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Participative Renewable Energy Community—How Blockchain-Based Governance Enables a German Interpretation of RED II

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Abstract: Distributed solar photovoltaic generation is less expensive than the retail price of electricity from the grid in most parts of Europe. Growing shares of variable generation place a focus on Renewable Energy Communities (REC) to increase the economic benefits of local energy systems. Civil society could play an influential and necessary role in the development of such communities, the expansion of renewable energy capacity and the provision of flexibility. However, current RECs models still confine tenants to their role as non-participating consumers. This article provides a concept to enable participative RECs within the German regulatory framework through collective self-consumption by including consumers for a fair allocation of renewable electricity using the blockchain technology.

Keywords: renewable energy community; participation; self-consumption; blockchain; energy transition; consensus; prosumer

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1. Introduction

The RED II directive [1] of the European Parliament was due to be incorporated into national law in all EU countries by 30 June 2021. According to this directive, a Renewable Energy Community (REC) is a legal entity whose primary purpose is to provide environmental, economic or social community benefits for its stakeholders. It demands the right of EU citizens to be able to supply themselves or collectively with local electricity, as self-consumption of electricity from solar photovoltaics (PV) generation is less expensive than the retail price of electricity from the grid in most parts of Europe [2,3]. However, Germany has still not fully translated the EU directive in its national law(s) and more specifically is lacking the REC part, thus hindering the development of RECs in which civil society could play an influential and necessary role for development of the energy transition and renewable energies.

Nevertheless, there is a broad social consensus that by 2050 at the latest, Germany's entire energy supply should come almost entirely from renewable energy [4]. To reach 100% renewable energy, the participation of prosumers plays a significant role. "Prosumers" are consumers in the traditional, passive sense who also produce goods or services for sale in the energy marketplace [5,6]. In 2019, more than 40% of Germany's installed renewable energy capacity was owned by private individuals (30.2%) and farmers (10.2%) [7]. They account for 48% of the installed solar power [7] and for 40.6% of installed onshore wind power. However, those statistics do not differentiate whether private individuals are homeowners or tenants living at rent. While homeowners can self-consume the electricity produced on top of their own roof by their own PV modules, tenants usually cannot utilize the roof and/or facade of their residence to install PV modules in order to operate self-consumption. At best, tenants can *"produce goods or services for sale in the energy marketplace"* by owning shares in a solar or wind park. While such prosumers increase the installed renewable energy capacity, they have no (economic) incentive for (self-)consumption of renewable electricity. Because distributed PV generation is less expensive than the retail price of electricity from the grid in most European countries [2,3], a prosumer who can operate self-consumption might have a significant advantage over a prosumer who cannot, such as a tenant living at rent. Furthermore, the German household sector can contribute significantly to system stabilization, with an average potential of 30 GW negative and 3 GW positive flexibility by 2025 and, respectively, 90 GW and 30 GW by 2030 [8]. However, the study focused on single-family and twin homes that optimize their self-consumption and not on apartment buildings with residents living at rent.

Nonetheless, by developing rental buildings into REC's, residents, including tenants, could play an influential and necessary role in the development of renewable energy capacity and the provision of flexibility, in order to optimize the energy system.

In this work, we provide a concept to enable a German interpretation of RED II within the current national legislative framework, that is empowering consumers, including tenants, to collective self-consumption organized using the consensus mechanism of blockchain.

In Section 2, a literature review of the regulatory framework demanded by the RED II directive as well as the current regulatory framework in Germany is provided. Further review of the current and prospected economic situation of PV self-consumption and a description of the distinguishing features of the Blokchain technology is done, leading to the identification of a research gap. In Section 3, the concept for a cooperative REC is presented, showing that with dynamic tariffs, cooperative load balancing can be incentivized without operating prosumer to prosumer (P2P) trading, thus being applicable within the scope of current German regulations. Section 4 describes one method for a REC to organize itself to consensually generate electricity bills characterizing self-consumption beyond doubt without the use of a trusted third party. In Section 6, we end with a conclusion and a discussion about basic data protection regulation of future applications and extensions.

2. Literature Review

2.1. Review of the Benefits of Self-Consumption

As falling costs have made distributed PV generation less expensive than the retail price of electricity from the grid in most European countries [2,3], it is of economic interest to optimize self-consumption. In Germany, photovoltaic systems with battery storage are a fast-growing market as the number of home storage systems reached 185,000 units in 2019 [9], up from 5000 units in 2013, underlining the population's interest in self consumption optimization. In 2021, the levelized costs of electricity (LCOE) of hybrid PV-battery systems in Germany range from 5.24 to 19.72 c€/kWh [10]. Forecasts show that in 2040, the LCOE will be between 3.58 and 6.77 c€/kWh for small rooftop systems, and small PV-battery systems are expected to achieve an LCOE between 5 and 12 c€/kWh [10]. In contrast, the household electricity prices in the first semester of 2021 in the EU range from 31.93 c€/kWh (highest, in Germany) to 10.03 c€/kWh (lowest in Hungary) [11]. The EU average price in the first semester of 2021—a weighted average—was at 21.92 c€/kWh [11]. A graphical presentation of these values has been compiled in Figure 1.

Further financial advantages of increasing individual self-consumption can be achieved by not having to pay network fees compared to purchasing electricity from the public supply grid. Additionally, further levies, such as the offshore liability levy, AbLaV levy, §19 StromNEV levy and concession fee can be avoided. All these fees and levies apply per kilowatt-hour on grid electricity. In Germany, the current business models for small-scale PV and PV battery storage systems only exist because they are based on avoiding the need to purchase electricity from the grid and thus avoiding paying taxes and levies on consumed electricity [12].

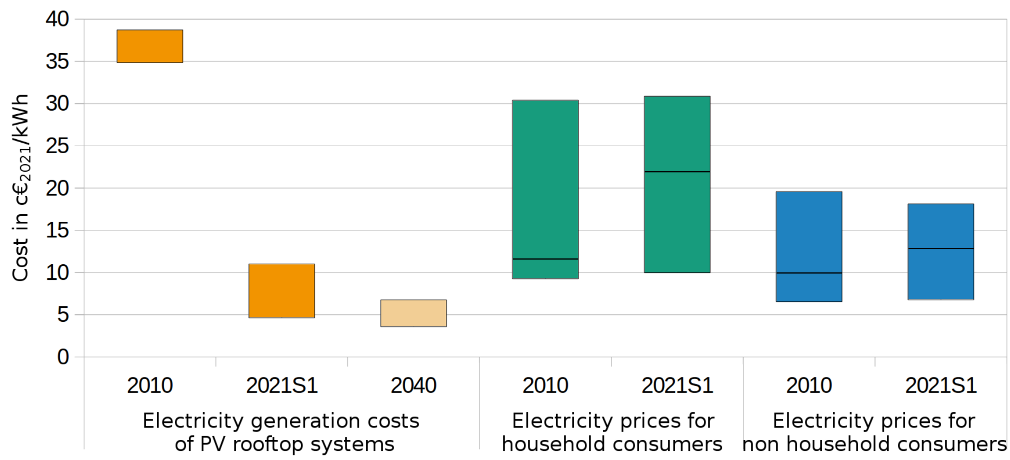

Figure 1. Levelized cost of electricity (LCOE) for rooftop PV systems in Germany and electricity prices for household and non-household consumers in the EU by year. The horizontal line drawn in the middle of the electricity prices boxes represents the EU weighted average price. All prices adjusted for inflation in EUR 2021. Data source: [10,11,13,14]. Graph: S.P.M. Chantrel—Fraunhofer ISE.

Furthermore, the potential economic benefits of local markets arise from the coordination of local supply with demand for locally generated electricity, local provision of grid-serving flexibility or local provision of security of supply [15]. The increased efficiency of local energy markets through residential demand response showed that the electricity price can be reduced by up to 10 c€/kWh [16] or reduce electricity bills for the community by 6% [17].

2.2. Review of the Regulatory Framework for Collective Self-Consumption

Various initiatives at the European level give collective self-consumption a greater importance and the report of the European Regulators' Association CEER on regulatory aspects of self-consumption and energy communities [18] reflects two main directions of the classification of self-consumption concepts:

- A rather broad allocation of self-consumption to the role of "active customers" (with explicit inclusion of groups of such actors) with the description "who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes" in accordance with the EU energy market directive [19].
- A rather narrow variant with limitation to one building or one building block according to the Renewable Energies Directive of the EU "*jointly acting renewables self-consumers* means a group of at least two jointly acting renewables self-consumers in accordance with point (14) who are located in the same building or multi-apartment block".

With the RED II directive, the European Parliament introduced a series of legal notions such as the renewable self-consumer (or prosumer) and the REC. A year later it introduced Citizen Energy Communities (CECs) in [19]. The definition of these legal notions aim at the empowerment of smaller actors in the energy market as well as an increased decentral renewable energy production and consumption [20]. The year 2020 saw a major progress of EU member states in implementing the neu European regulatory framework into national laws. However, member states mainly focused on developing approaches for collective self-consumption and RECs, while CECs are addressed to a much lower extent so far [21].

According to the RED II directive, a REC is a legal entity whose primary purpose is to provide environmental, economic or social community benefits for its stakeholders rather than financial profits. Such concept is already adopted by French [22], Walloon [23] and Austrian [24] regulation and other European countries are adopting similar legislative decisions [6,20,21]. Furthermore, the RED II requires that RECs are "effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects". Some countries further specify membership and shareholder conditions. Greece, for instance, set minimum numbers of members and a maximum share in the community's capital depending on the involved types of actors [25]. In other EU countries, the governance framework is linked to existing organization structures such as consumption cooperatives in Spain [26], energy associations in Estonia [27], or economic associations in Sweden [21]. In Austria, only a group of at least two natural persons, local authorities and/or small businesses are allowed to exercise control over citizen energy communities [24].

The directive has to become law in EU countries by 30 June 2021. In addition, the variants "Citizen Energy Community" and "Renewable Energy Community" are also addressed, which are comparable with citizen energy cooperatives (in the second case with physical proximity to the producers). Various existing and planned variants of implementing collective self-consumption in the member states are presented in the CEER report. These differ very much in terms of basic concept, legal classification, technical implementation and financial factors. An overview by member state can be found in [21,28].

To date, Germany has not fully translated the EU directive in its national law(s). In §3 of the Renewable Energy Sources Act (EEG) [29], "self-consumption" describes geographical restriction as well as requirements of personal identity of consumer and supplier. Furthermore, the electricity must not be transmitted through a public grid. Based on this definition, the act formulates various specifications regarding remuneration, apportionment payments, reporting obligations and other aspects.

The requirement of personal identity for consumers and suppliers creates a difficulty for "collective self-consumption". While a community of owners can form a legal entity, for example, in the form of a GbR (civil partnership under civil law) with regard to the generation plant, only in some cases is it possible to grant that consumption is also carried out by this community as a legal entity. This would be the case for electricity consumption by common property. In the case of individual consumption by natural persons in the community, at least in the view of the Federal Network Agency and various legal experts, there is no personal identity of consumer and supplier [30]. An alternative could be the artificial division of the generation plant into small, individually measured sub-systems which belong to the individual members of the GbR.

Recent policy initiatives aim at removing this obstacle by the legislator [31]. However, while a situation in which a community supply from a jointly operated electricity generation plant does not constitute "self-consumption" within the meaning of the EEG, it does not mean that such supply is not possible as a business model. A GbR can certainly supply its members with electricity from its own plants, but it then constitutes a "direct supply" as defined by the EEG. This leads to financial and administrative disadvantages, such as an obligation to pay the full EEG levy. Additionally, the supplier has to become respectively an energy supply company (EnWG) [32] or an electricity supply company (EEG) [29] or a utility (StromStG) [33] with all associated obligations and requirements. In this case, the idea of a collective self-consumption hardly offers any advantages over the bundling of all producers and consumers by a service provider with an established administrative infrastructure, for example, a local utility company or municipal utility.

The introduction of tenant electricity within the EEG establishes a subsidy claim for the direct supply of electricity from PV systems on buildings by the residents of the building. However, the direct sale of electricity from one resident to his neighbour(s) is not allowed, because even in the tenant electricity construct, the end consumers are limited to have only one contractual supplier, even if the electricity comes from different sources.

In conclusion of the review of the regulatory framework, in Germany a technical collective self-consumption legally represents a case of "direct supply" of electricity from a (collectively operated) producer to (collectively bundled) consumers, which from the consumer perspective leads to financial and administrative disadvantages when compared to self-consumption. The direct sale of electricity from one resident to his neighbour is not possible, thus hindering prosumer to prosumer (P2P) trade.

2.3. Review of the Regulatory Framework Regarding Legal Contracts, "Smart Contracts" and Blockchain

In Germany, "smart contracts" are considered to follow the expression of a human will, which has been expected by their programming. Therefore, it is accepted that legally binding agreements (contracts) can be concluded as smart contracts by automated devices [34–36]. In addition to this legal definition, a smart contract can also be a computer program that consists of a set of rules executed within a blockchain [37,38]. Smart contracts can be tailored to the specific needs of an application [38,39].

Blockchains consist of consecutive chained blocks, where blocks are created in a distributed fashion by means of a consensus algorithm [40]. Such algorithms enable distinguishing properties of blockchain: decentralization and democratic control of data [41]. The meaning and usage of the word consensus relate to both a generally accepted opinion, and a decision based on collective agreement [42]. Both the process and outcome of consensus decision-making are referred to as consensus.

Blockchain and smart contracts can be combined [43], and the combination has the potential to revolutionize the functioning of transaction systems and enable fully decentralized market platforms [44]. However, such revolution has yet to happen.

Existing literature on the use of blockchain in energy communities currently focuses on the technical feasibility, without explaining if and how they make use of the added value provided by distinguishing properties of the blockchain technology. An example for this is provided by the authors of [45], who set up a database with no further specification, deployed a simplified consensus protocol reserved for development purposes and required the definition of a central authority that is trusted by every other actor. Another example is provided by the authors of [46], who, despite referring to blockchain, only made use of participants of a network to exchange items through a distributed ledger. Permissioned (also called private) blockchains were implemented and described, but lacked details about how the community was self-governed [17,47]. In [48], the authors recommended permissioned blockchains for local energy markets where participants seem to be limited to trading without participation in the governance. Another blockchain based local energy market required a central utility to register participants and assigns authority to prosumers with a genuine PV for block validation [49,50]. In [51], the authors investigated several blockchain-based energy trading systems and identified improvement potentials for the use of blockchain, and especially the consensus mechanism, to finally discuss the potential future research directions. More generally, the use of open or permissioned blockchain only makes sense when multiple mutually mistrusting entities want to interact and change the state of a system, and are not willing to agree on a trusted third party [52].

2.4. Research Gap

The German legislative environment still lacks the proper integration of RECs despite the cut-off date to integrate the EU directive by 30 June 2021. The closest interpretation of the EU directive within German law is the tenant electricity model, in which tenants are confined to their role as non-participating consumers. While the blockchain toolbox provides a variety of energy applications, usage of the participative consensus mechanism is sparse.

3. Concept of a Participative Renewable Energy Community

This section presents a technologically open concept for achieving a participative REC. In this paper, we set the objective of the community to increase its self-consumption share by use of local loads, including, but not being limited to, the flexibility of consumers.

3.1. Collective Load Balancing and Incentives

In the simplest case, a large, jointly used flexibility is used inside a community. In this case, a simple, central control system is obvious, and as it does not require the participation, coordination or consensus of individual consumers, it will not be considered further here. Instead, an REC relying on consumer flexibility is considered. As consumers are not used to load control, it is expected that they request to retain control over their own flexible load. Furthermore, consumers might expect a compensation for adjusting their load for community purposes.

3.2. Dynamic Pricing of Electricity

Figure 2 shows that high consumption with low generation leads to 100% self-consumption within the REC, and conversely, high generation with low consumption leads to a high degree of self-sufficiency of the REC. Adjusting the consumption of flexible loads both in function of RE and the consumption of others allows to optimize the self-consumption and the self-sufficiency of a local energy system. In the following, three different billing options are described.

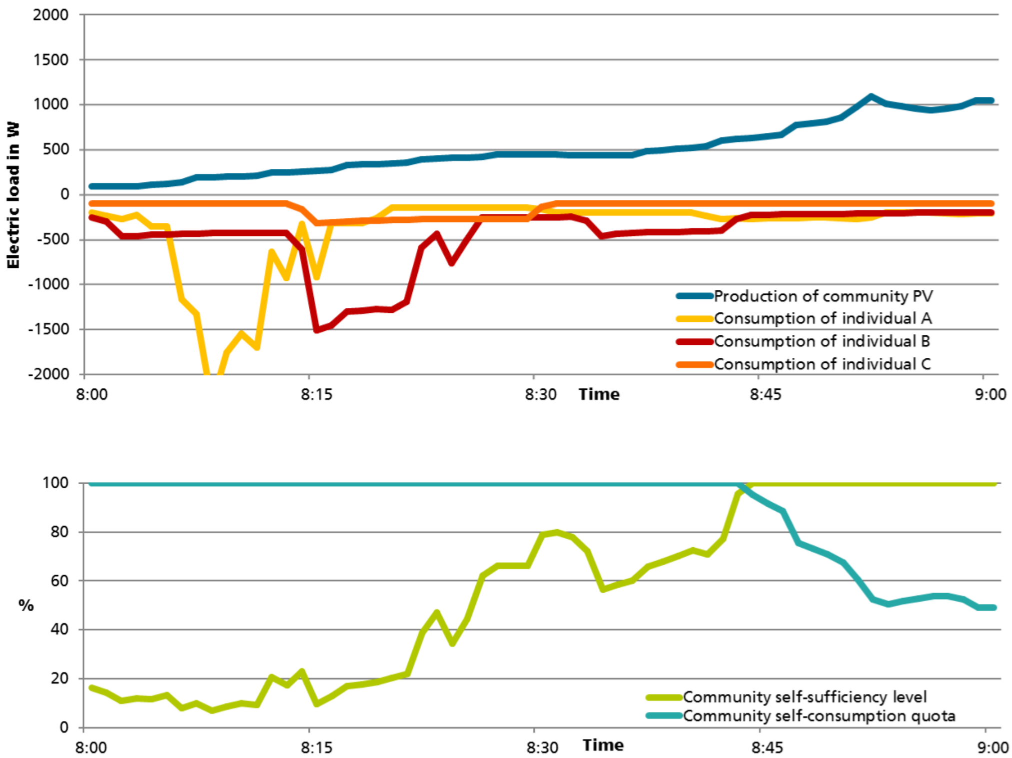

Figure 2. Electrical loads of a community PV system and three individual dwellings on a day from 8:00 to 9:00 a.m. and the associated community self-sufficiency and self-consumption. *Data and graph: S.P.M. Chantrel—Fraunhofer ISE.*

1. **Collective uniform tariff**
   A variable tariff that is identical (collective uniform) for all participants would create an economic incentive for load balancing. The main issue of a collective uniform tariff, is that it does not exclude the possibility of an overreaction leading for example to every one charging their electric vehicle at the same time and possibly increase the electric load above the local PV production as shown in Figure 3.
2. **Collective variable tariff**
   To improve this, another financial incentive for consumers to support load balancing by optimizing collective self-consumption, could be an individual and variable

electricity price based on individual consumption quota [47] such as described in Equation (1).

$$P_{community}(t) = (P_{max} - P_{min}) \times SC(t) + P_{min} \tag{1}$$

This way, collectively equal electricity prices (upper and lower price limits) known to the participants of the community are coupled to the limits of 0% and 100% collective self-consumption quota (SC) as shown in Figure 2. The community members could for example set that in case that the REC has a self-consumption quota of 100%, the electricity price reaches a maximum (P_{max}). This maximum could be defined to be equal to the grid price which the community members would have to pay anyway when no community PV is available. A minimum price (P_{min}) could be defined in the case that the REC has a self-consumption quota of 0%. It could be indexed to the feed-in tariff, which the community would get for any excess kilowatt-hour. The coupling of price limits with the self-consumption share of the community result in a variable electricity price ($P_{community}$) which, when summed up for each time step, gives an individual price. The point is that participants project their load and possible generation and share this information within the community. Based on communicated projections, individual consumers can estimate the resulting electricity price and take a decision regarding their own electric load. Of course, it is unrealistic to expect human participants to project and communicate their consumption behaviour, but these tasks could be integrated within the management systems of charging poles for electric vehicles [53,54].

3. **Individual tariff**
The main motivation for an individual electricity price is a fairer distribution of an "entitlement" to community electricity quantities. The entitlement would ensure individual members of the REC the right to consume a dedicated fraction of the PV production at any time, such as depicted in Figure 4. As PV production is variable, the entitlement quantity is variable. As shown in Figure 4, participants with low electricity consumption benefit more than average, as their electricity price is less determined by the collective electricity mix as shown in Figure 3, but more by the entitlement to a defined fraction of community electricity. This ensures fairness between large consumers with flexible loads, such as owners of electric vehicles, and simple consumers who make an effort to reduce their consumption. Each participant is only entitled to a guaranteed minimum share of the community capacity and is only awarded more if other participants do not use up their quota within the same time step.

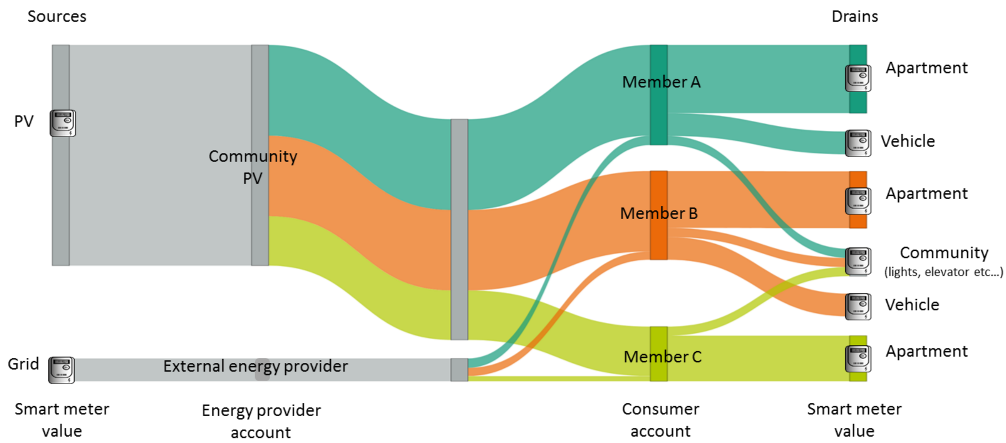

Figure 3. Each member of the community gets the same percentage of community PV and grid electricity. *Data and graph: S.P.M. Chantrel—Fraunhofer ISE.*

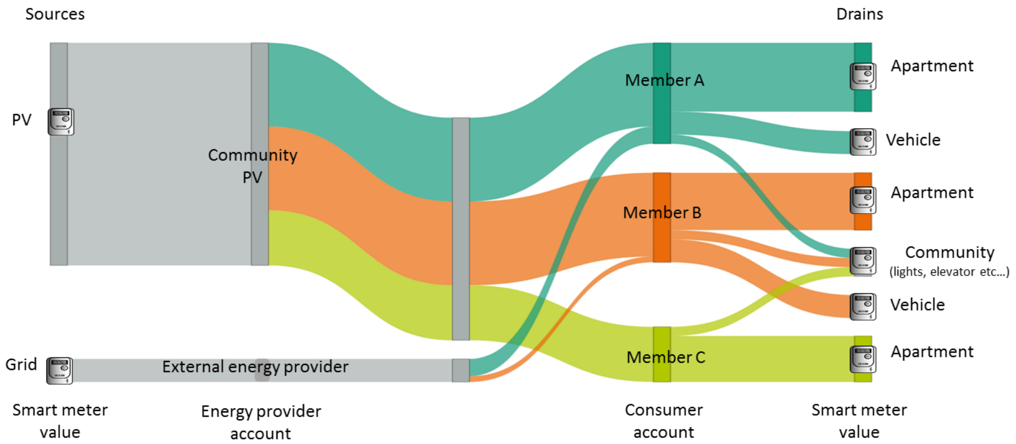

Figure 4. Members of the community are equally entitled to community PV. Here a member (C) with a consumption smaller than his entitlement is not billed for grid electricity as other members (A and B) are responsible for the purchase of grid electricity within that time step. *Data and graph: S.P.M. Chantrel—Fraunhofer ISE.*

In all three cases, the electricity price of one consumer depends on the consumption of the others. In the first case, summed up values of PV generation and total consumption are sufficient to determine the price, while in the second and third cases the meter values, which would be resolved over time, must be known by all parties involved in order to transparently calculate the shares of electricity consumed. Therefore, in cases 2 and 3, timing creates a mediation between individuals to allocate unused PV quantities.

Approaches 2 and 3 are unusual because the electricity price relevant for billing can only be determined after the delivery has taken place ("ex-post"). The financial risk of balancing local generation and consumption, which is otherwise borne by the electricity provider, is partially transferred to the consumer. However, the risk is limited and the final price varies within known limits.

This ex-post concept allows electricity to be supplied over classical electricity supply contracts between an electricity provider and a consumer. Therefore, it is applicable within the German regulatory framework. From an administrative point of view, the REC would select an electricity provider (similarly to the selection of an insurance company) and recommend it to all consumers inside the REC. While non-participating members would be limited to the grid electricity provider, participating members would benefit from cheaper community PV electricity provided by the electricity provider of the REC. Moreover, the introduced electricity pricing concept allows participating consumers, including tenants, to have an influence over the electricity price which gives them an incentive to adjust their load to support local load balancing, which leads to an optimization of the local energy system.

3.3. Measurement and Billing

One challenge resulting from the electricity pricing described previously lies in the retrospective distribution (ex-post) of self-consumption shares among the individual consumers within the REC.

Assuming that all metering points are recorded with sufficient time resolution, the distribution of self-consumption shares and the corresponding invoices can be calculated. This calculation can either be done by a trusted company or by the community itself. The first case is pretty standard and is not considered in this paper. Instead, we investigate the possibility of a consensual billing in which participants organize themselves in order to guarantee a fair, causer-based electricity pricing depending on user behaviour.

The time resolution necessary for load balancing generates data that are not suitable for manual billing and therefore require automated billing. As automated billing would be based on a disclosed settlement process, the demand for transparent, tamperproof documentation of settlement-relevant transactions increases. To address this challenge, we discuss in the next section whether and how the blockchain technology can be applied.

4. Consensual Billing with Blockchain

Previously we described an incentive for load balancing in which community members rely on a disclosed central billing process. With regard to the creation of an open system of participation by involving individual members of an REC, trust in a billing process could be based on decentralized governance. One approach for this is the blockchain technology.

4.1. Governance

When setting up a blockchain, defining its governance is the first step. Typically, there are three types of governance available: private (or permissioned), public (or permissionless) and hybrid, as presented in Table 1. The governance type defines who can participate with which rights.

Table 1. Type of Blockchain governance.

	Public Blockchain	**Private Blockchain**	**Hybrid Blockchain**
Management subject	All participants	Managed by central institution (authority)	Participants of the blockchain network
Identification	Anonymous	Identified	Identifiable
Transaction verifier	Miner cannot be known in advance	Single authority is the trusted verifier	Multiple authorities known through certification, transaction verification and block mining
Consensus	Participative	Single authority is the sole decider	Participative

Inside an REC, the circle of members is limited to the participants of a defined section of the electric grid. As required by energy laws, all consumers, prosumers and suppliers connected to the grid must be identified both contractually and technically, e.g., by use of a registered meter. Therefore, the use of a public blockchain, such as Bitcoin, will not reflect the governance of the REC because unknown participants should not be able to intervene within the REC. However, that participants are known either to a central administrator or among themselves, does not mean that they trust each other. This is especially true for economically oriented actions such as those that take place in the previously described electricity pricing mechanism.

Private blockchains require the definition of an administrator who sets and controls the rules for operation, including granting access to the blockchain [55]. Accordingly, private blockchains require the trust of their participants in one administrator. In the case of a community, defining one common actor inside the community as a trusted administrator of this community can be an organizational challenge, addressed by questions such as can the administrator neutrally arbitrate the competing price interest between consumer and producer? Can he neutrally arbitrate the competing “share of entitlement” between consumers? Such an administrator would de facto be a central actor of the community who would have to act as a trusted third party. As this research paper focuses on participative governance, the use of a private blockchain administrated by a single operator is not appropriate [52].

Hybrid blockchain can be set up with a consensus mechanism that allows a collective governance. The collective consensus mechanism can additionally be used for setting and controlling the rules in operation, including access control. In the following sections, we discuss how we use different consensus mechanisms to enable a self-organized REC and discuss its application under aspects of current data protection regulations.

4.2. Finding a Consensus

One of the main challenges addressed by the present use case is to allocate the shares of self-consumption and grid purchase among the consumers within a time step (e.g., a minute). We want to investigate if this task is to be solved collectively, i.e., without a central authority. To be able to automate this process, participants of the community should find a consensus on how they want to define this allocation mechanism. Figure 5 shows how the allocation process could be discussed during a classic (e.g., annual) face to face meeting of the community (1). The agreed rules (2) would then have to be recorded within a program that is uploaded to the REC's blockchain (3), where participants could again verify its content and validate its legitimacy.

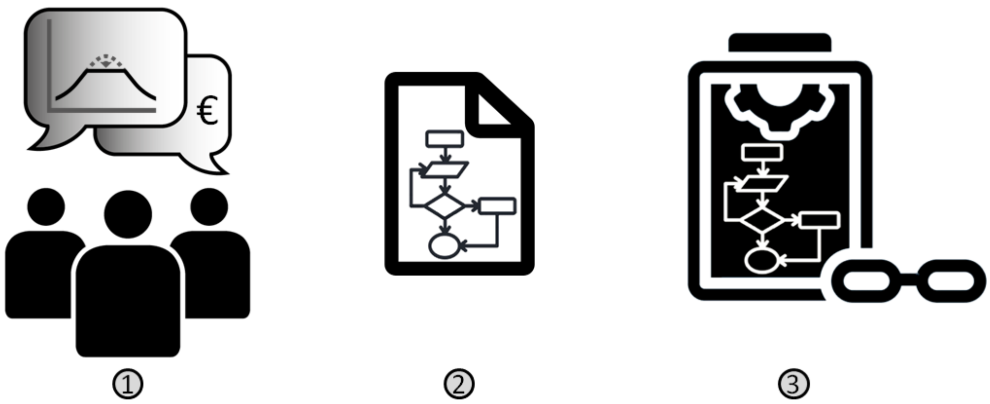

Figure 5. Members discuss and agree on a set of rules before uploading it to the blockchain. *Illustration by S.P.M. Chantrel—Fraunhofer ISE.*

Once validated by a majority of the REC members, the program, which is technically a smart contract [37,38], would be used to calculate for each time step the self-consumption share of the REC as shown in Figure 6. To do so, the smart contract accesses all the consumption/production values of each smart meter. With the self-consumption share of the REC, the price for electricity from the community PV plant can be established. Knowing the price for community PV, the price from grid electricity, the individual entitlement to community PV and possibly the share of grid electricity, an individual electricity price can be determined for each member of the REC. The validation of these individual parameters enables the automated generation of individual electricity bills. Such automated billing process can be considered as a legal contract [34–36]. The resulting electricity bills are not required to be stored in the blockchain.

However, as the self-consumption share of the community depends on the consumption of all members, these values must be disclosed inside the blockchain to all members. The resulting privacy issue could be addressed by a consensus mechanism that would allow a pseudonymized disclosure and would thus not require explicit publication of all consumption data. Personal data confidentiality can be taken even further [50] to guarantee that the user's individual load profile is not leaked to any third party despite using a blockchain.

In conclusion, the blockchain technology is suitable for automating the reconstruction (smart contract) as well as for finding a consensus within a community of participants (definitions of the rules within a smart contract) without having to publish individual consumption values.

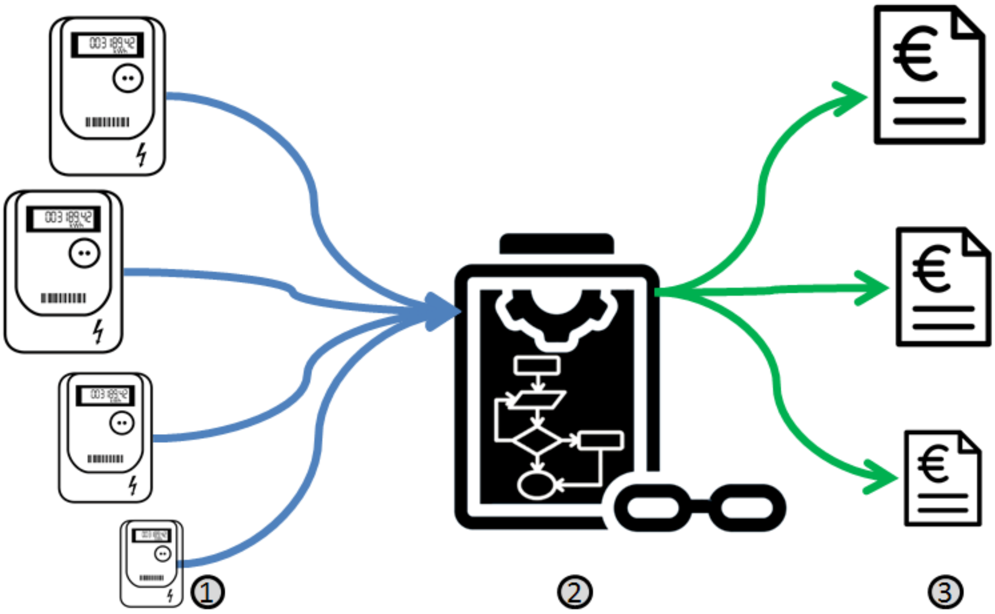

Figure 6. For each time step, the smart contract (2) processes all consumption values (1) within the REC to allocate each member of the REC an individual electricity price (3) by assessing the flows of grid and PV electricity. *Illustration by S.P.M. Chantrel—Fraunhofer ISE.*

Even though many consensus algorithms exist, proof of work and proof of authority are currently the most widespread consensus mechanisms. Both consensus algorithms are described hereafter. In the Bitcoin blockchain, a so-called proof-of-work (also called "mining") mechanism is used to find consensus over which transactions are to be recorded within a new block. The purpose of this consensus mechanism is to secure a transaction history and at the same time to ensure the governance of the decentralized system over as many (anonymous) participants as possible. Due to the high energy demand of the proof-of-work mechanism, this consensus mechanism is not suitable for applications targeting energy efficiency [48].

The proof-of-authority consensus mechanism represents an alternative where so-called "authorities" have to take decisions. The identity of these authorities is known, they are morally recognized by a community and technically defined as blockchain authority. Instead of mining new blocks, the authorities vote on the validity of the next block. If an authority repeatedly votes for blocks that should not be valid and would not be confirmed by the majority of the network, this authority risks losing its moral recognition and therefore the trust placed in it. If an authority loses the trust of the members of a blockchain, the status "authority" can technically be revised by a majority of other authorities.

As all participants are identified and willing to participate in the community, it is assumed that every participant wants to be morally recognized. Therefore, a proof-of-authority mechanism can be applied. Active members of the community can provide their computer agent (the one which also operates load balancing) as authority to verify the community blockchain. Thus, the blockchain would show a secure and transparent breakdown of the consumed and generated electricity quantities, as well as their flow within the community.

In conclusion, a blockchain with a proof-of-authority consensus mechanism and access control can be applied in energy communities willing to be self-organized.

5. Conformity with Basic Data Protection Regulation

In the EU, and specifically in Germany, data protection is of importance. Within the context of this article, particular aspects coming from Art. 5 of the Basic Data Protection Regulation (DSGVO) have to be considered:

1. Accuracy; "all reasonable steps must be taken to ensure that personal data which are inaccurate are erased or rectified without delay".
2. Storage limitation; data must be "stored in a form which permits identification of data subjects for no longer than is necessary".

Regarding accuracy, incorrect consumption values could be recorded in the event of a defective smart meter. Correcting the error is required by law and necessitates to change an information which is stored inside a "block". With each block comes a unique "hash" which singularly describes the information stored inside a block. With every, even marginal, change of the content of a block, the corresponding "hash" changes. When a new block is added, the "hash" of the previous block is encapsulated within the new block. The new block, which contains the hash of the previous block as well as new information, also has a unique hash. The recursive inclusion of the hash of the previous block is what chains blocks to form a blockchain [56]. For this reason, changing an incorrect entry is extremely challenging: all subsequent entries would first have to be saved temporarily in order to be re-entered after a correction. While re-entering would be very time and resource consuming for a long blockchain with a proof of work consensus, it should be faster for a blockchain using a proof of authority consensus.

Regarding storage limitation, consumption values of a particular member of the REC can indicate a personal usage profile, which is considered personal data. This is relevant when a member is leaving the REC and the personal data should be erased. In order to do so, the blockchain can be reset on the day a member leaves. To do so, any block added after the exit of a member can be defined to be the first block of a new chain. All previous blocks can be erased to comply with regulation about storage limitation. Erasing those blocks erases every information about every member to a certain moment. As this operation would be organized by the community, any member who would keep a copy of the blockchain could be held responsible for a violation of the decided deletion.

These two solutions to solve the DSGVO requirements for accuracy and storage limitations are possibilities for the presented blockchain application. However, the whole topic of DSGVO conformity is a topic for all other blockchain applications where sensitive data are involved as well. This topic needs to be researched further and the suggestions presented here do not present a final solution for the problem at hand.

6. Conclusions and Discussion

As self-consumption of electricity from solar photovoltaics generation is less expensive than the retail price of electricity from the grid in most parts of Europe, the European Union's (EU) package of directives demands the right of EU citizens to be able to supply themselves or collectively with local electricity. For this reason, regional, national and supranational authorities are creating new legislation and frameworks that enable the emergence of energy communities. Civil society could play an influential and necessary role in the development of such communities, however current RECs models still confine tenants to their role as non-participating consumers.

In Germany, a technical collective self-consumption legally represents a case of "direct supply" of electricity from a (collectively operated) producer to (collectively bundled) consumers, which leads to financial and administrative disadvantages when compared to self-consumption. The direct sale of electricity from one resident to his neighbor is not possible, thus hindering prosumer to prosumer trade.

Building exclusively on classical electricity supply contracts between an electricity provider and a consumer, a concept for cooperative load balancing using consumer flexibility has been described. The concept allows consumers, including tenants, to influence their electricity price, which provides a direct incentive to support local load balancing and proposes a concept for an individual time-dependent tariff. The main motivation for the individual electricity price is a fair distribution of community and grid electricity quantities. This approach is unusual because the electricity price relevant for billing is determined after the delivery has taken place.

In order to guarantee fair prices, the billing mechanism is consensually made by, and transparent to, the members of the REC. The REC can organize itself to consensually generate electricity bills without a trusted third party, thus opening the door to self governed RECs. The trust relies on the blockchain technology, which offers the possibility to characterize self-consumption beyond doubt. Thus, a hybrid blockchain with a proof-of-authority mechanism and an access control restricted to community members can be embedded in RECs with respect to legal and regulatory requirements. As discussed in the previous section, only requirements from the DSGVO challenge this use of blockchain technology, as the modification of a (faulty) entry is against the concept of blockchain.

Excluding requirements of the DSGVO, the presented concept enables participative RECs within the German regulatory framework. REC members can participate in providing flexibility, coordinating load balancing, defining pricing rules (smart contract) and billing. Therefore, the introduced concept allows a strong economic and social involvement of consumers within RECs, by providing transparency in pricing and billing processes for a fair and consensual allocation of cheaper and local renewable energy.

While the presented concept was specifically designed for use within Germany, the approach presented could be applied in multiple locations around the world. However, the use of blockchain only makes sense when multiple mutually mistrusting entities want to interact and change the state of a system, and are not willing to agree on a trusted third party, thus limiting its use to communities where the governance has to be participative. With the introduction of citizen energy communities by the EU directive, countries like Austria, Estonia, Greece, Spain or Sweden have modified their national laws towards communities with participative governance. The communities of these countries are more likely to adopt blockchain solutions such as the presented concept than centrally managed communities.

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