorgern im Bereich erneuerbare Elektrizität, die sich in demselben Gebäude oder Mehrfamilienhaus befinden (Art. 2.15). Dieses Konzept beschreibt eine Form von kollektiver Selbstkonsum, nur möglich für Haushalte, die einen gemeinsamen geographischen Standort haben.

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[50] Das Beispiel stammt aus EnergieSchweiz, BFE, Leitfaden Eigenverbrauch vom Dezember 2019, S. 8, abrufbar unter https://pubdb.bfe.admin.ch/de/publication/download/9329.

[51] https://eur-lex.europa.eu/legal-content/DE/TXT/HTML/?uri=CELEX:32018L2001&from=DE

Am 26.3.2019[52] wurde von der Europäischen Union das Elektrizitätsmarktgesetz (P8_TA(2019)0226) in die Vernehmlassung gegeben. Darin werden in Artikel 16 die Bürgergemeinschaften definiert.

Den Bürgerenergiegemeinschaften stehen offen: Erzeugung, Verteilung, Versorgung, Verbrauch, Aggregierung, Speicherung von Elektrizität sowie, wenn dies die Mitgliedstaaten im Rahmen der Umsetzung zulassen, auch der Betrieb von Netzen.

Vorgesehen ist auch das „Electricity Sharing“. Dieses erlaubt, innerhalb der Gemeinschaft jene Elektrizität gemeinsam zu nutzen, die mit den eigenen Produktionsanlagen erzeugt wird. Entscheidend ist, dass die Mitgliedschaft offen und transparent ist sowie dass die Bürgerenergiegemeinschaft von ihren Anteilseignern bzw. Mitgliedern tatsächlich kontrolliert wird.

Deutschland

Die wichtigste für die Prosumenten relevante Gesetzgebung ist das Erneuerbare-Energien-Gesetz 2017 (EEG). Das EEG definiert die Eigenversorgung und enthält eine Definition der Energiegemeinschaft, wörtlich übersetzt als "Bürgergemeinschaft" (EEG, § 3 Nr. 15[53]).

In Deutschland trifft diese neu geschaffene europäische Begriffsbestimmung der Eigenversorgung auf die bestehende Definition in § 3 Nr. 19 EEG 2017. Danach ist Eigenversorgung „der Verbrauch von Strom, den eine natürliche oder juristische Person im unmittelbaren räumlichen Zusammenhang mit der Stromerzeugungsanlage selbst verbraucht, wenn der Strom nicht durch ein Netz durchgeleitet wird und diese Person die Stromerzeugungsanlage selbst betreibt.“

Ziel der Mieterstrom-Förderung ist, Mieterinnen und Mieter unmittelbar an der Energiewende zu beteiligen und weitere Anreize für den Betrieb von Solaranlagen auf Wohngebäuden zu schaffen. Nach diesem System kann der Gebäudeeigentümer, der ein lizenzierter Lieferant werden muss, Strom aus Sonnenkollektoren auf dem Dach erzeugen und an seine Mieter verkaufen. Für überschüssigen Strom, der ins Netz eingespeist wird, erhalten die Mieter die gleiche Einspeisevergütung. Für ihre selbst verbrauchte Energie erhalten sie einen zusätzlichen "Mieterstromaufschlag" (EEG 2017, §§ 19(3) und 21(3)). Im Gegenzug sind sie verpflichtet, 40% der für traditionelle Stromverbraucher vorgesehenen EEG-Vergütungen zu zahlen (EEG 2017, § 61b Abs. 1).

Die Höhe des Mieterstromzuschlags hängt von der Grösse der Solaranlage und dem Photovoltaik-Zubau insgesamt ab. Sie liegt zwischen 2,2 Cent/kWh und 3,8 Cent/kWh. Der von den Mietern nicht verbrauchte Strom wird ins Netz der allgemeinen Versorgung eingespeist und vergütet.

Der Mieterstromzuschlag wird nur für Strom aus Solaranlagen gewährt, die mit beziehungsweise nach Inkrafttreten des Gesetzes (25. Juli 2017) in Betrieb genommen worden sind. Zudem muss die Anlage, für die der Mieterstromzuschlag in Anspruch genommen werden soll, bei der Bundesnetzagentur registriert werden.

Um die infolge der Mieterstromförderung entstehenden zusätzlichen Kosten zu begrenzen, wird der durch den Mieterstromzuschlag förderfähige Solaranlagen-Ausbau auf 500 Megawatt pro Jahr beschränkt. Wichtig ist, dass der Mieter seinen Stromanbieter weiterhin frei wählen kann und Mieterstrom zu attraktiven Konditionen angeboten bekommt. Daher beinhaltet das Gesetz Vorgaben für die Laufzeit des Mieterstromvertrags, verbietet die Kopplung mit dem Mietvertrag und sieht eine Preisobergrenze für Mieterstrom vor. Im Vergleich zu anderen Ländern scheint Deutschland einen stärkeren Regulierungsrahmen für kollektive Prosumenten zu haben, aber nicht alle Änderungen waren finanziell vorteilhaft.

Eine Gesetzesrevision steht aber schon in Aussicht, um die Europäische Richtlinie Clean Energy Package (Richtlinie (EU) 2018/2001) und das Elektrizitätsmarktgesetz (P8_TA(2019)0226) in Deutsche Gesetzgebung zu paragraphieren.

Österreich

Bezogen auf den Zusammenschluss zum Eigenverbrauch gibt es in Österreich seit 2017 eine Regelung für jede Art von Gebäude, einschliesslich Mehrfamilienhäuser. Die Hauptaspekte sind wie folgt:

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[52] http://www.europarl.europa.eu/sides/getDoc.do?type=PV&reference=20190326&secondRef=ITEM-007-06&language=DE&ring=A8-2018-0044 und http://www.europarl.europa.eu/doceo/document/TA-8-2019-0226_DE.html und http://data.consilium.europa.eu/doc/document/PE-10-2019-REV-1/DE/pdf

[53] https://www.gesetze-im-internet.de/eeg_2014/__3.html

- Im Mittelpunkt des Modells stehen ein Betreiber der Erzeugungsanlage und die lokalen Nutzer des lokal erzeugten Stroms. Weitere relevante Parteien sind der Netzbetreiber (DSO), einzelne Anbieter (Einzelhändler) von Restenergie, die von den beteiligten Nutzern aus dem Netz bezogen wird, und der Marktakteur, der die ins Netz eingespeiste Energie vergütet.

- Neben der Anforderung, dass ein Betreiber der Erzeugungsanlage definiert werden muss, unterliegt das Modell, das die vertraglichen Beziehungen (Rechte und Pflichten) zwischen dem Eigentümer der Anlage, ihrem Betreiber, den Nutzern und anderen Parteien widerspiegelt, grundsätzlich der Vertragsfreiheit der Vertragsparteien.
- Technisch wird die PV-Anlage an die Hauptstromversorgung des Gebäudes angeschlossen (die ohnehin in der Regel zur Domäne des Gebäudes gehört).
- Smart Metering ist sowohl für die Erzeugung als auch für den Verbrauch erforderlich, um eine genaue Abrechnung der Energiemengen zu ermöglichen.
- Zudem werden keine Netzgebühren erhoben.

Der Netzbetreiber (DSO) ist verantwortlich für die Erhebung, Berechnung und Bereitstellung aller relevanten Messdaten (erzeugter Strom, direkter lokaler Verbrauch der beteiligten Nutzer, netzimportierter Restverbrauch durch jeden Nutzer, eingespeiste überschüssige Energie). Die Verteilung der lokalen Produktion auf die lokalen Nutzer erfolgt durch das DSO gemäss einer vertraglichen Vereinbarung.

In Österreich sind – über den auf die so genannte „private Hauptleitung“ begrenzten Rahmen „gemeinschaftlicher Erzeugungsanlagen“ nach § 16a ElWOG [Konzept 2] hinausgehende – Umsetzungen von Quartiers- oder Stadtmodellen momentan noch nicht bekannt, da deren wirtschaftliche Rentabilität in der Regel nicht gegeben sein dürfte. Dies liegt vor allen an der Netzentgeltstruktur gemäss dem politisch-regulatorisch festgelegten Kostenverteilungsmodell[54].

Frankreich

Die wichtigsten zu berücksichtigenden Parameter, die sich aus der aktuellen Regulierung ergeben, können folgendermassen zusammengefasst werden:

- Der individuelle und kollektive Eigenverbrauch ist nach dem französischen Energiekodex nach der Annahme einer Reihe von Rechts- und Verwaltungsvorschriften in den Jahren 2016 und 2017 zulässig. Bislang können PV-Anlagen auf Gebäuden und Dächern jedoch derzeit nicht mit dem Endkundenpreis für Strom konkurrieren.

Regelungen zum Eigenverbrauch wurden im französischen Energie Kodex in den Jahren 2015[55] und 2016[56] schont erwähnt. Der Energiekodex definiert einen "individuellen Selbstverbrauchsbetrieb" und eine "kollektive Selbstverbrauchsaktion" (CSO) (Art. 315) mit folgenden Angaben dass der Eigenverbrauch kollektiv ist, wenn die Elektrizität zwischen ein oder mehrere Hersteller und ein oder mehrere Endverbraucher, die gebunden sind (untereinander) innerhalb einer Rechtsstruktur einer juristischen Person, die sich in Nähe, und deren Entnahme- und Einspeisepunkte auf gleicher Nieder- bis Mittelspannungs-Transformatorstation-Ebenen sind.

In Frankreich ermächtigte ein Ausführungsdekret seit 2017 (Verordnung 2016-1019) Personengruppen (Miteigentümer, Verbände oder Genossenschaften), den Eigenverbrauch: Die strenge Regulierung des Energiegesetzes, die sich auf Anlagen beschränkte, die maximal zehn Meter weit weg von Verteilkästen liegen, führte zu nur wenigen Eigenverbrauchsgemeinschaften. Mit dem neuen " décret d'application " (Artikel 43 bis[57] zum 11. April 2019 und l'arrêté du 21 novembre 2019) wird der Umfang der Eigenverbrauchsgemeinschaften jedoch auf 2[58] km erweitert. Dieses Gesetz ist aber auf 5 Jahre befristet.

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[54]https://www.pvp4grid.eu/wp-content/uploads/2018/08/1.-PVP4Grid_D2.4_Report_Final_AT.pdf
[55]https://www.legifrance.gouv.fr/affichCode.do?idSectionTA=LEGISCTA000031748681&cidTexte=LEGITEXT000023983208&dateTexte=20161005
[56]https://www.legifrance.gouv.fr/affichCodeArticle.do;jsessionid=512359383CADD5504C85D0E7B87D95E5.tplgfr24s_2?idArticle=LEGIARTI000031830292&cidTexte=LEGITEXT000023983208&categorieLien=id&dateTexte=20161231
[57]https://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGIARTI000031738002&cidTexte=LEGITEXT000023983208&dateTexte=20160129
[58] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000039417566&categorieLien=id

Der Zusammenschluss zum Eigenverbrauch ist in Frankreich erst am Entstehen. Haupthindernisse für die Entwicklung des Eigenverbrauchs mittels privaten PV-Anlagen sind in der Erlangung behördlicher Genehmigungen. Ein weiteres Hindernis für die Umsetzung des peer to peer-Konzeptes ist die Unvorhersehbarkeit der Netzanschlusskosten, die bei Anlagen mit geringer Leistung (9 kW - 36 kW) besonders volatil sind. Jedoch wird die Steuer zum Eigenverbrauch ab Herbst 2019 aufgehoben und das französische Parlament muss die Europäische Richtlinie Clean Energy Package (Richtlinie (EU) 2018/2001) und das Elektrizitätsmarktgesetz (P8_TA(2019)0226) in Ländergesetz umsetzen, was vermutlich zu mehr Eigenverbrauch führen könnte.

Es gibt keine rechtliche Definition für eine «Gemeinschaften für erneuerbare Energien» aber diese können die Rechtsform einer «Eigenverbrauchsgemeinschaft[59],[60]» annehmen. Die Bewohner von Mehrfamilienhäusern oder Eigentumswohnungen können diese Rechtsform ebenfalls annehmen und sich gegenseitig überschüssige Energie verkaufen und so zu gemeinsam handelnden Selbstverbrauchern werden.

Italien

Trotz des Fehlens spezifischer Gesetze für den Selbstverbrauch bietet das italienische Recht (Nr. 578/2013/R/EEL[61].) eine Definition des Begriffs "Selbstproduzent" (Autoproduttore), die die Selbsterzeugung und den Selbstverbrauch von erneuerbarer Energie erlaubt. Die geltende Gesetzgebung erlaubt keine ZEV-Anlagen, weder im Wohnbereich noch für gewerbliche oder industrielle Anwendungen. Mit der Adaptierung der EU Richtlinie 2018/2001 und dem Elektrizitätsmarktgesetz dürfte dies mittelfristig ändern.

Spanien

Unter der RD 900/2015 wurde eine Steuer auf jeden erzeugten und selbst verbrauchten EE-Strom erhoben. Die 2018 (Königliches Gesetzesdekret (RD-L 15/2018)) und 2019 (RD244/2019[62]) erlassenen Gesetze schafften die so genannte "Solarsteuer" ab und sahen eine gesetzliche Regelung für kollektive Formen des Eigenverbrauchs vor. Das Dekret RD 244/2019 bietet neue Anreize für spanische Prosumenten, indem es Ausgleichsmechanismen einführt und die Verwaltungsverfahren vereinfacht. Die Änderungen betreffen die Definition des Selbstverbrauchs (um den kollektiven Selbstverbrauch einzubeziehen) und reduzieren die Formen des Selbstverbrauchs auf zwei (Selbstverbrauch mit oder ohne Überschuss, autoconsumo sin excedentes», «autoconsumo con excedentes»).

Auch die Möglichkeit eines Modells welches einen kollektiven Eigenverbrauch beinhaltet ist vorgesehen. Hierbei könnte mehr als ein Verbraucher von derselben Anlage profitieren (Eigentümerwohngemeinschaft). Die Voraussetzung wäre in diesem Fall, dass alle Verbraucher dieselbe Form des Eigenverbrauchs nutzen[63].

Der spanische Ministerrat hat im Mai 2019 das Königliche Dekret verabschiedet, mit dem die administrativen, technischen und wirtschaftlichen Bedingungen für den Eigenverbrauch von Energie neu geregelt werden sollen. Unter anderem wird auch die so genannte Sonnensteuer, also die Belastung des Photovoltaik-Eigenverbrauchs wegfallen[64].

Zwischen-Schlussfolgerung

Die aktuelle Gesetzgebung in der Schweiz ist sehr progressiv und zurzeit fortschrittlicher als in der EU. Mit der Einführung des Clean Energy Package und dem kommenden Elektrizitätsmarktgesetz, passt die EU das Gesetz für eine kommende dezentrale Produktion an. Jedes Land muss in den nächsten 18 Monaten seine Gesetze dazu anpassen. Da ein gewisser Spielraum in der Gesetzgebung herrscht und die Länder progressivere Gesetzgebung erlassen können, wird erst per 1.1.2021 klar, wie stark Eigenverbrauchsgemeinschaften und Bürgerstrommodelle in der EU gefördert werden.

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59 https://www.greenunivers.com/2017/02/autoconsommation-delectricite-la-loi-du-24-fevrier-2017-complete-le-cadre-juridique-avis-dexpert-158308/
60 loi n° 2017-227 du 24 février 2017
61 https://www.arera.it/allegati/docs/13/578-13.pdf
62 https://www.boe.es/diario_boe/txt.php?id=BOE-A-2019-5089
63 http://www.roedl.net/es/blog/area_legal/zusammenfassung_des_koeniglichen_dekretes_2442019_vom_5_april_2009_der_die_administrativen_technischen_und_wirtschaftlichen_bedingungen_fuer_den_eigenverbrauch_von_elektrischer_energie_regelt.html
64 https://www.pv-magazine.de/2019/04/12/sonnensteuer-ade-spanien-setzt-neue-vorschriften-fuer-photovoltaik-eigenverbrauch-in-kraft/

Ein Erlass der Netzebenen 1 – 5 ist weder in der Schweiz noch in der EU in Aussicht, falls der Strom auf der gleichen Netzebene produziert und verbraucht wurde. Die EU schreibt zwar vor, dass die Netzentgelte fair und kostenorientiert sein müssen. Was das genau heisst, wird sich auch erst per 1.1.2021 weisen.

Verhältnis der einzelnen Beteiligten in der Schweiz

Verhältnis des ZEV zum EVU

Nach Art. 17 Abs. 1 EnG haben die an einem ZEV beteiligten Grundeigentümer mit dem Anlagebetreiber und unter sich eine Vereinbarung zu treffen. Während ZEV-intern Privatrecht gilt, so regelt sich das Verhältnis nach aussen zum Netzbetreiber nach StromVG.[65] Das Verhältnis des Grundeigentümers und der Grundeigentümerin zum Netzbetreiber wird in Art. 18 EnG und Art. 18 EnV konkretisiert. Art. 18 Abs. 1 EnG hält fest, dass die Endverbraucherinnen und Endverbraucher nach dem Zusammenschluss gegenüber dem Netzbetreiber gemeinsam über einen einzigen Messpunkt verfügen wie eine Endverbraucherin oder ein Endverbraucher. Der ZEV gilt damit als Endverbraucher mit den entsprechenden Rechten und Pflichten. Den Netzbetreiber trifft damit eine Anschlusspflicht nach Art. 5 StromVG. Darüber hinaus hat der ZEV gegenüber dem Netzbetreiber einerseits Anspruch auf Grundversorgung durch den Netzbetreiber nach Art. 6 Abs. 1 StromVG[66] und Anspruch auf Abnahme der nach Abzug des Eigenverbrauchs angebotenen Überschussproduktion.[67] Ersteres selbstverständlich nur dann, wenn der ZEV seinen Strom nicht auf dem freien Markt einkauft.[68] Vom Begriff des festen Endverbrauchers erfasst werden auch sog. «Prosumer» und damit Grundeigentümerinnen, die am Ort der Produktion Endverbraucherinnen sind.; Art. 16 Abs. 1 EnG). Als Prosumer gelten Grundeigentümer,[69] welche Elektrizität aus erneuerbaren Energien sowie aus fossil und teilweise fossil befeuerten Wärme-Kraft-Kopplungsanlagen und Biogas gewinnen.[70] Mit dem Anspruch auf Abnahme der Überschussproduktion stellt der Gesetzgeber sicher, dass die von der Eigenverbrauchsregelung profitierenden Produzenten für ihre Überschussproduktion auf jeden Fall einen Abnehmer haben, der ihnen einen «angemessenen» Preis bezahlt.[71]

Im Hinblick auf einen Zusammenschluss darf der Netzbetreiber das Recht auf Zusammenschluss zum Eigenverbrauch nicht durch einen entsprechenden Leitungsbau in grundsätzlicher Weise untergraben. Er darf den Wechsel der Anschlüsse nicht verweigern und muss die notwendigen Anpassungen des Anschlusses vornehmen.[72] Grundeigentümerinnen und Grundeigentümer haben dem Netzbetreiber je drei Monaten im Voraus die Bildung und Auflösung eines ZEV sowie den Einsatz eines Speichers und dessen Verwendungsart zu melden.73

Verhältnis der beteiligten Grundeigentümer eines ZEV

Nach Art. 17 Abs. 1 EnG haben die an einem ZEV beteiligten Grundeigentümer nicht nur mit dem Netzbetreiber, sondern auch unter sich eine Vereinbarung zu treffen. Diese ist in den Formen des Privatrechts zu treffen, doch macht das Gesetz keine weiteren Vorgaben zur Art dieser Vereinbarung. Während die Zusammenschlüsse zum Eigenverbrauch zwar in der Form der einfachen Gesellschaft geschlossen werden können, so empfiehlt es sich für Eigentümer separater Liegenschaften, den ZEV durch Dienstbarkeitsverträge sowie einer Nutzungs- und Verwaltungsordnung zu ergänzen sowie im Grundbuch einzutragen. Dies aus Gründen des Investitionsschutzes, welcher mit einer einfachen Gesellschaft nicht gewährleistet werden kann.[74]

Zum Inhalt der Vereinbarung hält Art. 16 Abs. 3 EnV fest, dass die Vereinbarung zumindest die Vertretung des ZEV nach aussen regeln muss (lit. a) sowie «die Art und Weise der Messung des internen Verbrauchs, der Datenbereitstellung, der Verwaltung und

[U]VEK, Erläuternder Bericht (FN 3), S. 15 mit Verweis auf Art. 18 Abs. 1 EnG; so im Grundsatz auch Föhse (FN 48), N. 18.

66 Art. 6 Abs. 1 und 6 StromVG i.V.m. Art. 17 Abs. 2 und 3 sowie Art. 18 Abs. 1 EnG.

67 Die Überschussproduktion entspricht der tatsächlich ins Netz eingespeisten Elektrizität (Art. 11 Abs. 2 Satz 1 EnV). Sie ergibt sich nach dem Abzug des Selbstverbrauchs des einen Teils der Elektrizität am Ort der Produktion (Art. 11 Abs. 1 lit. a i.V.m. Art. 14 EnV); davon erfasst wird auch die Überlassung des Verbrauchs durch einen oder mehrere Dritte.

68 Vgl. Art. 6 Abs. 2 StromVG; BGer, 2C_12/2016 E. 2, 3.

69 Art. 17 Abs. 1 EnG.

70 Art. 15 Abs. 1 lit. a-b EnG i.V.m. Art. 11 Abs. 1 EnV.

71 Art. 15 Abs. 3 i.V.m. Art. 21 Abs. 2 EnG; Botschaft ES 2050, 7667; Botschaft EnG 1996, 1093; Botschaft ENB, 513.

72 Die allfällig anfallenden Kosten beim Zusammenschluss werden in Art. 3 Abs. 2^{bis} StromVV geregelt. Vgl. dazu UVEK, Erläuternder Bericht (FN 3), S. 15.

73 Art. 18 Abs. 1 EnV.

74 Vgl. dazu Leitfaden BFE (FN 50), S. 24 f.

der Abrechnung» (lit. b) sowie das Stromprodukt, welches von aussen bezogen werden soll und Modalitäten dieses Bezugs (lit. c).

Stellung von Mietern und Pächtern

Auch Mieter und Pächter sind grundsätzlich Teil eines ZEV, sie können sich nur sehr eingeschränkt weigern, an einem ZEV teilzunehmen. Da die Grundeigentümer ihnen gegenüber in einer ähnlichen Position stehen wie der Netzbetreiber gegenüber den Endkunden, auferlegt das Gesetz den Grundeigentümern gewisse Pflichten und stellt relativ detaillierte Voraussetzungen für die Kostenberechnung gegenüber den Mietern und Pächtern auf.[75] Um deren Rechte und im Rahmen des ZEV zu sichern, schreibt Art. 16 Abs. 4 EnV gewisse Elemente vor, die im Zeitpunkt des Zusammenschlusses zum gemeinsamen Eigenverbrauch mindestens schriftlich festzuhalten sind: wer den Zusammenschluss gegen aussen vertritt (lit. a); die Art und Weise der Messung des internen Verbrauchs, der Datenbereitstellung, der Verwaltung und Abrechnung (lit. b); das Stromprodukt, das extern bezogen werden soll, sowie die Modalitäten für einen Wechsel dieses Produkts (lit. c). Es empfiehlt sich, diese Elemente im Rahmen des Mietvertrages festgehalten.[76] Die Grundeigentümerin und der Grundeigentümer bleibt für die vereinbarte Umsetzung der Vorgaben verantwortlich, kann aber interne Abläufe wie Messung, Datenbereitstellung, Abrechnung etc. ohne weiteres an einen Dienstleister fremdvergeben.[77] EVU und andere Dienstleiter bieten solche Dienstleistungen an.[78]

Besonderheiten der Organisation eines ZEV mit Handelsplattform im Sinne des Projekts «Quartierstrom»

Der wesentliche Unterschied eines ZEV, wie er im Projekt Quartierstrom geschaffen wurde, ist die zuvor beschriebene Handelsplattform, mit welcher ein lokaler Strommarkt innerhalb des ZEV geschaffen wird. Die rechtliche Handhabung dieser Handelsplattform steht in den folgenden Ausführungen daher im Zentrum. Eine ganz grundsätzliche Unterscheidung ist dabei, ob die Plattform im Eigentum des ZEV steht und von diesem selber betrieben wird oder ob der ZEV Bereitstellung und Betrieb einem Dritten etwa in der Form eines sog. Contracting überträgt. Handelt es sich bei diesem Dritten gleichzeitig um den Netzbetreiber, so kann dieser die Flexibilität der Plattform womöglich auch zu seinem eigenen Nutzen verwenden, indem er etwa «peak-shaving», also den Ausgleich von Verbrauchsspitzen betreibt. Bereits heute bieten eine grosse Zahl von Unternehmen Dienstleitungen im Zusammenhang mit ZEV an,[79] womit es durchaus realistisch ist anzunehmen, diese Unternehmen könnten ihr Dienstleistungsangebot dereinst auch auf solche Handelsplattformen ausweiten. Angesichts dessen, dass Einrichtung und Betrieb einer solchen Plattform zumindest bei der allfälligen Einführung dieser Technologie aufwändig sein wird, ist eher damit zu rechnen, dass ZEV diese Aufgabe durch Dritte erfüllen lassen werden.

Variante 1: Dritter betreibt Plattform

Organisation der Unternehmung in Falle von Netzbetreibern als Dienstleistern

Eine Reihe von Energieversorgungsunternehmen bieten auch Contracting-Dienstleistungen an. Art. 10 Abs. 2 StromVG verbietet es nun aber den Netzbetreibern Informationen, welche sie aus dem Betrieb der Elektrizitätsnetze gewinnen, für andere Tätigkeitsbereiche zu nutzen (informatorische Entflechtung). Ob diese Bestimmung aber auch den Betrieb des internen Netzes eines ZEV umschliesst, scheint nicht geklärt. Da das Projekt Quartierstrom das Verteilnetz des Netzbetreibers nutzen kann, handelt es sich hierbei ohne Zweifel um Daten, welche durch den Betrieb des Elektrizitätsnetzes gewonnen werden. Da ZEV jedoch ausserhalb eines solchen Pilotprojektes das Verteilnetz für ihren internen Austausch nicht beanspruchen dürfen und nur an einem Messpunkt mit dem Verteilnetz verbunden sind, liesse sich argumentieren, dass diese Daten der Handelsplattform, soweit sie die internen Transaktionen betreffen, nicht von Art. 10 Abs. 2 StromVG erfasst werden. Ohne Zweifel von Art. 10 Abs. 2 StromVG erfasst werden aber die Daten, welche aus der Lieferung und Rücklieferung von Strom ins Verteilnetz herrühren.

Ein Netzbetreiber kann aus diesem Grund nur dann eine Handelsplattform wie diejenige im Projekt Quartierstrom anbieten, wenn er zu diesem Zweck eine eigene Vertriebs AG gründet und diese unabhängig am Markt aktiv ist. Dieser Tochtergesellschaft darf

[75] Art. 16 EnV, sehr kritisch zu dieser Regelung Föhse (FN 48), N. 24 ff.
[76] UVEK, Erläuternder Bericht (FN **Error! Bookmark not defined.**), S. 16.
[77] UVEK, Erläuternder Bericht (FN 3), S. 16.
[78] Vgl. Leitfaden BFE (FN 50), S. 25.
[79] Vgl. zum Contracting etwa Leitfaden BFE (FN 50), S. 28, 42

diesfalls kein direkter Zugriff auf Adress- und Zählerdaten der Muttergesellschaft möglich sein. Soweit die Vertriebs AG für ihre Tätigkeit im Rahmen der ZEV auf Daten des Netzbetreibers angewiesen ist, hat sie diese vom Netzbetreiber zu erwerben

In der Branchenempfehlung zur Data Policy[80] werden als wirtschaftlich sensible Daten aufgeführt:

- Name, Adresse und andere Stammdaten von Netznutzern;
- Verbrauchsdaten, die aus intelligenten Mess-, Steuer- und Regelsysteme gewonnen werden;
- In Zusammenhang stehende Meta- und Strukturdaten wie bspw. wartungsrelevante Informationen.

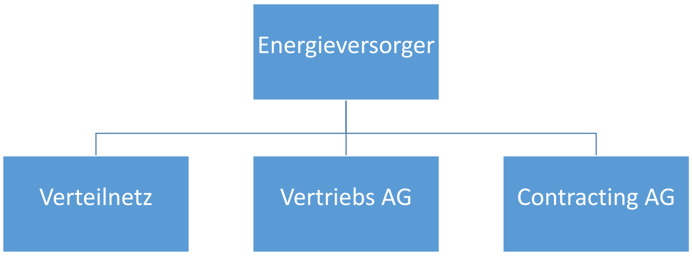

Abbildung 27: Struktur eines Energieversorgers, mit Vertriebs AG

Vertragsverhältnisse im Konzern
Der Verteilnetzbetreiber muss aufgrund kartellrechtlicher Kontrahierungspflicht Zähler-Daten an Vertriebs AG und andere Interessenten verkaufen. Der Kaufpreis setzt sich aus Zählerdaten-Kosten plus angemessenen Gewinn (entweder WACC oder 5 – 10 %) zusammen. Für den Datenaustausch zwischen den Smart Metern kommt das Glasfasernetz in Frage, falls EW dies besitzt, sonst Powerline oder Handy.

Installiert Vertriebs-AG eigene „Smart Meter“ Geräte mit einer «trusted execution environment[81]» und einem Linux System, um die Handels-Software laufen zu lassen, so muss Vertriebs AG Daten nicht einkaufen.

Vertragsverhältnis zwischen Drittem und ZEV
Ähnlich wie bei Contracting-Lösungen im Bereich von Solarmodulen, würden mutmasslich auch die Komponenten der Handelsplattform im Eigentum des externen Dienstleisters bleiben. Dieser würde dem ZEV den Betrieb der Handelsplattform in der Form einer Dienstleistung erbringen und dazu einen Vertrag mit dem ZEV schliessen.[82] Je nach konkreter Ausgestaltung des jeweiligen Contracting-Verhältnisses würde es sich dabei rechtlich besehen um einen Auftrag oder einen Werkvertrag handeln.

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[80] Branchenempfehlung: Data Policy in der Energiebranche – VSE, Juli 2019, https://www.strom.ch/de/media/5749.
[81] Eine Trusted Execution Environment (TEE) stellt eine sichere bzw. vertrauenswürdige Laufzeitumgebung für Applikationen zur Verfügung. Dabei kann ein TEE isoliert auf einem separaten Prozessor, direkt auf dem Hauptprozessor(en) eines Computersystems oder aber in einem Multiprozessor-System existieren. Auf dem TEE können nur speziell dafür freigeschaltete Applikationen ausgeführt werden.
[82] Vgl. für den typischen Fall des Contractings bei «klassischen» ZEV Leitfaden BFE (FN 50), S. 28, 42

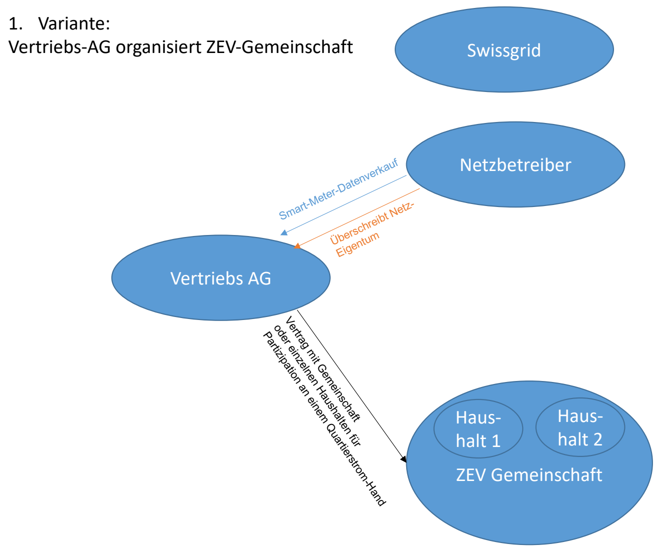

Abbildung 28: Peer-to-Peer Lösung wird von der Vertriebs AG aufgesetzt

Variante 2: ZEV betreibt Plattform

Wie bereits erwähnt, lässt das Bundesrecht den ZEV eine grosse Freiheit darin, die vertraglichen Verhältnisse unter den beteiligten Grundeigentümern zu regeln.[83] Damit scheinen auch der Integration einer Handelsplattform in den ZEV, welche sog. smart contracts verwendet und damit Transaktionen automatisch durchführt und beendigt,[84] keine spezifischen Hindernisse aus dem Energierecht entgegenzustehen.[85]

Was die Daten betrifft, welche durch die Handelsplattform erhoben werden, so gehören diese Daten der Gemeinschaft, womit sich keine Probleme aufgrund des informatorischen Unbundlings der Netzbetreiber stellen (vgl. dazu oben 0).

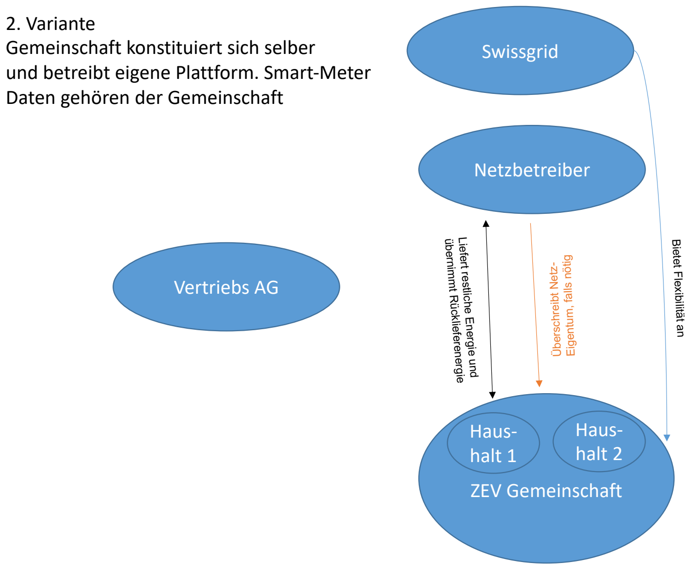

Abbildung 29: ZEV-Gemeinschaft setzt selber eine Peer-to-Peer-Lösung auf

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[83] Vgl. schon oben 0.

[84] Vgl. dazu nur Florian Möslein, Smart Contracts im Zivil- und Handelsrecht, in: ZHR 183 (2019) S. 254–293 (260 ff.); Francesco A. Schurr, Anbahnung, Abschluss und Durchführung von Smart Contracts im Rechtsvergleich, in: ZVglRWiss 2019 S. 257–284 (262 f.).

[85] Wenngleich smart contracts grundsätzlich sehr wohl mitunter höchst umstritten sind, vgl. Schurr (FN 84), S. 262 f.; Florian Möslein, Smart Contracts im Zivil- und Handelsrecht, in: ZHR 183 (2019) S. 254–293 (268 ff.).

Schlussfolgerungen für den rechtlichen Teil

Zusammenschlüsse zum Eigenverbrauch weisen aus wirtschaftlicher und technischer Sicht eine Reihe von Vorteilen auf im Vergleich zu traditionellen Netzarchitekturen. Ausgestaltung und Umfang von solchen Zusammenschlüssen sind jedoch nicht nur aus politischer, sondern auch aus rechtlicher Perspektive umstritten.[86] Im Moment steht dem weiteren Ausbau solcher ZEV vor allem die restriktive Regelung im Weg, dass solche Grundstücke grundsätzlich benachbart sein müssen und ein ZEV das Verteilnetz des Netzbetreibers nicht in Anspruch nehmen dürfen. Ein Zusammenschluss einer Verbrauchsgemeinschaft unter Beanspruchung des Verteilnetzes – welche für ZEV überhaupt nur sehr eingeschränkt möglich ist – führt nach geltendem Recht, wie im vorliegenden Text ausgeführt, zur Pflicht, Netzentgelte zu entrichten. Dies würde wiederum die Wirtschaftlichkeit eines solchen Verbundes beeinträchtigen.

Das vorliegende Projekt zeigt jedoch, dass solche Verbrauchsgemeinschaften ein grosses Potenzial haben. Sollte der Gesetzgeber dies ebenfalls erkennen, so wäre es an ihm, die nötigen Grundlagen zu schaffen, auf dass solche Zusammenschlüsse über die bestehenden Möglichkeiten von ZEV hinaus möglich würden.

11.3 The Quartierstrom business model

Lead author: Gian Carle, ZHAW

In Walenstadt, the added value consists of selling surplus photovoltaic electricity directly from prosumers to consumers. Thus, the prosumers receive higher payments for the renewable energy generated compared to the feed-in tariff. Consumers benefit from lower electricity prices (lower than the standard household tariff, the so called H4 tariff) and greater transparency and flexibility in their preferred energy mix. Prosumers, consumers and utility companies benefit from lower administrative costs. However, the model tested in the project, is not directly applicable in practice due to current legal regulation of self-consumption communities in Switzerland.

This chapter examines whether a profitable business model for self-consumption community projects (in German called ZEV) with a decentralized energy exchange markets - similar to Quartierstrom - can be developed and thus, whether the concept is scalable from an economic point of view under the current regulatory conditions. The analysis is conducted from the perspective of a start-up company (and not an incumbent in the utility sector).

The Business Canvas Model

The Business Model Canvas developed by Osterwalder and Pigneur (Osterwalder und Pigneur 201087) is a tool widely used in business to analyze the necessary foundations for a profitable business model.

The 9 individual elements of this analysis are not to be considered in isolation but interact closely with each other. In the following the concept of a Quartierstrom model approach is described on the basis of the Business Canvas Model. The central element is the value proposition. It describes the products and/or services in the form of a value proposition.

1. Value Proposition:
    a. With a Quartierstrom-model, producers can sell surplus photovoltaic electricity to consumers. This enables the prosumers to obtain higher remuneration for the renewable energy generated. The consumers benefit from lower electricity prices.
    b. Producers and consumers benefit from increased transparency, as they know where their electricity comes from. Self-consumption from the neighborhood district can be increased.
    c. By trading local electricity in the neighborhood district, the customer relationship with the product electricity and its origin is strengthened.

[86] Walther sieht etwa die Möglichkeit, dass ganze Gemeinden oder Quartiere ZEV bilden könnten (Walther (FN 4), S. 57.), während Föhse allzu grossen ZEV kritisch gegenüber steht (Föhse, (FN 48), N. 20).

[87] Osterwalder, A., & Pigneur, Y. (2010). Business model generation: a handbook for visionaries, game changers, and challengers. John Wiley & Sons.

d. The set-up also ensures stronger customer loyalty with the utility company.

e. The system reduces network costs for the distribution network operator and thus also for the end customer, as power-peaks can be capped and therefore the electrical power utility pays less to the upstream supplier.

f. The network system operator can use the data collected from trading for billing, which can simplify the billing process.

g. At a later date, the collected data could be used in aggregated and pseudo- anonymous form for further business processes (grid expansion, load management, offering flexibility as a primary balancing energy etc.)

2. Customer Segmentation: There is the utility company as network operator, the consumers and the producers. Producers with self-consumption-optimization-opportunity are important customers. A further target group includes technology enthusiasts as customers, as well as customers with an interest for green electricity that are willing to pay an extra fee per kWh for being part of a self-consumption community.

3. Channels: The communication channels of the platform can be used to communicate with customers and project partners via the platform, blog, newsletter, on-site events and e-mails. The distribution and sales channels would be via the electrical power utility, solar technicians, mailing and telephone campaigns.

4. Customer relationship: A customer relationship exists with the grid operator in the form of an electricity supply contract. There is also a customer relationship between prosumers, distribution grid operator and consumers with the platform operators.

5. Revenue Stream: The platform operator can either charge a fixed usage fee for the platform or a fee per kWh of traded electricity. As a third option, the platform could be sold as a white label product and then generate the following revenue streams:

   - A fee based on the number of registered end users
   - A fee per registered production plant depending on its capacity
   - A fee per kWh traded
   - Selling the App to potential household customers

6. Key Resources: The key resources are the software development team, the trading platform implementation team and the customer interaction team. The utility company is a central key resource in addition to the customer base. On the infrastructure side, the smart meters with a and an operating system per producer and consumer are central, as are the trading and visualization software, the smart meters and the fiber optics/powerline infrastructure.

7. Key Activities: The key activities were the provision of trading services (including customer service + quality assurance) and the management of the platform (including maintenance).

8. Key Partners: The key partners are the energy supplier and the metering service provider for reading the meter data.

9. Cost Structure: The costs for an online energy marketplace can be divided into two elements: Firstly, the costs for setting up the platform and secondly, the costs for operating the platform. The costs for an online energy marketplace, as in Walenstadt, can be divided into two elements: First, the costs for setting up the platform and second, the costs for operating the platform.

Self-consumption community as a possible business model

This chapter attempts to determine, using a comparative approach, whether the neighborhood self-consumption community could become a business model for a start-up under current or liberalized legal conditions. However, the cost of the Quartierstrom project in Walenstadt cannot be taken as a benchmark because the project was as research project. A different approach therefore had to be chosen in order to be able to compare the costs and returns of a business model (see Table 1). The cost side was represented in this calculation by a cost estimate (wages, infrastructure, ...) for an existing start-up in the Blockchain sector with currently 7 employees (Table 2). The costs for the hardware were excluded from the calculation, since hardware with integrated ripple control can be charged to the general network costs of an electricity company (see Art. 8c StromVV paragraph 4). For example, the smart meter "Smart power" from Evulution (www.evulution.com) could be used, which meets all the requirements of a Blockchain smart meter. Additional hardware costs would make the business case less attractive.

	Parameter	Calculated on the basis of information from the following companies
Income of a start-up:	Fee per kWh and/or one-off fee	SEL[88], ewz[89], ewl[90], iwb[91], esolva[92], Ormera[93]
Costs/expenses of a start-up:	Wages, marketing, IT infrastructure	Start-up from the Blockchain-self-consumption community scene

Table 10 Parameters used to calculate a possible business case

In order to be able to quantify possible revenues, the fees for a self-consumption community (ZEV) were used as an analogy, since here a decentralized energy exchange is implemented similar to the one for neighborhood electricity. The self-consumption community fees of the companies SEL, ewz, iwb, ewl, esolva and Ormera were used. Ormera, and esolva charge a yearly fee, SEL a yearly fee and a one-time fee. ewz, ewl and iwb charge a fee per total self-consumed kWh (from rooftop and neighbors, excluding energy form the electrical power utility) (see **Error! Reference source not found.**). In the case of Ormera, a self-consumption community with a Blockchain will be set up. SEL also integrates boilers, batteries and heat pumps into the self-consumption community in order to achieve a high self-consumption. Thus, these two solutions are most comparable to the Quartierstrom-project. However, the Quartierstrom-solution offers even more functionalities with the trading platform. Table 4 shows how much revenue would be generated if a district in Walenstadt, with same size, energy consumption and same PV production were equipped as a self-consumption community-solution with the parameters in Table 3.

Table 4 also shows how many self-consumption communities of the same configuration as in Walenstadt would be needed before the system would reach the break-even point. It was assumed that in the first year of the start-up 5 such self-consumption communities could be installed, in the second year 10, in the third year 20, in the fourth year 40. Each following year the number of new installations would again double. Almost all solutions (esolva[94], ewz, iwb, ewl, ormera) require an average of at least 9 years with 838 to 1'776 Quartierstrom-self-consumption communities before reaching the break-even point. With the current legal framework and even with more liberal regulation, however, it will hardly be possible to find so many suitable neighborhood districts and equip them with a self-consumption community. Only SEL's solution, which is also the most expensive, would lead to the break-even point being reached within approx. 4 years, with 62 Quartierstrom- self-consumption communities (one-off set-up fee without hardware of 112,000 CHF plus annual income of 30,000 CHF).

These assumptions are based on the fact that the start-up company employs a constant 7 people. However, due to the high number of Quartierstrom- self-consumption communities, at a certain point the 7 employees will no longer be sufficient to handle the services and billing. Therefore, the profit thresholds calculated here are very optimistic.

In summary, it must therefore be stated that this business model is currently not realistic, unless the income for the start-up or the costs for residents are very high per Quartierstrom-clone. The business model assumptions are also highly ambitious, with the calculated 7 employees for the start-up. The chances for a realistic business model would increase if the legal framework for self-consumption communities were to be liberalized. Today's conditions for a self-consumption community (especially with regard to the grid entry point and the ban on shared use of the distribution grid) are deliberately restrictive in order to counteract excessive

[88] https://smartenergylink.ch/
[89] https://www.ewz.ch/de/geschaeftskunden/solarenergie/solarenergie-fuer-eigentuemer/eigenverbrauchsgemeinschaft.html
[90] https://www.ewl-luzern.ch/privatkunden/energie/strom/produzieren/eigenverbrauch/
[91] https://www.iwb.ch/Fuer-Zuhause/Solarenergie/Solarstrom-nutzen.html
[92] https://www.esolva.ch/angebot/zev-b2b
[93] http://ormera.ch/

loss of solidarity; there are calls for these conditions to be softened so that in future "virtual self-consumption communities", e.g. behind a transformer, would also be possible.

Unfortunately, no exact figures are available for the current number of self-consumption houses or self-consumption communities in Switzerland. According to VESE[95] there are around 500 self-consumption communities in Switzerland. Since no predictions can be made about the number of new buildings or self-consumption communities, the approach taken here is to determine how many buildings with several consumption points in an apartment building already have a PV potential. The company Geoimpact has - based on its Swiss Energy Planning Tool - made some calculations for the author to give some clues for possible self-consumption community-potentials, since self-consumption houses can be a possible driver for the merger to self-consumption communities if neighboring buildings can be connected without using the public grid network.

In Switzerland there are 66'575 plots with more than 10 consumption points and at least 3 kWp PV potential, of which 62'162 are multi-family homes with more than 10 apartments. There are also 356'337 buildings with a PV potential of at least 30 kWp, which could also be a nucleus for a possible self-consumption community-solution.

Cost factors	**Swiss Francs**
Wage costs (Assumption of average wage is 100'000 CHF of the 7 employees) and occupational benefits (21.6 % of wage for AHV, ALV, NBU, BVK)	851'000
External software programming (blockchain)	150'000
Office costs 250 CHF per workplace and month[96]	21'000
Marketing budget	59'000
IT costs 200 CHF per employee and month[97]	17'000
bookkeeping (150 CHF per month) [98]	2'000
Total per year	1'100'000

Table 11 Assumption of yearly cost of an existing blockchain start-up providing self-consumption community

Quartierstrom-Parameters	Values Jan. 2019 to Jan. 2020
Number of measuring points/households	32/37
Total energy consumption (in kWh)	469'467
Production volume of PV in the neighborhood district (in kWh)	152'669
PV electricity fed-in into the grid (in kWh)	100'418
Self-consumption (in percent)	32 %
Compensation for PV feedback in the neighborhood power project (cent/kWh)	4
Payment for PV energy feed-in for all other districts of Walenstadt (cent/kWh)	9
Grid costs for electricity purchases from within Quartierstrom (in centimes/kWh)	5.79
Grid costs for electricity purchases from WEW (in centimes/kWh)	10.08

[95] VESE – Verband unabhängiger Energieerzeuger – eine Fachgruppe der SSES
[96] http://www.derhauptsitz.ch/#patenschaft
[97] https://www.runmyaccounts.ch/2013/07/wie-viel-kostet-ein-mitarbeiter-wirklich/
[98] https://www.startups.ch/de/services/buchhaltung

Table 12 Quartierstrom parameters, based on the setup in Walenstadt[99]

	Self-con-sumption community/ Block-chain-solution	revenue per kWh (cent-imes)	revenue per smart meter	fixed fee	Annual income for a self-consumption community-Quartierstrom-solution	*Number of solutions implemented to cover start-up costs*	Number of years to reach break-even point
iwb	self-consumption community	5.0	0		7'746[100]	1'421	10
ewz	self-consumption community	4.0	0		6196	1'776	10
ewl		3.0			4'647	2'367	10
esolva	self-consumption community		95 CHF per metering Point and year		7'030[101]	838	9
Ormera	self-consumption community **with Block-chain-billing**	0	118 CHF per meter and one-time fee of 5000 CHF		13'732	953	9
SEL SMART ENERGY LINK	self-consumption community	0		110'780 CHF in the first year, subsequent years 5,920 CHF	110'780 CHF in the first year, subsequent years 5,920 CHF	62	4

Table 13 Company-earnings for self-consumption community-solutions (ewz, ewl, iwb, SEL and esolva) and a self-consumption community-blockchain solution (Ormera)

The idea of selling the collected data of a household or neighborhood for marketing purposes or additional business models does not work out, as the StromVV and the data protection act are very restrictive in this respect.

Costs for prosumers/consumers in these business models

Here the perspective is changed, and the costs are considered from the perspective of the prosumers/consumers, since they ultimately have to pay the fees for a self-consumption community and help to reach the break-even for the business model if these prosumers/customers implement such a solution. In this chapter, costs are defined the following way:

- Electricity costs (energy and grid costs) plus self-consumption community service fee costs minus feed-in tariff.

A cost comparison for prosumers/consumers between the following scenarios was made:

[99]

[100] 154´920 kWh * 5 cents/kWh

[101] =95 CHF per metering point*37 housolds*2 meters per household

- Costs in the Quartierstrom-project (scenario 1), grid levels 1 - 4 do not have to be paid (scenario 1)
- Costs of Quartierstrom with the fully allocated grid costs (levels 1 - 7) (scenario 2)
- Costs if each household in the district with a PV system on the roof consumes the electricity itself as far as possible (self-consumption model without self-consumption community and neighborhood district-internal trade) (scenario 3)
- Costs of a self-consumption community with a solution from ewz, ewl or iwb (scenario 4)
- Costs of a self-consumption community with the SEL solution (scenario 5)

In order to compare the different models, the costs of Quartierstrom-projects are taken as a reference in each case with the full allocation of grid fees (scenario 2), as partial allocation of grid levels is not legally permissible in Switzerland. The parameters for this can be found in Table 6.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Self-consumption (%)	18	18	18	18	18
Electricity from the neighborhood (%)	15	15	0	15	15
Feed-in tariff (in centimes/kWh)	4	4	9	9	9
Grid costs for electricity purchases from WEW (in centimes/kWh)	10.08	11.41	11.41	10.08	11.41
Grid costs for electricity purchases from the neighborhood district (in centimes/kWh)	5.79	10.08	11.41	11.41	11.51
Energy costs, excluding network costs HT/NT (in centimes/kWh)	7.72	7.00	7.00	7.72	7.00
Quartierstrom-internal remuneration PV electricity (average price of traded energy) (in centimes/kWh)	9.84	9.84	-	-	-
Number of buildings/flats	32/37	32/37	32/37	32/37	32/37
Number of heat pumps	28	28	28	28	28
Number of PV systems	26	26	26	26	26
Number of battery storage systems	9	9	9		9
Quartierstrom energy consumption from January 2019 to January 2020	469’467kWh	469’467 kWh	469’467 kWh	469’467kWh	469’467kWh
Yearly fixed grid fee (37 households) (in CHF) for the whole neighborhood	2’960	2’960	2’960	2’960	2’960
Total Grid cost (in CHF) for the whole neighborhood	38’946	55’651	38’946	54’231	54’231
Energy costs (in CHF) for the whole neighborhood	31’291	29’828	30’720	31’291	30’720
Return tariff for surplus energy	4`017	4´017	6´792	9’038	9´038
self-consumption community service fee				6’196	111’878
Total costs (in CHF)	66’220	**78’702**	**71’687**	81’506	**189’874**

Table 14 Cost comparison of different scenarios (all with 37 households consuming as much electricity as the Walenstadt project (for the period January 2019 to January 2020))

Place	Scenario	Difference to Reference Scenario in %	Difference to Reference Scenario per Year
1.	Self-consumption solution (Scenario 1)	19 % cheaper	15’286 CHF cheaper
2.	Quartierstrom without full grid charges (Scenario 3)	12 % cheaper	9’818 CHF cheaper
3.	Quartierstrom with full grid charges (Scenario 2)	3.4 % cheaper	2’804 CHF cheaper
4.	Walenstadt with simple self-consumption community solution (Scenario 4)	reference-scenario	reference-scenario
5.	SEL-solution (one-off costs paid the first year) (Scenario 5b)	133 % more expensive the first year, and afterwards 5 % more expensive	108’368 CHF more expensive the first year and afterwards each year 2’726 CHF more expensive, yet additional benefits are to be expected which are outside the scope of this analysis

Table 15 Comparison of the different scenarios

Considering all costs and revenues of the prosumer/consumer, the Reference Scenario is therefore not the most economical solution. The most economical is the Quartierstrom-solution. However, due to the actual regulatory restrictions this setting can’t be copied at the moment in other regions. A simple self-consumption solution or a simple self-consumption community solution would be more economical under the actual legal situation in Switzerland. However, a simple self-consumption (EVG) within a house no synergies by building up a self-consumption community could be leveraged.

The Scenario 5a and 5b is from point of view of a start-up the most attractive one. However, the self-consumption community has to spend the first year a one-off fee of 112´000 CHF, which might be for many potential self-consumption communities to high. The financial more or less attractive solution would be spreading the one-off fee over 5 years.

If one leaves the purely economic perspective of a start-up, there are the following points which nevertheless speak in favor of a neighborhood community model:

- The system lowers the network costs for the distribution network operator and thus also for the end customer, as the power peaks can be capped and therefore, less has to be paid to the upstream supplier. The participants in such a Quartierstrom-model do not receive any additional revenue for this network service today.
- At a later date, the collected data could be used in aggregated and anonymized form for further business processes (network expansion, load management, etc.). Above all, the provision of flexibility (primary and secondary energy) could make an additional financial contribution.

11.4 Q&A on Business Model from an author’s perspective

Author: Nick Beglinger, Cleantech21 Foundation

1. How can different local communities best/the fastest-possible be built/marketed?

(Wie werden verschiedenste lokale Communities am besten/schnellsten aufgebaut/vermarktet?)

The best way to assure the rapid development of prosumer-centric energy market is to set the incentive structure right, such that all market participants are motivated, from a purely financial point of view, to invest in local energy infrastructure and partner with others over the public grid. Key in this respect are network regulations and standards. Today, trading energy over public networks is still prohibited (not even pilot licenses are available), and network regulations disincentivize networked prosumption (network tariffs do not reflect true costs, the market for selling and buying power is not efficient from a prosumer’s point of view).

2. What is the interplay between the business model/value chain and the consensus mechanism?

(Wie spielt das Business Model/Value Chain und der Consensus Mechanismus zusammen?)

There is little direct relation between the business model and the consensus mechanism. In fact, the business model is much more driven by regulatory than by technological drivers. Furthermore, blockchain technology should not be regarded as the only (or even the key) technology for prosumer-centric energy communities. Rather, it is the combination of IoT, DLT and AI that, together, represent a technological innovation opportunity. In order to operate an energy community such as Quartierstrom, with a central player active as service provider, there is little need for the application of blockchain technology in the first place. This is likely to change, however, once communities are organized in a fully distributed manner, e.g. as decentralized autonomous organizations (DAOs).

3. With which key drivers – price, autarky and sustainability – can prospective customers best be reached? What would be the best branding?

(Mit welchen der Hauptfaktoren Preis, Autarkie und Nachhaltigkeit erreichen wir unsere Kunden am besten? Was wäre das beste Branding?)

It is possible to reach a niche market based on autarky and sustainability, as for some market participants these factors carry strong emotional/intrinsic value. However, in order to bring prosumer-centric energy markets to the mainstream (and thus renewable energies to rapidly scale), it is price, and only price, that counts (as is the case in almost all other markets).

The branding should reflect the key novelty in the business model approach – and that is the turning-on-its-head of the traditional centralized/top-down energy market, to a decentralized/bottom-up market. Furthermore, the branding should empower prospective customers to take energy in their own hands (i.e. invest in the necessary, decentralized and infrastructure-integrated assets they control).

4. Which data sources permit the foreseen application functions (e.g. the calculation of the tariff charged), and at what costs?

(Welche Datenquellen erlauben die vorgesehenen App Funktionen (z.B. Errechnung Stromtarif eines Interessenten), zu welchen Kosten?)

The foreseen application functions (those allowing a bottom-up energy market over public networks) depend on a large number of data sources. At the core of it all is the smart meter (or ‘energy gateway’), representing the intersection between a user’s internal network with the public grid. Additionally, different prosumption infrastructure needs to be IoT-enabled, allowing, for example, in the context of a particular energy market situation, a battery to stop charging, or a heat-pump to start working. Also, as production and consumption will fluctuate, weather-related information sources play a role. Furthermore, while bottom-up energy is emerging, information relating to the electricity market situation outside of a prosumer community is relevant. Lastly, information on network tariffs, as these will increasingly be dynamic (time and location dependent), is of course also very relevant.

The costs of these data sources are difficult to determine in a generic way. They will also rapidly evolve (scaling effects, etc). The Quartierstrom pilot as well as other projects have demonstrated, however, that neither the cost of technology (or the energy needed to run it), nor the cost of data are the main cost drivers in prosumer energy networks. The main cost drivers are the infrastructure investment costs (assets and installation) and network tariffs.

5. How to best identify target markets?

(Wie werden Zielmärkte am besten definiert?)

For developed energy markets, given the importance of the regulatory framework, target markets should be identified where regulations permit bottom-up energy communities. Prior to the enactment of the needed regulatory innovation, this will include selected target areas for which a local utility is cooperating and enabling pilot operations (in exchange with the energy market authority).

For developing markets, where no or limited network infrastructure and regulatory barriers exist, the situation is very different. To identify the right target markets there, existing local knowledge and operating/service capacity seem the key selection drivers (apart from finance available, e.g. as part of development aid or philanthropic activities).

6. What is the relevance/importance of a prosumer smart-meter?

(Welcher Stellenwert hat ein Prosument-Smart-Meter (bez. Marktposition, Identifikation, Community-Performance)?)

The current smart-meter approach was defined as part of traditional top-down energy markets – with utilities and consumers, and not prosumers in mind. If a prosumer invests in energy infrastructure that provides 50% or more of the prosumer's power needs, market participation dynamics change, and so those the role of the smart meter (and the utility, other energy market participants). Prosumers should be the owners of the information gathered by the smart meter. They will want to use that information to their (and not the utility's) advantage. They will want to be in charge of their inhouse power management, and also regarding network access (i.e. selling and buying decisions as part of overall prosumption optimization). A prosumer smart meter must thus be regarded as a vital element for the emergence of prosumer energy communities.

7. Which would be the best hardware strategy?

(Was wäre die beste Hardware Strategie?)

The best hardware strategy for a prosumer smart meter is 'open source' and 'standards based'. Different from current smart meters, data should be allowed to be shared among different market participants (from regulatory bodies to hardware manufactures). Open source also makes sense with respect to security, and as a differentiation to current smar -meter providers. Because smart meters have a vital role to play with respect to network monitoring, a standards-based approach presents itself. Standards will facilitate network monitoring (for security of supply as well as the calculation of the soon-to-by dynamic network tariffs), and they will speed up adoption (allowing different market players to interact as part of a prosumer's energy solution). The smart meter should be engineered in Switzerland and produced in many places, close to where it will be deployed. There should be possibilities to add hardware components – such as interfaces to other measuring infrastructure, for new functionalities, etc.

8. How secure is a software-only strategy?

(Wie sicher ist eine Software-only Strategie (insbes. bez. Datenzugang)?)

A software only strategy could make sense if an open source prosumer smart meter would be available in the market, and if regulations would permit bottom-up energy communities over public networks. As this is not the case, any software-only business model would be at the mercy of data being shared by the existing smart meter producers and their operators. Given the central role of a smart-meter as part of a prosumer's overall infrastructure, its relevance concerning the interaction with the regulator, the power-dynamics with the local utility, as well as its relatively low cost compared to other prosumer energy infrastructure – such as PV panels and batteries) a hard- and software strategy is considered to be the most sensible way forward.

9. What is the foreseen interaction with (i) the local utility/network operator, (ii) other power market participants, (iii) the network regulator?

(Wie ist die Interaktion mit (i) dem lokalem EVU/Netzwerk Betreiber, (ii) weitern Strommarkt Akteuren, (iii) dem Netzregulator?)

(i) For developed markets, the interaction with the local utility is currently key regarding network provision. Once network regulations have changed, the significance of the utility diminishes. Important to note in this respect is that the term ‘utility’ includes a range of different market activities. Some of these are in the process of being heavily disrupted (e.g. the sale of power, given that prosumers start to emerge and cover at the very least a substantial share of their power demand with their own distributed energy infrastructure). Other activities will continue to be important in a bottom-up context, in particular the servicing of the local distribution network. In the short term, the utility interaction will remain key until all regulatory barriers are systematically removed – as only with the utility’s active participation, a pilot setup can be run. Once regulations are where the author believes they should be (reflecting the true costs of network usage), interaction with the utility will depend on the utility’s strategy and positioning, as well as on the preferences of prosumers. In the one extreme, utilities could act as a community’s main service provider, centralizing aspects of reporting, billing and interaction between the community and third parties. On the other extreme, the role of a utility could be reduced to being a community participant, contributing the network as shared infrastructure asset, while prosumers self-organize with decentralized approaches (such as DAOs). In many developing markets, neither utilities nor networks exist in certain areas, and thus their role is different and may be very limited from the outset. Theoretically at least, in both developed and developing markets, a energy system without the current ‘utilities’ can be envisaged, one in which energy flows between prosumers bottom-up, without the utility as a ‘middleman’. Such system, however, will still depend on service providers in specific areas – and it is forward-thinking utilities who are best positioned for many such service provider roles.

(ii) Important with respect to other market participants are commercial consumers of large amounts of energy (such as power-intensive businesses). Prosumers should be empowered to sell power to these businesses. A prosumer’s excess power generated during the day (when production is greatest, many prosumers are not at home, and thus have little power demand) should be made available to businesses (with their peak power demands during that time). This should be regarded as a key lever to rapidly transit to renewables and reduce dependence of imported energy. Other power market participants, such as whole-sellers of energy and operators of larger-scale production or storage infrastructure, are foreseen to interact with individual prosumers or prosumer communities similarly to how they are currently interacting with a local utility – as third parties, on business terms.

(iii) It is anticipated that prosumers will eventually directly interact with the regulator, through their smart meters. The regulator thereby would set infrastructure quality and data standards. The regulator would also have the right to certain data from each market participant, allowing for the monitoring of overall network performance and the right decisions with respect to capacity markets, new public network infrastructure, etc.

10. What is the role of providers of smart home systems?

(Was ist die Rolle der Smart-Home Anbieter?)

The smart home market is already substantial and includes some of the world’s most powerful companies. These shall not be regarded as competitors but rather as distant partners. The open source smart meter shall interact with smart home systems, so that these can be integrated into the prosumers overall energy management. In this context, again, a standards-based approach assuring the interoperability of energy-related data is vital.

11. Who are the best partners, who is competition?

(Wer sind unsere besten Partner, wer ist Konkurrenz?)

Prosumers (e.g. homeowners), providers of energy infrastructure (e.g. a utility, with the local network and a community battery), and consumers looking to source price-competitive renewable energy (such as nearby businesses) are the target customer groups. Several energy market participants represent interesting partners. This includes the producers of distributed energy equipment, planners and installers, as well as providers of related data (such as weather, wholesale energy market prices, etc). Depending on regulations and a utility’s positioning, it can either be a close partner or a ‘competitor’ in the sense of a non-partner for piloting communities. Direct competitors are firms offering similar prosumer value propositions and those working in the field of distributed energy management (PowerLedger, Grid+, EWF, etc).

12. Which areas need further research?

(In welchen Bereichen braucht es Forschung?)

Key to unleashing distributed renewable energy is not more technology research but better network regulation. The technology is largely available. Development efforts should focus on scaling technological innovation, with these domains benefiting from further research:

Specifying and testing different models of true-cost network regulation with dynamic tariffs. Ideally, models reflect the cost of every network-meter and every additional infrastructure component needed, while also adapting to the actual network usage at the time. 'Capacity markets' shall be included, as these will increasingly work with capacity allocations in distributed prosumer storage system.

Defining quality- and data-standards for bottom-up energy network policy. This is key for assuring quality network operations as well as interoperability between different devices, service domains, etc.

Further work on the technicalities of dynamic network tariffs, evaluating all relevant parameters (outside any prevalent political preferences, which, if needed, can be introduced subsequently with full awareness regarding their effect on true/fair pricing). Measurement shall be assumed to take place via the distributed, network-connected, open source smart meters. Important to note in this respect are the ongoing political processes calling for such regulation.

Prosumer value-at-risk models, including different scenarios regarding available infrastructure, different demand patterns, and various types of network tariffs – with the goal to, as a regulator, be able to set network tariffs such that prosumption is systematically incentivized (i.e. that infrastructure investment decisions are optimized in a networked context, optimized for overall network performance as defined by a combination of technical and political drivers).

Prosumer smart agent, optimizing prosumption decisions based on: (i) asset-owner defined preferences- (e.g. degree of desired autarky, temporary demand shits…such as for EV travel), (ii) optimized energy management of local energy infrastructure (production, storage, and consumption), and (iii) optimized interaction with public network (buying/selling decisions at the prevailing market conditions, customized with communities and/or centralized service providers, or in an open market).

13. What is the best organizational strategy?

(Was ist die beste Organisationsstrategie?)

It is premature to specifically define the optimal organizational strategy. In general, the focus shall be on software and standards development, as well as hardware engineering. Large-scale customer service/support operations as well as hardware production, shall be outsourced. Switzerland offers advantages as organizational center, whereby the type of talent involved requires flat decision making structures, and a decentralized operating approach.

14. What are the risks?

(Welche Risiken bestehen?)

The two main risk-drivers are regulations and competition. They are closely linked as those market players who can operate under regulatory frameworks that allow for piloting and then scaling up have a distinct competitive advantage over others. There are also uncertainties on the technology front – e.g. the specific role of AI in the management of bottom-up energy networks is not yet well understood. These uncertainties, however, are of limited significance to the overall value proposition (as a system without such uncertain components would still excel in terms of functional advantage vis a vis the status quo).

15. What is the financing need, which the best financing strategy?

(Was ist der Finanzierungsbedarf, die beste Finanzierungsstrategie?)

The data generated by the Quartierstrom pilot was not yet sufficient to develop detailed business modelling for a fully prosumer-centric approach. Key pricing points are still uncertain – such as dynamic tariffs for public network usage, prices paid for capacity-type services, value-at-risk-type consideration on the prosumer/asset-owner side, etc. Despite the lack of details, some drivers regarding financing need and financing strategy became apparent:

I. Given the considerable regulatory risk, a sufficient liquidity buffer must be available. To limit liquidity need, team size shall initially be kept small. Research and related activities shall continue to be co-finance through public, academic, and philanthropic partnerships.

II. Given the open-source and bottom-up focus of the venture, it clearly lends itself to crowd financing. This is best done after a first or second round of see finance.

III. The specific type of best financing for the venture can only be defined once the strategic decision on structure, and linked to that, for- or not-for-profit nature, has been determined. This has not yet been done. The core motivation of the team is to accelerate renewable energies in order to address the climate crisis. Should a not-for-profit structure, however, prove difficult to finance and thus scale, a different approach may be chosen.

11.5 Background Review on Prosumer-centric Business Models

Author: Nick Beglinger, Cleantech21 Foundation

As per the objectives specified at the outset of the Quartierstrom pilot, the project shall develop a working prototype for managing a prosumer-centric energy community. Here, the various options with respect to a business model for the pilot shall be reviewed, and opportunities to scale-up post-pilot operations are highlighted.

Key takeouts:

- The energy market is rapidly changing, driven by the emergence of distributed renewable energies and the advent of disruptive digital technologies (incl. IoT, DLT/Blockchain, and AI). This leads to regulatory uncertainties but also offers unprecedented market opportunities for new and existing players.

- Quartierstrom's key objective is to enable prosumer-centric energy communities, independent of the technology engaged to do so. Given that this essentially entails the linking of *distributed* prosumers, the application of *distributed* ledger technology makes sense. Key is to select the right type of DLT, assuring appropriate consensus mechanism, interoperability with other communities, transaction speed and scalability, as well as low costs per transaction.

- Quartierstrom, in cooperation with its commercial partners, should find market potential in both developed and developing countries – in markets with or without existing grid infrastructure, incumbents, etc. The key challenge for success will not be on the regulatory front (where at least 'sandbox' regulation will likely be available), but rather on alternative solutions by competitors.

- The project's key differentiator is not so much 'being Switzerland's first local energy market'1 but rather the first 'energy community operating over public network infrastructure'.

- Long-term competitiveness and business model success depends on rapid scale-up and thus partnering. Regulation will unlikely be a stumbling block. Specific revenue stream can be defined at a later stage.

General Energy Market Considerations

The current 'energy market' is in flux. Climate-related pressure, changing risk perspectives (e.g. concerning nuclear, stranded fossil assets), as well rapid technological innovation (both concerning core energy infrastructure as well as the digital domain) lead to fundamental, disruptive changes[102]. Traditionally, energy was regarded as a highly regulated market with considerable

[102] Given the urgency of action in climate, different reports emerge on the needed measures in different domains, including energy. Their analysis shows that electricity generation needs to be carbon free by (or even before) 2050 and that the needed transition to reach that goal will need to be 'exponential' and will be 'disruptive'. The specifically refer to the need for

barriers to entry for new players. It required large investment, was strongly influenced by state and regional monopolies, and regarded to include a significant 'regulatory risk' for investors.

The rise of renewable energies, and in particular the notion that a large part of future generation and storage will originate from small distributed sources rather than large central ones, now brings forward unprecedented opportunities for new market entrants – and at the same time threatens incumbents.

Because of the important role of energy-related regulation as well as diverse geographic/climatic, social and cultural aspects, energy markets differ greatly from country to country. As a consequence (and a difficulty for traditional energy-related businesses), each national market requires a customized review in terms of the feasibility of any particular energy-related business model. And, two main market-categories need to be differentiated:

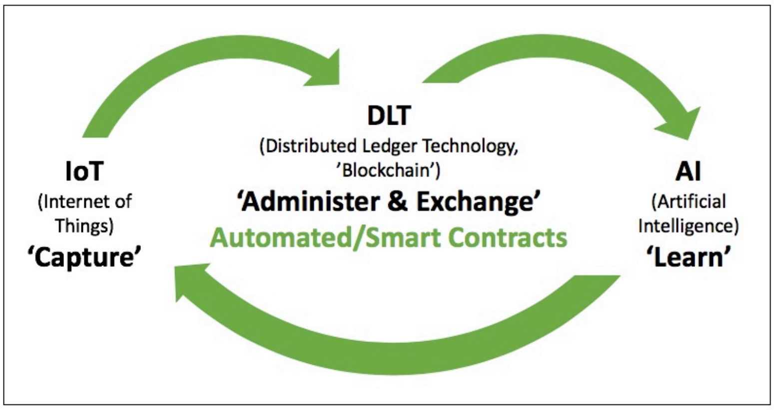
- Developed energy markets with existing grid infrastructure and incumbent 'utilities',
- Developing energy markets with no grid infrastructure and to a large extent with only few significant incumbents.

In both of these main market categories, different energy market players may take charge of one or several functions in the energy value chain. Which function(s), depends on the prevailing regulatory frameworks, the competitive situation, as well as the particular strategy elected by the individual market player. Given the significant drivers for change regarding regulatory and technological innovation, both market categories are currently experiencing significant risks and opportunities.

The 'Energy-Blockchain Market'

With the generally recognized trend of energy provision moving towards distributed renewable systems, it seems logical that 'distributed ledger technology' (DLT, aka 'blockchain') is gaining attention in the context of energy. Despite this, however, it is important to note that it would be wrong to speak of an 'energy-blockchain market', for the following reasons:

- The main objective is not to apply a particular technology to the energy market, but rather to find solutions to manage the integration of distributed renewable energy sources as part of a robust and fair overall system of energy provision that allows for the rapid transition to renewable energy and is carbon free by or before 2050.
- Real-world use cases demonstrate that the application of DLT is generally complemented with other technologies (e.g. dynamic web applications, smart contracts, IoT, AI). For business models applying DLT, as well as for those which don't, key is to offer a competitive value proposition independent of the technologies engaged.
- There are many types of DLT, one of them being 'the blockchain'. If at all, a business model may differentiate itself competitively by applying a specific type of DLT for specific tasks in the overall business proposition. The drivers behind the decision if and which DLT is to be applied are technical (scalability, user interface, interoperability, etc.), economic (transaction costs, information sharing incentives, etc.) as well as regulatory (data privacy/ownership, quality standards, smart-meter-related issues, etc.).
- According to several observers103, DLT will have a far-reaching, disruptive effect on almost all industries (energy being one of them). It is compared to the internet in terms of its overall



technologies such as distributed renewables as well as DLT, IoT and AI. One example of such a report is 'Exponential Roadmap' (http://exponentialroadmap.futureearth.org).

[103] Including WEF06/2017 (http://www3.weforum.org/docs/WEF_Realizing_Potential_Blockchain.pdf) & The Economist 10/2015 (https://www.economist.com/leaders/2015/10/31/the-trust-machine)

disruptive/innovation force. As was and is true for the innovation-power of the internet, however, it is wrong to think of DLT as an ‘industry’ or ‘business model’ by itself. Rather, DLT will become part of business models in many types of industries – whereby the actual use of the technology is integrated into a business value proposition without end-users actually realizing that DLT is involved.

In sum, this means that the Quartierstrom project shall not primarily be seen as an ‘energy-blockchain’ project, but rather as the first step towards a ‘prosumer-centric distributed renewable energy community’. As for all other projects, the decision to apply (or not to apply) DLT, is best taken on the basis of whether it is with DLT that the underlying value proposition elements can be offered in a competitive way. Thus, the task is predominantly a technical one, i.e. one of translating the specifications of the value proposition.

At present, there are in excess of 200 projects/companies internationally, which broadly fall in the ‘blockchain for energy’ category. There are numerous papers, analyzing and referencing the various types of projects[104].

Ongoing efforts include various value propositions – from energy wholesale trading and certificates of origin verification, to Quartierstrom-comparable community management approaches. The most relevant ‘competitors’ are: Energy Web Foundation[105], Grid+[106], PowerLedger[107], Swytch[108], MeSolShare[109] as well as the organizations behind selected pilot projects ongoing in Germany, in several Nordic countries, as well as selected ones in Asia and the Americas (incl. the first practical effort in Brooklyn[110]).

For a project such as Quartierstrom, the relevant ‘market’ is not ‘energy-blockchain’ but ‘prosumer-centric energy’. This relates to both developed and developing markets. In the former, the main challenge is to enter a space cluttered with incumbents, many rules and regulations, and many of them in flux, as well as several new players entering the market. For the latter, there is little or no existing infrastructure, as well as local regulatory uncertainty beyond the energy domain. In both markets, attractive energy-community opportunities will exist, if and when the pilot is ready to scale. A solid partnership strategy is thus of decisive importance.

Grid+ energy gateway (‘prosumer smart meter’) ©Grid+

‘Blockchain’ or Not?

In the light of ‘blockchain’ (i.e. DLT) receiving much attention during the past 24 months, several studies have appeared, all elaborating on when to apply blockchain and when not (generally, not just for energy). There are different approaches and methodologies to this[111], but they all center around the following key questions:

- Does the business model involve a distributed set of stakeholders using common data base?
- Is there distrust among these stakeholders?
- Do stakeholders want to shape the rules with which they transact?

[104] This is one example by Solarplaza, https://ipci.io/wp-content/uploads/2017/12/Energy-Blockchain-Report.compressed.pdf
[105] https://energyweb.org/
[106] https://gridplus.io/
[107] https://www.powerledger.io/
[108] https://swytch.io/
[109] https://www.me-solshare.com/
[110] https://www.brooklyn.energy/
[111] This is one example by IEEE, https://spectrum.ieee.org/computing/networks/do-you-need-a-blockchain this another by NIST

If the answer to any one of these questions is ‘no’, DLT is unlikely to be the right approach from a business model and/or a technology point of view. If any one of the answers is ‘yes’, DLT may represent the right approach (noting that also in such case there would be alternative technologies available).

For Quartierstrom, the above questions bring about the following answers:

- Yes, the project involves different stakeholders (different prosumers, different owners of network and other infrastructure, etc.) sharing their ‘prosumption’ (production, storage, distribution) data.
- Yes, the different stakeholders don’t trust each other as they represent independent agents, each optimizing their role in the energy value chain.
- Yes, community members are best seen as independent peers. Together, they form the community and want to have a say in the way ‘their’ community functions.

It can thus be safely concluded (as well as derived from similar projects) that Quartierstrom does fit the criteria for applying DLT. Furthermore, the ‘prosumer-centric’ attribute in Quartierstrom’s core value proposition indicates that there is a clear value of offering decentralization and a fair consensus mechanism for how individual members cooperate in the community (i.e. good reason for applying DLT), as well as how they share/monetize their consumption data.

Which DLT & How?

More challenging than the DLT yes/no question is the one relating to which type of DLT is best to be employed – and how to do so most effectively, in cooperation with other technologies, to arrive at a winning prosumer-centric energy community solution.

The choice of DLT fundamentally entails the selection between permissioned (only some users can join) or permission-less ledgers (anyone can join). In the light of underlying business model drivers:

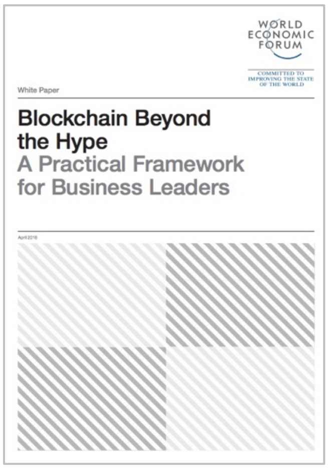
- Different communities and service providers will choose different ledgers. The market will likely see both permissioned and permission-less energy ledgers. A regulator’s target should be to also see transactions between them, allowing communities to cooperate and to follow the bottom-up logic for organic upwards expansion.
- One energy community (e.g. in a certain area/with a certain network usage, licensed and operating in line with the prevailing regulation) may be seen as a permissioned community in the sense that only those prosumers/users can join who are in the covered network area and operate equipment and processes that comply with regulation.
- On the other hand, it could be envisaged that there is one ‘global energy ledger’, ultimately open to everyone.
- Given the fact that various ledgers are currently being tested and implemented, the ‘global’ roll-out approach should be to allow for interoperability of ledgers, independent of whether they are permissioned or permission-less.
- A global ledger may serve as an ‘interoperability-bridge’ to numerous local, regional, and maybe also national and international community-ledgers emerging and cooperating by forming larger communities as they expand (and thus are benefiting from lower energy prices and higher energy provision quality as they grow).
- The best choice for the Quartierstrom pilot is to examine and test different DLT approaches. A permissioned ledger is likely the right choice for a pilot implementation.

The difficulty of selecting the right DLT approach results from the fact that both detailed technical and business-process knowhow is required. From an energy technology and business perspective, these factors are key for the right distributed ledger choice for a prosumer-centric energy community:

- Consensus Mechanism: How decisions on the ledger are made is relevant for operational as well as positioning matters. Transparency and fairness must prevail. How decentralization, scalability/speed and cost factors are optimized must be clearly understood.
- Scalability, Transaction Speed: The number of transactions involved in running a distributed energy community is likely very high. It can generally be assumed that more transactions will lead to better network management (allowing a more

fine-grain tuning of loads) – and that optimal network management will depend on high transaction speeds (e.g. when working with virtual inertia).

- Transaction Costs: The costs of entering transactions to the ledger and of running the ledger. Given the need for a large number of transactions, the cost per transaction must be minimal.
- Interoperability: Likely, different stakeholders will start to form different communities, using different DLTs. A good ledger should thus be interoperable with other ledgers – those existing as well as those emerging.
- Ledger Governance & Security: Investing into the development of a system that works and conforms to the relevant regulatory frameworks will require considerable efforts on the part of those developing solutions. This, in turn, presumes confidence in the long-term governance of the underlying ledger technologies, as well as in the ledger's security parameters.



Important to note with respect to all these issues is the fact that different DLTs offer different ways to address transaction performance, by separating on- and off-chain transactions and by simplifying consensus. The implications of such measures, on each of the above listed performance factors, must be well understood.

Prosumer-centric Energy Community Value Proposition

Based on the exchange with the Selber[112]-Team of Quartierstrom-Partner Cleantech21 foundation, the value proposition of a prosumer-centric energy community is now being defined. Independent of such proposition, however, it is important to note that:

- Few prosumers make their decisions based on idealistic values, a movement at scale will only happen if/when prosumer-centric communities offer clear monetary benefits (which depends on technical and regulatory innovation).
- Energy represents a comparatively small share of a consumer's budget (be it in the household or at firm-level). This implies that, while there is interest in how energy is generated, stored, and managed, such interest is likely only very high at the outset of implementing self-consumption and when joining a prosumer community. During normal use, systems will have to run in a fully automated way, not requiring user-based actions (i.e. only for certain consumption preferences falling outside the norm – e.g. having an EV fully charged prior to starting a holiday trip).
- Households and firms will become increasingly aware of the importance of privacy with respect to energy data, as well as the value of energy-related consumption data that can be captured (in particular if systematically analyzed and processed).
- Bottom-up energy communities will likely emerge in both central and decentral organizational setups, meaning with or without certain master users who contribute infrastructure (such as a local distribution grid) and/or providing certain management functions on behalf of all community members (such as maintenance of shared infrastructure, buying/selling power to third parties outside the community, etc.). This implies that utilities, service providers (e.g. of an application that can be used across communities) as well as user associations (in traditional and decentralized autonomous forms) have opportunities for roles in the value chain.

[112] Selber (previously 'PowerID') is an energy venture by Cleantech21 and its partners. It originates from the planned cooperation between Nick Beglinger, Michael Bützer, Sandro Schopfer and Gian Carle – as per the first submission of the Quartierstrom Project. Sandro and Gian decided not to pursue commercial plans further, while Nick and Michael did. Selber thus entered into the Hack4Climate innovation program (H4C), first by representing a challenge in the H4C 2017 hackathon at COP23, and then entering the use case accelerator with an extended team. Selber performed research, partnership development (incl. Fraunhofer Institute and the International Solar Alliance), as well as different DLT tests in 2018. The Selber team is keen to cooperate with Quartierstrom during the pilot and to be part of operationalizing the knowhow gained with the Quartierstrom pilot.

The following 13 main business process elements of a prosumer-centric energy community value proposition were defined in cooperation with the Selber team:

1. Potential community member learns about prosumer-centric energy communities and distributed renewable energies via the website of a service provider (such as Selber), via installation partners (engaged for optimizing self-consumption), or via local utilities actively promoting bottom-up energy management (such as the utility in Walenstadt, partner of Quartierstrom).
2. Downloading the service provider's app allows the user to evaluate the potential benefits of being part of a community at the user's location (and stay up-to-date on local community developments happening).
3. A user joins a community by agreeing to do so and thereby subscribing to community rules.
4. Joining a community goes in line with the purchase of the user's energy gateway hardware (incl. professional installation of the necessary hardware to connect to any local metering infrastructure still required). The gateway is certified according to the quality- and data-standards set by the local regulator (assuring network stability in line with current smart-meters, but remaining under the user/prosumer's control and interacting with other users via the network according to community rules). Important to note is that the gateway may also serve a user independent of community access – e.g. with respect to assuring privacy when monetizing consumption data). Key is to recognize the gateway as the prosumer centric version of a 'smart meter', physically and data-wise assuring user data privacy and control.
5. With the gateway and a user's mobile phone, the user is identified/geo-located/verified.
6. With the gateway, a user registers/identifies her IoT enabled infrastructure/devices – allowing them to be managed as part of an automated system capable of managing demand/supply. across the network. Existing 'things' with high electricity relevance (e.g. a heat pump or boiler) maybe IoT enabled with additional hardware bridges.
7. With the combination of the gateway hardware and the community application's software, the user has a secure way to manage her energy-related data in a dynamic way (regarding community access as well as monetizing consumption data). User data is shared via the ledger and made accessible as part of a 'data marketplace'113.
8. Via a user's account on the service provider's app, she can customize her prosumption according to her preference (e.g. selecting between price and autarky/resilience performance, temporarily altering EV charging specifications for an upcoming long-range trip).
9. The community functions fully automated, without any further user interaction, optimizing performance according to user and network-wide parameters, which also integrates AI (learning from consumption patterns, optimizing individual user and network load management).
10. Via a user's account, her own prosumption performance as well as that of the overall community network can be monitored (individual prosumers and individual communities should best start to compete for performance). This includes suggestions on infrastructure upgrades for prosumers (e.g. an additional battery lowering the prosumer's overall cost and increasing her quality of supply) as well as for the community as a whole (e.g. a shared seasonal storage solution invested collectively by community members).
11. With the same account, the user manages a wallet, allowing her (i.e. her account) to make and receive payments for buying or selling energy and capacity from the network (from other community members or from power purchased collectively by the community from a third party).
12. The user's energy gateway also acts as a node for the distributed ledger network. Via the app, community members vote on community decisions (such as altering existing sharing rules, joining another community).

[113] Explain, Market Place, https://data.iota.org/#/

13. Via the gateway the prosumer also controls (i.e. shares and monetizes) all consumption type information gathered by the gateway (e.g. usage patterns of household devices, EV charging habits, etc.).

Specific Business Model Options

While the value proposition of a prosumer-centric energy community is apparent, the business model of running a single community, as well as a service solution for multiple communities/diverse prosumers, is not. With the fundamental assumption that, under the right technology deployment (high speed, low transaction cost, straight-forward/fair consensus) and true-cost network regulation (time and space dependent), prosumer-centric energy will be the lowest cost and highest resilience option for households and businesses, below are a list of potential revenue sources. These may also be combined:

1. Simple subscription fee, e.g. by way of a monthly app subscription (noting that some user groups may be opposed to that).
2. Monetization right of selected community-generated data, e.g. quality-related performance data – sold to regulator/network operators, new infrastructure needs – auctioned with a margin to suppliers, user consumption profiles – sold to insurers, consumer goods manufacturers, etc.
3. Margin on the power exchanged between community members and/or third parties, noting that: (i) initially, communities will likely be allowed to aggregate their buying- and selling-power, and thus being able to freely choose their trading partners even under current market regulations (reflecting a partial liberalization). (ii) In a foreseeable timeframe it seems likely that markets will be fully liberalized, allowing each participant/prosumer to individually interact – and margins charged accordingly. In must be stated, however, that margins on power exchanged may not be competitive in the long term as alternative offers with 'no margins' (but other revenue streams) will emerge.
4. Share of savings (and/or quality improvements) prosumers benefit from by joining a community (essentially a decentralized energy contracting model), noting that this may entail methodological complexities.
5. Margin on hardware sales relating to the energy gateway (full consumer device sold to consumers, or components/chip sold IoT/component manufacturers).
6. Margin/project management fee on value added services (e.g. sales/installation of batteries and PV panels, appliance sales, EV-leasing).
7. Margin on use of (and/or capital gain on) crypto currency assets, necessary to transact in the community (with an exact 'token'/'crypto-economics' model to be specified).

When analyzing these options for revenue streams and putting them into perspective with process realities and the value proposition drivers, also with respect to roll-out/scale-up, the following key business model lessons emerge:

- All revenue streams are subject to competitive pressure and regulatory uncertainties.
- For the overall value proposition to work best (many prosumers/communities emerging), and for the revenue- (i.e. data-) streams to become significant, scaling communities is crucial (leading to both, better performance and higher revenue).
- Given the importance of scale, and the size of the distributed energy market opportunity, competition will center around scale-up. This, in turn, makes for the paramount importance of the right technology and partnering strategy.
- The business models for developed and developing markets may be partially different[114].
- Two main business model tasks need to be separated: (i) Developing and maintaining a suite of technologies offering a community management system, and (ii) Implementing/operationalizing the system in a particular community (such as Quartierstrom in Walenstadt).

[114] ongoing research by Cleantech21

- Prosumer-centric distributed energy communities can be expected to offer strong 'impact-' and 'crowd-investment' potential (incl. TGEs/ICOs). This indicates that also business- and roll-out models requiring substantial upfront investment are feasible.

The objective of the Quartierstrom project, also in combination with other projects, is to test user perspectives and process feasibilities of different energy community value propositions. Overall, likely the best strategy will be to find the right model allowing usage to spread as quickly as possible. The more data flows through the system, the better the system operates for prosumers, the better it can be optimized for network management, and the more it is worth for generating revenue.

The Quartierstrom Pilot in Walenstadt was initiated by a team of energy and technology experts. Some members of that team are linked to the #Hack4Climate115 innovation program. Their main objective is to develop an energy venture that fosters renewable energies at scale. Based on their successful cooperation during the innovation program's 12/2017 hackathon, the team continued development efforts (picture, test set-up 02/2018). To this date, their overall scaling objective remains the same.

[115] http://www.hack4climate.org

11.6 Media coverage – outlets of the press release in Feb. 2020

Detailed list of publications in the media

- February 2020, Blockchain und Solarstrom: Die Dezentralisierung des Energiesektors, btc-echo.de
- February 2020, Quartierstrom: Feldphase von lokalem Solarstrommarkt basierend auf Blockchain erfolgreich abgeschlossen, ee-news.ch
- February 2020, Lokaler Stromhandel per Blockchain, gruenden.ch
- February 2020, Schweiz: Testphase des lokalen Photovoltaik-Stromhandels auf Blockchain-Basis erfolgreich abgeschlossen, pv-magazine.de
- February 2020, Schweizer Blockchain-Lösung soll lokalen Solarstrom fördern, www.inside-it.ch
- February 2020, www.netzwoche.ch/krypto (short text in news ticker)
- February 2020, Rete di approvvigionamento decentralizzata: il progetto pilota svizzero "Quartierstrom" testa l'approvvigionamento energetico basato su blockchain, https://it.0xzx.com
- February 2020, Pionierprojekt: Lokaler Strommarkt fördert Eigenverbrauch, energate-messenger.ch
- February 2020, Lokaler Stromhandel per Blockchain, startupticker.ch
- February 2020, Blockchain kurbelt Solarstromverbrauch an, Punkt4.info
- February 2020, Haushalte versorgten sich zu einem Drittel selbst mit Strom, Die Ostschweiz
- February 2020, «Quartierstrom» – erfolgreicher Abschluss der Feldphase, Presseportal Schweiz
- February 2020, "Quartierstrom": Erster lokaler Strommarkt in der Schweiz arbeitet mit Blockchains, finanzen.ch
- February 2020, Blockchain-Stromhandel: Schweizer Quartierstrom-Projekt meldet erfolgreichen Abschluss, de.cointelegraph.com
- February 2020, Dezentrales Versorgungsnetz: Schweizer Pilotprojekt „Quartierstrom“ testet blockchainbasierte Energieversorgung, finanzen100.de

In February 2020, the press release *'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed* has been published by at least the following 191 media outlets:

- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Xpert (UK)*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WZVN-TV ABC-7 [Fort Myers, FL]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WRDE-TV CBS [Milton, DE]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WRCB-TV NBC-3 [Chattanooga, TN]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WRAL-TV CBS-5 [Raleigh, NC]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, World-Generation*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WLNE-TV ABC-6 [Providence, RI]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Winslow, Evans & Crocker*

- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WICZ-TV FOX-40 [Binghamton, NY]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WICU-TV NBC-12 / WSEE-TV CBS-35 [Erie, PA]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WFMJ-TV NBC-21 [Youngstown, OH]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WENY-TV [Horseheads, NY]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WBOC-TV FOX-21 [Salisbury, MD]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, WBOC-TV CBS-16 [Salisbury, MD]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Wapakoneta Daily News [Wapakoneta, OH]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Virginia Renewable Energy Alliance*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Value Investing News*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Valley City Times-Record [Valley City, ND]*
- *February 2020, 'Quartierstrom' - Field Test of Switzerland's First Local Electricity Market Successfully Completed, Utah Solar Energy Association*
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