The Photovoltaic Energy Systems within Renewable Energy Communities

Subjects: Engineering, Electrical & Electronic
Contributor: Arne Surmann , Stefan P.M. Chantrel , Manuel Utz ,

Energy communities are on the rise globally, as they enable electricity consumers to advance the decarbonization of the energy system, while benefiting economically. Thus, they can involve the collaboration of individual consumers within residential buildings, as well as several neighborhoods, for the common purpose of expanding renewable energy and increasing their own share of locally generated renewable electricity. To reduce the entry boundaries for such a system of cummunity owned renewable energy (RE) plants and to enable trading of RE shares smart contracts within a community governed blockchain can provide a solution. In such a system prosumers could jointly buy real world PV assets and implement a digitial representation using tokens or utilities could offer token rewards for energy system beneficial behaviour thereby gradually increasing their customers' RE shares and enabling the evolvement towards active prosumership.

photovoltaic energy energy communities

1. Introduction

The transition of the German energy sector towards small-scale, distributed electricity resources has led to the strong growth of renewable energy prosumership over the past decade [1][2]. According to [1], a large proportion of the more than 1.6 million installed PV systems is made up of systems with less than 10 kilowatts of peak (kWp) installed generation. The potential for further development is even greater, since more than 3.8 million apartments within residential buildings are suitable for equipment with building-integrated PV systems [3]. Despite their importance and future potential, the expansion of PV systems within renewable energy communities (RECs) is currently proceeding at a slow pace [4]. In addition to the legal framework, this is mainly due to the difficulty of individual residents to acquire shares of PV systems without major organizational or technical effort, and to differentiate the distribution of the generated electricity on a verifiable basis [2]. So, instead of buying individual PV shares, consumers have been sharing PV systems in RECs via so-called "third party ownership" (TPO) models [5]. This can be designed as a “lease” or a “power-purchase agreement” (PPA) [5]. A lease involves the consumer paying the owner of the PV system a fixed monthly amount, regardless of the PV system’s energy production. In a PPA, the consumer pays the owner a predefined fixed price per unit of energy produced [6]. In both cases, however, ownership of the PV system does not transfer to the consumer. Consumers only receive rights of use. This only partially fulfills the goal of an inclusive energy transition according to the UN Sustainable Development Goals [2], as residents are given access to renewable energy, but are denied active participation through the purchase of PV shares.

2. Energy Communities

Energy communities are on the rise globally, as they enable electricity consumers to advance the decarbonization of the energy system, while benefiting economically [2][7]. In contrast to microgrids, energy communities do not necessarily have to be physically linked, i.e., via a grid infrastructure [8]. Thus, they can involve the collaboration of individual consumers within residential buildings, as well as several neighborhoods, for the common purpose of expanding renewable energy and increasing their own share of locally generated renewable electricity. For example, [9] examine how the expansion of residential PV systems affects electricity self-consumption rates. [1] extend this approach by combining a PV system with a storage system, and calculating the achievable annual savings of residents in energy communities. A similarly designed research issue is investigated by [8][10][11]. Approaches to optimizing energy flows within energy communities are also being developed, studied, and tested in scientific literature [12][13][14][15]. Legal frameworks as well as challenges are explored by [9][16]. Indeed, the lack of sufficient legislation to ensure viability is one of the reasons for the delayed further development of energy communities [17][18]. In addition to these specific research questions, [7] provides a very comprehensive study of energy communities. The study examines not only the social interaction of their members, but also the technological feasibility of such communities, as well as social and technical implications. In this context, [19] perform a techno-economic analysis focusing on the Japanese energy system. An examination of whether RECs, as defined under the European Union's Renewable Energy Directive (RED II), can be a useful facilitator for future energy systems is provided by [4]. According to Article 22 of RED II, an REC is a community in which consumers can produce, consume, distribute, and trade renewable energy, and in which every member must be able to access and acquire renewable assets co-ownership [4]. In addition to the REC defined in RED II, with the citizen energy community (CEC), the directive on common rules for the internal electricity market [20] provides another construct for energy communities. The main differences are that RECs include all forms of energy and demand within a spatial proximity of the RE project, while CECs only consider electricity, while having no spatial limitations.

The way in which renewable energy is generated and distributed within RECs, the benefits for their members and legal challenges, as well as social implications, have already been studied. What is missing, however, is an easily accessible way towards the co-ownership of shared PV systems for consumers within an energy community, as the evolvement of consumers to become prosumers is relevant for the success of a sustainable energy system design [21][22][23][24].

3. Novel Energy Business Models and Co-Ownership of PV Assets

In the past, energy utilities made profit by primarily selling electricity and recovering the cost of their investment from standard electricity-tariff consumers [25]. Since RECs are on the rise and electricity self-consumption rates are increasing, less and less electricity will be consumed via standard electricity contracts. Thus, energy utilities are rethinking their business models towards becoming electricity service providers [26]. In this context, the installation of PV systems and the marketing of the electricity generated via TPO is becoming increasingly important [27], both in the commercial and residential sectors. In the commercial sector, for example for industrial customers, there are currently two options: direct ownership (DO) of a PV system or TPO. In the first case, companies purchasing PV systems for industrial buildings, for instance, may receive government subsidies and feed-in tariffs [27]. However, the initial investment and the cost of maintenance and repair can be substantial. This financial risk is considerably reduced by TPO for corporate customers, who either pay a monthly amount and are allowed to use the PV systems (“lease” model, see Section 1), or pay a fixed price per energy generated (PPA model, see Section 1) [5][27]. In a commercial context, the number of PPA-based PV systems is growing steadily [6]; PPA approaches are also beginning to appear in the private sector as part of the installation of PV systems in RECs [5]. However, the creation and execution of PPAs and lease contracts for PV systems are complex and do not meet the requirements of RECs from two perspectives: (1) a transfer of ownership of the PV system between system owner and resident does not take place. While the consumer can increase the share of renewable generated energy, becoming a prosumer is not feasible. (2) Within an REC, changes of residents/consumers within a residential building occur frequently. An administratively and technologically easy and quick transfer of electricity usage rights from PPAs is not possible. To address this problem, the concept of “co-ownership” has evolved [4]. According to [4], “consumer co-ownership” within RECs is understood as “participation schemes that (..) confer ownership rights in [RE] projects (..) to consumers (..) in a local or regional area”. An important criterion of the RED II of the European Clean Energy Package is that individual shareholders may not own more than 33% of the PV system in co-ownership within RECs [4]. One possibility is for members of an energy community to join together at the outset and jointly purchase plant shares in PV plants [28]. However, this is a one-time transfer of ownership that is detached from the future electricity consumption of the members. A possibility for the gradual tokenized transfer of the ownership of PV shares based on electricity consumption is currently lacking, as the technological and administrative implementation of such a stepwise sale and co-ownership is cumbersome [4].

4. Blockchain in Energy Communities and Use of Tokens

Storing data from distributed PV assets in blockchain networks, which are also organized in a distributed manner, seems to be an obvious approach, and is one of the reasons for the already numerous pilot applications of the use of blockchain technology in the energy industry [29][30]. According to [29], the applications to date can be divided into eight areas, with “decentralized energy trading” making up the largest in terms of the number of applications. For example, [31] are investigating the design of a “local electricity market” built on a peer-to-peer trading mechanism. In the context of an energy community, such a mechanism was studied in [32]. The topic of data security was investigated in [33], resulting in the development of a trading mechanism optimized for security. The use of so-called smart contracts and tokens plays a role in almost all peer-to-peer use cases. A smart contract is a computer program or a transaction protocol which is intended to automatically execute, control or document legally relevant events and actions according to the terms of a contract or an agreement. According to [34], smart contracts are: (a) programs, but not contracts in the legal sense (b) tamper-proof after deployment (c) deterministic. In Germany, smart contracts are considered to follow the expression of a human will that has been anticipated by their programming. Therefore, it is accepted that legally binding agreements can be concluded as smart contracts by automated devices [35][36][37]. As there is currently no standardized definition of tokens [38], using the term "token" as a representation of electricity usage and asset ownership rights within an energy community [38][39]. **Table 1** provides information about the general properties of tokens.

Table 1. Classification of blockchain token.

Description	Native Token	Application Token
Token transmission	linear or circular	linear or circular
Available Quantity	unlimited or limited	limited
Fungibility	fungible	fungible or non-fungible
Duration of Validity	unrestricted	restricted
Transferability	transferable	transferable or non-transferable

A distinction can be made between native tokens and application tokens [29]. A native token (e.g., Bitcoin or Ether) is a platform's own currency, and serves its network as an economic incentive to achieve a higher common goal and to sanction manipulation attempts economically [38][40]. Application tokens represent ownership or access rights to digital and physical assets [41]. Within an energy community, native tokens may represent electricity usage rights, while application tokens represent PV asset ownership rights.

The offer of a token can be designed in limited or unlimited quantities, so that the stability of the token value can be regulated. The token transmission can be categorized as linear or circular. A token with a linear transmission will expire after a single use. A token with a circular transmission can be used as often as desired, and expires only when the asset that it represents no longer exists. Furthermore, the validity of a token can be limited in time. To reduce the complexity of creating application tokens within the developer community, numerous de facto token standards (such as ERC 20 and ERC 777) have been created in recent years.

The existing literature focuses on the use of tokens as specific features of blockchain-based energy markets, such as crypto-currencies [42] or data protection measures [43]. The implementation scope hereby ranges from small power markets in private blockchain applications [44] to markets for anonymous emissions trading between independent actors in public blockchains (peer-to-peer trading) [45]. Regardless of the scope and size of the projects, tokens are predominantly used in the form of native tokens (e.g., one kWh corresponds to one token), especially in the peer-to-peer sharing context. The use of utility tokens to represent the ownership rights of PV systems and the exchange of native into utility tokens, however, has not yet been sufficiently addressed.

References

1. Henni, S.; Staudt, P.; Weinhardt, C. A sharing economy for residential communities with PV-coupled battery storage: Benefits, pricing and participant matching. Appl. Energy 2021, 301, 117351.
2. Norbu, S.; Couraud, B.; Robu, V.; Andoni, M.; Flynn, D. Modeling economic sharing of joint assets in community energy projects under LV network constraints. IEEE Access 2021, 9, 112019–112042.
3. BMWi. Mieterstrom: Energiewende im eigenen Haus. 2017. Available online: https://www.bmwi.de/Redaktion/DE/Artikel/Energie/mieterstrom.html (accessed on 16 February 2022).
4. Lowitzsch, J.; Hoicka, C.E.; van Tulder, F.J. Renewable energy communities under the 2019 European Clean Energy Package—Governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 2020, 122, 109489.
5. Davidson, C.; Steinberg, D.; Margolis, R. Exploring the market for third-party-owned residential photovoltaic systems: Insights from lease and power-purchase agreement contract structures and costs in California. Environ. Res. Lett. 2015, 10, 024006.
6. Bruck, M.; Sandborn, P.; Goudarzi, N. A Levelized Cost of Energy (LCOE) model for wind farms that include Power Purchase Agreements (PPAs). Renew. Energy 2018, 122, 131–139.
7. Gjorgievski, V.Z.; Cundeva, S.; Georghiou, G.E. Social arrangements, technical designs and impacts of energy communities: A review. Renew. Energy 2021, 169, 1138–1156.
8. Radl, J.; Fleischhacker, A.; Revheim, F.H.; Lettner, G.; Auer, H. Comparison of profitability of PV electricity sharing in renewable energy communities in selected European countries. Energies 2020, 13, 5007.
9. Roberts, M.B.; Bruce, A.; MacGill, I. A comparison of arrangements for increasing self-consumption and maximising the value of distributed photovoltaics on apartment buildings. Sol. Energy 2019, 193, 372–386.
10. Tervo, E.; Agbim, K.; DeAngelis, F.; Hernandez, J.; Kim, H.K.; Odukomaiya, A. An economic analysis of residential photovoltaic systems with lithium ion battery storage in the United States. Renew. Sustain. Energy Rev. 2018, 94, 1057–1066.
11. Wang, Z.; Gu, C.; Li, F. Flexible operation of shared energy storage at households to facilitate PV penetration. Renew. Energy 2018, 116, 438–446.
12. Yazdanie, M.; Orehounig, K. Advancing urban energy system planning and modeling approaches: Gaps and solutions in perspective. Renew. Sustain. Energy Rev. 2021, 137, 110607.
13. Li, S.; Pan, Y.; Xu, P.; Zhang, N. A decentralized peer-to-peer control scheme for heating and cooling trading in distributed energy systems. J. Clean. Prod. 2021, 285, 124817.

14. Fernandez, E.; Hossain, M.; Mahmud, K.; Nizami, M.S.H.; Kashif, M. A Bi-level optimization-based community energy management system for optimal energy sharing and trading among peers. J. Clean. Prod. 2021, 279, 123254.

15. Das, L.; Munikoti, S.; Natarajan, B.; Srinivasan, B. Measuring smart grid resilience: Methods, challenges and opportunities. Renew. Sustain. Energy Rev. 2020, 130, 109918.

16. Warneryd, M.; Håkansson, M.; Karltorp, K. Unpacking the complexity of community microgrids: A review of institutions' roles for development of microgrids. Renew. Sustain. Energy Rev. 2020, 121, 109690.

17. Heaslip, E.; Costello, G.J.; Lohan, J. Assessing Good-Practice Frameworks for the Development of Sustainable Energy Communities in Europe: Lessons from Denmark and Ireland. J. Sustain. Dev. Energy Water Environ. Syst. 2016, 4, 307–319.

18. Reijnders, V.M.; Laan, M.D.V.D.; Dijkstra, R. Energy communities: A Dutch case study. Behind Beyond Meter. 2020, 137–155.

19. Kobashi, T.; Yoshida, T.; Yamagata, Y.; Naito, K.; Pfenninger, S.; Say, K.; Takeda, Y.; Ahl, A.; Yarime, M.; Hara, K. On the potential of "Photovoltaics+ Electric vehicles" for deep decarbonization of Kyoto's power systems: Techno-economic-social considerations. Appl. Energy 2020, 275, 115419.

20. Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944 (accessed on 16 February 2022).

21. Wolsink, M. Distributed energy systems as common goods: Socio-political acceptance of renewables in intelligent microgrids. Renew. Sustain. Energy Rev. 2020, 127, 109841.

22. Bandeiras, F.; Pinheiro, E.; Gomes, M.; Coelho, P.; Fernandes, J. Review of the cooperation and operation of microgrid clusters. Renew. Sustain. Energy Rev. 2020, 133, 110311.

23. Milchram, C.; Künneke, R.; Doorn, N.; van de Kaa, G.; Hillerbrand, R. Designing for justice in electricity systems: A comparison of smart grid experiments in the Netherlands. Energy Policy 2020, 147, 111720.

24. Jiang, Y.; Zhou, K.; Lu, X.; Yang, S. Electricity trading pricing among prosumers with game theory-based model in energy blockchain environment. Appl. Energy 2020, 271, 115239.

25. Su, W. The Role of Customers in the U.S. Electricity Market: Past, Present and Future. Electr. J. 2014, 27, 112–125.

26. Richter, M. Utilities' business models for renewable energy: A review. Renew. Sustain. Energy Rev. 2012, 16, 2483–2493.

27. Guajardo, J.A. Third-party ownership business models and the operational performance of solar energy systems. Manuf. Serv. Oper. Manag. 2018, 20, 788–800.
28. Chronis, A.G.; Palaiogiannis, F.; Kouveliotis-Lysikatos, I.; Kotsampopoulos, P.; Hatziargyriou, N. Photovoltaics Enabling Sustainable Energy Communities: Technological Drivers and Emerging Markets. Energies 2021, 14, 1862.
29. 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. Renew. Sustain. Energy Rev. 2019, 100, 143–174.
30. Di Silvestre, M.L.; Gallo, P.; Guerrero, J.M.; Musca, R.; Sanseverino, E.R.; Sciumè, G.; Vásquez, J.C.; Zizzo, G. Blockchain for power systems: Current trends and future applications. Renew. Sustain. Energy Rev. 2020, 119, 109585.
31. Lüth, A.; Zepter, J.M.; del Granado, P.C.; Egging, R. Local electricity market designs for peer-to-peer trading: The role of battery flexibility. Appl. Energy 2018, 229, 1233–1243.
32. Tsao, Y.C.; Thanh, V.V. Toward sustainable microgrids with blockchain technology-based peer-to-peer energy trading mechanism: A fuzzy meta-heuristic approach. Renew. Sustain. Energy Rev. 2021, 136, 110452.
33. Wang, S.; Xu, Z.; Ha, J. Secure and decentralized framework for energy management of hybrid AC/DC microgrids using blockchain for randomized data. Sustain. Cities Soc. 2022, 76, 103419.
34. Antonopolous, A.M.; Wood, G. Mastering Ethereum: Building Smart Contracts and DApps, 1st ed.; O’Reilly UK Ltd.: Farnham, UK, 2018.
35. Heckelmann, M. Zulässigkeit und Handhabung von Smart Contracts; Neue Juristische Wochenschrift (NJW), Verlag C.H.BECK oHG: München, Germany, 2018; p. 504.
36. Kaulartz, M. Rechtliche Grenzen bei der Gestaltung von Smart Contracts; DSRI-Tagungsband, Verlag C.H.BECK oHG: München, Germany, 2016; p. 504.
37. Köhler, M.; Arndt, H.W.; Fetzer, T. Recht des Internet, 7th ed.; C.F. Müller: Heidelberg, Germany, 2016.
38. Lo, Y.C.; Medda, F. Assets on the blockchain: An empirical study of Tokenomics. Inf. Econ. Policy 2020, 53, 100881.
39. Esmaeilian, B.; Sarkis, J.; Lewis, K.; Behdad, S. Blockchain for the future of sustainable supply chain management in Industry 4.0. Resour. Conserv. Recycl. 2020, 163, 105064.
40. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. 2017. Available online: https://bitcoin.org/bitcoin.pdf (accessed on 16 February 2022).

41. Westerkamp, M.; Victor, F.; Küpper, A. Tracing manufacturing processes using blockchain-based token compositions. Digit. Commun. Networks 2020, 6, 167–176.

42. Mihaylo, M.; Jurado, S.; Avellana, N.; Van Moffaert, K.; de Abril, I.; Nowe, A. NRGcoin: Virtual currency for trading of renewable energy in smart grids. In Proceedings of the 11th International Conference on the European Energy Market, Krakow, Poland, 28–30 May 2014; pp. 1–6.

43. Aitzhan, N.; Svetinovic, D. Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams. Trans. Dependable Secur. Comput. 2018, 15, 840–852.

44. Sikorski, J.; Haughton, J.; Kraft, M. Blockchain technology in the chemical industry: Machine-to-machine electricity market. Appl. Energy 2017, 195, 234–246.

45. Al Kawasmi, E.; Arnautovic, E.; Svetinovic, D. Bitcoin-based decentralized carbon emissions trading infrastructure model. Syst. Eng. 2015, 18, 115–130.