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Industry-Led Blockchain Projects for Smart Grids: An In-Depth Inspection

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***Abstract*—In this paper, we investigate industry-led blockchain projects in the field of smart grids. Our investigation is guided by five research questions related to each industry-led project: (1) is the project active? (2) what smart grid applications does the project target? (3) what technical approach does the project take? (4) what is the maturity level of the project? and (5) what we can learn from the success or failure of the project? Our findings show that only a few projects are still active, and many have been terminated when the funding was exhausted. Nevertheless, the few active projects give us hope that sustainable technical approaches in conjunction with sound business models could lead to long-term blockchain-based projects in smart grids. Most of the active projects are targeting energy trading and using custom tokens to incentivize the production of green energy and energy savings. Furthermore, it appears that layer-2 blockchains are becoming the preferred platform for achieving high throughput with low transaction fees while preserving the security and trust of traditional large public blockchains.**

***Index Terms*—Smart grid, blockchain, renewable energy, green certificate, energy trading, smart meter, smart contract, decentralized consensus, data immutability, security, privacy, trust.**

I. Introduction

The blockchain technology [1]–[8] has been anticipated to be one of the critical enabling technologies for smart grids [9], [10], in conjunction with artificial intelligence [11], machine learning [12], and Internet of Things (IoT) [13], [14]. Numerous papers that describe academic research prototypes of blockchain-based smart grid applications have been published (for example [9], [10], [15]–[18]). However, these projects had very limited impact to the smart grid industry. Industry-led blockchain projects, on the other hand, may have much greater impacts and may pave the way of developing the killer app based on blockchain for smart grids.

The studies on blockchain-based smart grid applications have been well reviewed. Some of these reviews included industry-led blockchain projects for smart grids [12], [19]–[22]. However, none of them engaged in in-depth inspection of these projects. Many of these industry-led blockchain projects are no longer active. No technical information can be found for some of the inactive projects. To develop best practices in adopting the blockchain technology for smart grids and to learn important lessons from the blockchain projects, it is essential to extract deep technical information regarding the industry-led blockchain projects for smart grids, which is the primary goal of this paper.

In this paper, we examine the industry-led projects one-by-one with the following research questions: (1) Is the project active? (2) What smart grid application(s) does the project target? (3) What technical approach does the project take? (4) What is the maturity level of the project? (5) What we can learn from the success or failure of the project?

The findings in response to these research questions constitute the research contribution of this paper. More specifically, we find that (1) only a small subset of the projects cited in various academic publications are still active, which revealed the lack of sustainability in those terminated projects; (2) most projects, including the currently active projects, are targeting energy trading, green certificate and carbon credit trading, and providing incentives for the production of green energy and energy saving projects; (3) technically, there is trend to adopt the layer-2 blockchains, such as Polygon and Energy Web Chain, because such blockchains offer high throughput and low transaction fees for smart contracts while inherit the desirable properties of data immutability and trust in traditional large public blockchains; (4) finally, we propose a maturity level scale and identify a few projects at the highest maturity of practical use; and (5) these successful projects could provide important guidance on further research and development of blockchain-based smart grid applications.

II. Related Work

We are not aware of any papers that focus on documenting and analyzing industry-led blockchain-based smart grid projects. Several comprehensive reviews on blockchain-enabled smart grids included sections on industry-led projects [12], [19]–[21].

In [12], ten industry-led projects were identified. Only three of them are still active (Energy Web, Powerledger, and SolarCoin), which are included in our study. In [12], only the primary purposes of these projects were mentioned in a table.

In [19], seven industry-led projects were identified. Only four of them are still active (Energy Web, Powerledger, GridSingularity, and Prosume), which are included in our study. In [19], for each project, the purpose of the project was stated, and for some projects (namely Energy Web and Powerledger), some level of technical details were presented.

In [20], a very comprehensive list of 46 industry-led projects or companies were provided in a table. In the table, information regarding the blockchain applications, the blockchain platform, the blockchain type, consensus mechanism, year launched, and funding for the project were provided when available. Among these projects, we identified nine active projects, which we included in our paper. There could be other active projects. Unfortunately, the Websites for some of the listed projects/companies are not in English. Hence, we cannot make determination.

In [21], industry-led projects or companies were grouped according to their application domains. Seven projects/companies were mentioned for blockchain-based peer-to-peer energy trading, one company was mentioned for wholesale market energy trading, three projects/companies were considered for metering, billing, and retail market energy trading, four projects/companies were included for trading of green certificates and carbon credits, one project was identified for electric vehicle charging, three projects/companies were mentioned for encouraging investment in green energy, and six projects/companies were included for using blockchain to improve grid operation and management.

The above comprehensive reviews provided valuable sources for our current study. We improve these existing studies from several perspectives: (1) we identify active projects, which would be the most valuable ones for future development; (2) we investigate deep technical approaches taken by the active projects to highlight what makes these projects successful technically; and (3) we rank the maturity levels of the projects so that we can learn from those projects that have demonstrated maturity and sustainability.

III. Current Status of Industry-Led Projects

In this section, we report our findings regarding the first two research questions (status of the project and smart grid applications). We are most interested in currently active projects because only these projects could become long-term sustainable projects that demonstrate the utility of the blockchain technology in smart grids. We apply the following criteria in identifying active projects: (1) the project must have a dedicated Website; and (2) the Website must demonstrate ongoing activities and the most recent activity was within one year from July 2023. Besides the activeness of a project, we also evaluate sustainability of the project by the duration of the project to date (for active project) or to when the project ended (if such data are available).

A. Active Projects

In this section, we identify nine active projects. The project information is summarized in Table I.

1) Efforce: The Efforce project applies the token paradigm into the energy savings market. Via an energy savings smart contract, investors who are interesting in participating energy savings projects could purchase a custom-token. For businesses that want to improve their energy efficiency, the Efforce project provides them with a way to seek investment. Hence, the Efforce project can be considered a platform of crowdfunding. However, unlike traditional crowfunding, Efforce allows the investors to trade the tokens that they have acquired for their investment. The founders of Efforce argued that their platform resembles more to a marketplace for those who are interested in energy savings (*i.e.,* improving energy efficiency).

The project Website (https://efforce.io.) provides rich information regarding their business model and technical approach they take. From the road map outlined in the Efforce project white paper (https://efforce.io/WP_ENG_V1.pdf?v=3), the platform started to operate in the first quarter of 2020. Hence, Efforce is a relatively young project. As of writing of this paper in July 2023, two projects are listed in the Website. Both projects initiated in September 2022.

2) Greeneum: The Greeneum project (https://www.greeneum.net/) started in 2018 and it provides a blockchain-based platform to trade carbon credits and green certificates. Furthermore, the project offers a decentralized application to support and optimize the client's carbon emission reduction efforts. A key vehicle for accomplish the project's goal is via the issuance of the GREEN tokens. Renewable energy producers are rewarded with 1000 GREEN tokens per year provided that 1MW verified renewable energy have been generated. More specifically, the project builds two systems. One system is for local green energy trading facilitated by the GREEN tokens. The other is a global green energy data system that verifies and records the green energy production, which would lead to the issuance of green certificates (and the associated carbon credit). The green certificates could be sold for the GREEN tokens.

3) Powerledger: The goal of the Powerledger project is to create a blockchain-based energy trading platform (https://www.powerledger.io). According to the project Website (https://www.powerledger.io/timeline-powr), the project started in the second quarter of 2016.

4) Energy Web: The stated goal of the Energy Web project is very broad according to its Website (https://www.energyweb.org), *i.e.,* accelerate the energy transition using the blockchain technology. The project appears to be extremely active with a lot of news stories. The Website claims that it could provide solutions in green proof, asset management, and data exchange. The project was launched in the first quarter of 2017 with ten funding companies.

5) Block-Z: The Block-Z project (https://www.blok-z.com), launched in early 2019, aims to provide a blockchain-based platform for renewable energy matching. It appears that the project has become a partner with the Energy Web project (it is listed as one of the validators in Energy Web).

6) GridSingularity: The GridSingularity project (https://gridsingularity.com) is also affiliated with the Energy Web project. The goal of the project is to support energy exchange using a blockchain-based platform. The earliest activities posted on the project Website is in May 2016.

7) SolarCoin: The goal of the SolarCoin project (https://solarcoin.org/) is to encourage solar energy generation. Solar energy producers would be rewarded by the token called

TABLE I
ACTIVE INDUSTRY-LED PROJECTS

Project	Application	Project Website	Project Starting Date
Efforce	Incentivize energy savings	https://efforce.io	Q3, 2020
Greeneum	Green energy trading and green certificate management	https://www.greeneum.net	2018
Powerledger	Energy trading	https://www.powerledger.io	Q2, 2016
Energy Web	Blockchain-based energy decentralized operating system	https://www.energyweb.org	Q1, 2016
Block-Z	Renewable energy matching	https://www.blok-z.com	Q1, 2019
GridSingularity	Energy exchange	https://gridsingularity.com	Q2, 2016
SolaCoin	Incentivize solar energy	https://solarcoin.org/	2014
NRGcoin	Incentivize green energy	https://nrgcoin.org	2018
Presume	Energy data management	https://prosume.io	Q3, 2018

SolarCoins after registration and validation of the the solar energy production. For each MWh of solar energy generated, the solar producer will be rewarded by 1 SolarCoin. The SolarCoin project has been in operation since 2014.

8) NRGcoin: The NRGcoin project (https://nrgcoin.org) started to operate in 2018 [23] and it has rather similar goal as that of the SolarCoin project. The project would award both green energy consumers as well as producers 1 NRGcoin consumed/produced per kWh.

9) Prosume: The Prosume project started in August 2018 and it provides a blockchain-based energy data management platform (https://prosume.io). The platform is said to facilitate users to source energy from local and green energy generation, to carry out energy exchange at the local community levels, to allow full traceability, and to help users gain co-ownership of power plants. The platform would enhance grid operation and maintenance, increase transparency and trustworthiness, provide more flexibility in the choice of power sources, and perform cost control. More specifically, the project facilitates energy exchange, energy source tracing, energy data certification, grid balancing, and smart billing and automated payments.

B. Inactive Projects

For inactive projects, only those that still have a functional Websites in English are included in this section because we cannot perform our investigation otherwise. Hence, we only include a small set of inactive projects, which are summarized in Table II.

1) The Brooklyn Microgrid project: The Brooklyn Microgrid project [24] was launched to create a locally-generated solar energy marketplace (https://www.brooklyn.energy) in April 2016 [21]. The provided link on the Website about the parent company who sponsored this project, LO3 Energy, (https://lo3energy.com) is no longer accessible. Furthermore, another link provided on the Website about technical details of the project (https://exergyenergy.wordpress.com) is also not accessible. Hence, it is clear that the project is no longer active.

The Electron project was launched to create a digital energy marketplace (https://electron.net). The project Website does not contain any technical details. According to [20], Electron used Ethereum and had been used to support energy trading for demand-side response, to manage energy data asset, and to improve smart meter data privacy. According to the timeline provided by the project Website, the Electron project started in 2015 and concluded in 2020.

The Electrify project was launched to create a blockchain-based peer-to-peer energy trading platform (https://electrify.asia/). The project Website does not reveal any technical details. The company had an initial coin offering in 2018 and the new recent post on the project Website is dated in May 18, 2021.

The Pylon Network Blockchain (*i.e.,* PylonCoin) project was launched in 2019 as the first open-source blockchain for the energy sector (https://pylon.network/). Unlike many other industry-led projects, the source code for this project is available at GitHub (https://github.com/pylondata/pyloncoin) together with a white paper outlining the project's technical designs. Unfortunately, it appears that the PylonCoin is no longer in operation.

The Enerchain project was launched to support decentralized energy trading (https://enerchain.ponton.de/index.php). The project introduced its own custom blockchain called Enerchain, and Enerchain in turn uses the WRMHL blockchain framework. According to [21], the development of Energchain initiated in 2016, and the underlying blockchain platform is a permissioned blockchain. The project Website reported no recent activity.

The Nimray project was purported to establish a blockchain-based platform for promoting solar energy (https://nimray.com/index.html). According to the project Website, the company conducted an initial coin offering during the last two months of 2019. No further news stories were posted on the project's Website. Hence, we suspect that the project is no longer active.

IV. TECHNICAL APPROACHES

In this section, we report our findings regarding the third research question on technical approaches. Only active projects are considered because the technical details for inactive projects are scant. Even for active projects, some of them failed to disclose any technical approaches. These projects are omitted in this section. The technical approaches are summarized in Table III.

1) Efforce: In the Efforce project, smart contracts [25] are used to enforce the contract between the participants of the energy saving projects (businesses who want to improve their energy efficiency, companies who are specialized in implementing the energy efficiency projects, and investors

TABLE II
INACTIVE INDUSTRY-LED PROJECTS

Project	**Application**	**Project Website**	**Project Duration**
Brooklyn Microgrid	Solar Energy Marketplace	https://www.brooklyn.energy	Q2, 2016 - ?
Electron	Digital energy marketplace	https://electron.net	2015 - 2020
Electrify	Peer-to-peer energy trading	https://electrify.asia/	2018 - Q2, 2021
PylonCoin	Blockchain for the energy sector	https://pylon.network	2019 - Q4, 2021
Enerchain	Decentralized energy trading	https://enerchain.ponton.de/index.php	2016 - ?
Nimray	Platform for promoting solar energy	https://nimray.com/index.html	2019 - ?

TABLE III
TECHNICAL APPROACHES IN THE PROJECTS

Project	Blockchain	Instruments
Efforce	Ethereum ⇒ Polygon	NFT
Greeneum	Ethereum	GREEN token and green certificate
Powerledger	Ethereum+consortium blockchain	Custom token and state channel
Energy Web, Block-Z, GridSingularity	Energy Web Chain (Ethereum+consortium blockchain)	EWT and EWX
SolarCoin	SolarCoin ⇒ Energy Web Chain	SolarCoin
NRGcoin	Ethereum	NRGcoin

who fund the project). The smart contract would generate (*i.e.,* mint) non-fungible tokens (NFTs) according to a carefully planned schedule. Each NFT has certain lock-in period. After the lock-in period, the investors may choose to sell the NFTs.

Initially, the smart contracts are deployed on Ethereum in Efforce. Recently, Efforce announced that it is going to switch to Polygon, which is a layer-2 blockchain. Polygon uses proof-of-stake algorithm and maintains multiple application-specific blockchains. For each chain, there are a set of validators who will participate in the consensus process on how the next block should be created. To ensure the security of the Polygon system, a validator smart contract is deployed on Ethereum. Anyone who wishes to serve as a validator must place a stake via this smart contract. The consensus among the validators is achieved via a traditional distributed consensus protocol similar to practical Byzantine fault tolerance.

2) Greeneum: The Greeneum project issues a Green token to support its goal. The token is an ERC20-compliant token and the issuance and management of the GREEN token is via a smart contract deployed on Ethereum. The tokens are rewarded to green energy producers after the generation process has been verified using a proof-of-energy-transaction process. The green energy producers are expected to connect their renewable energy asset so that the related energy data can be certified. In addition to the GREEN tokens, asset owners are entitled to receive the Greeneum Green energy certificates. The funding of the project was accomplished via an initial coin offering of the GREEN tokens. A quarter of the tokens are allocated to the Green Fund, which are used to reward green energy producers.

3) Powerledger: The Website for the project offers a white paper that documents its project goal and the technical approach (https://www.powerledger.io/company/power-ledger-whitepaper). According to the white paper of the Powerledger project, a hybrid approach is used in its platform where both the Ethereum and a consortium blockchain are used together. The project's custom tokens are managed by a smart contract deployed on the Ethereum. Other transactional operations are supported by the consortium blockchain. In particular, the state channels is used to ensure high throughput of the operations for the platform's clients.

4) Energy Web, Block-Z, and GridSingularity: The Energy Web aims to provide a decentralized operating system for the energy sector. At the bottom of the proposed operating system consists of the Energy Web Chain (EWC), which offers the Energy Web Token (EWT); Energy Web X (EWX), which is a set of application-specific templates for clients to choose that fits their needs the best; and decentralized logic execution component, which allows clients to deploy their own decentralized algorithms. EWX allows the client to deploy worker nodes and the worker nodes are secured by the Energy Web Tokens. At the higher layer consists of identity management libraries, data management facilities, and smart contract templates.

Rather similar to Polygon, Energy Web depends on a smart contract deployed on the Ethereum to establish the set of validators for the operations of the Energy Web Chain (https://energy-web-foundation.gitbook.io/energy-web/foundational-concepts/ethereum). In Energy Web, only vetted companies may join Energy Web as validators. From this sense, Energy Web by itself is a consortium blockchain. The current validators are published at https://validators.energyweb.org. These validators determine the next block in a round-robin fashion, which is referred to as proof-of-authority. Once a block is created by one of the validators, other validators are expected to validate the block and sign the block if the block is deemed to be valid. A simple majority is needed to finalize a block.The basic assumption is that because the validators are vetted and are regarded to have the best interest of the consortium, they are unlikely to misbehave. Block-Z and GridSingularity are relying on the Energy Web Chain for their operations.

5) SolarCoin: The SolarCoin project initially used its own custom-built blockchain to generate the SolarCoins. The token issuance process can be both programmable and manual. A solar producer would need to provide a compliant wallet with a receiving address. In March 2021, the custom SolarCoin Chain (now referred to as SolarCoin Classic) ceased operation and switched to using the Energy Web Chain.

6) NGRcoin: The NRGcoin is generated via a smart contract deployed on Ethereum.

V. Maturity Levels

In this section, we report our findings for research question four. We propose to rate the maturity levels of the industry-led projects with a five-level scale: (1) L1: conceptual; (2) L2: demonstrated with simulation; (3) L3: demonstrated with experiments in the lab setting; (4) L4: pilot testing in the field; and (5) L5: practical use in the field, as shown in Figure 1.

At the L1 (conceptual) level, the requirements of the application and the potential benefits are presented without any validation. At the L2 (simulation) level, the feasibility and benefits of the proposed application are demonstrated using simulation. At the L3 (lab experiment) level, the proposed solution is validated using a small set of nodes to emulate the actual blockchain and power grid environment. At the L4 (pilot testing) level, actual users, actual components of the electric grid, and the blockchain platform are involved. At the L5 (practical use) level, the proposed solution would have been open to the customers with a fully-working blockchain platform. We summarize the maturity levels of both active projects and inactive projects in Fig. 2.

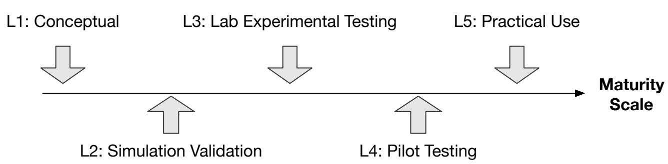

Fig. 1. The proposed five-level maturity scale.

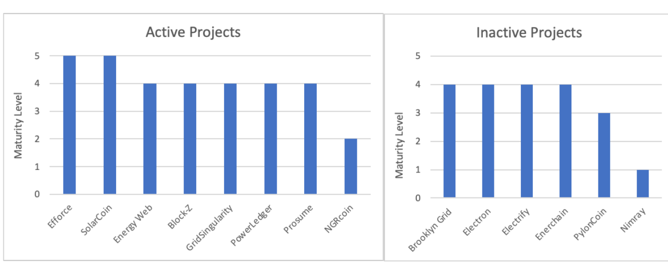

Fig. 2. The proposed five-level maturity scale.

A. Active Projects

The Efforce project is clearly at the L5 maturity level because it has been supporting real-world projects with businesses that wanted to improve energy efficiency, companies that are specialized in implementing energy savings, and investors who wish make an impact while getting returns in their investment.

The SolarCoin project has been in operation to support solar producers since 2014. Hence, we rank the project at the highest maturity level of L5. However, we are concerned about the sustainability of the project. Unlike Efforce and Energy Web projects, which appear to be self-sustaining, it is unclear who pays for the operation of the project.

The Energy Web project claims to have done 50 pilot project with various partners. Hence, we rank the maturity level at L4. Because Block-Z is one of the validators of the Enegy Web Chain, successful pilots may also be credited to Block-Z. Hence, the maturity level of Block-Z is also at maturity level of L4. GridSingular is recognized as one of the founding companies for the Energy Web. Hence, GridSingular is also ranked at the L4 maturity level.

According to the Powerledger Website (https://www.powerledger.io/timeline-powr), several pilots projects have been conducted over the years. The most recent project is the energy community project in Spain launched in the first quarter of 2022. The earliest pilot project was the uGRid application for peer-to-peer energy trading, which was deployed for the electric grid at the GenY apartments in White Gum Valley. Hence, we rank the maturity level at L4.

From the posts on the Prosume project Website, several pilot projects have been carried out with grant funding, for example, in quarter four of 2018, Prosume won a grant from the city council of Barcelona to develop an energy community for the city focusing on the logging of data related to energy consumption, production, and storage of municipal buildings on the blockchain. Hence, we rank the project at the L4 maturity level.

The NGRcoin project has been evaluated in a simulation environment with real data. From the project Website, we cannot find additional progress. Hence, we rank the project at the L2 maturity level.

B. Inactive Projects

The Brooklyn Microgrid project has been mentioned in several academic papers [20], [21], [24] as an example pilot project. Hence, we rank this project at the L4 maturity level. The Website for the Electron project listed several completed pilot projects, hence, we rank the Electron project at the L4 maturity level. According to the Electrify project Website, a pilot for blockchain-based peer-to-peer energy trading was conducted with 15 participants in quarter 1 of 2019. Hence, we rank the Electrify project at the L4 maturity level. According to [21], the Enerchain project piloted with the industry after the custom blockchain went live. Hence, we rank this project a the L4 maturity level.

Although the technical details for the PylonCoin project are available from the project's Github account, it is unclear if the blockchain has supported any industry pilots. The project is at least at the L3 maturity level, and could have been at the L4 level. Due to lack of evidence for any actual activities beyond the initial coin offering, we rank the Nimray project at the L1 maturity level.

VI. Lesson Learned

In this section, we report our findings for the last research question. From the technical approaches taken by active projects, we make the following observations.

First, all of the active projects introduced custom tokens. These tokens are indispensable tools to attract investments in green energy (such as the Efforce project) and to incentivize the production and usage of green energy (such as the Greeneum and SolarCoin projects). The offering of the custom tokens could be essential for the long-term sustainability of the project. However, not all projects that have made initial coin offering have survived the test of time. For example, the Electrify project made a successful initial coin offering, but it appears to be no longer active.

Second, it appears that the layer-2 blockchain design is becoming the mainstream. A layer-2 blockchain would rely on Ethereum to deploy one or more smart contracts to manage the set of validators and custom-chains operating in the layer-2 blockchain. These smart contracts deployed on Ethereum would establish the foundation for security and trust for the custom chains running on the layer-2 blockchain.

Third, the great majority of projects are about energy trading or about using tokens as incentives or payment tools. Energy Web is a rare exception because it offers many application templates that could prove to be useful to extend the blockchain technology in areas beyond trading of energy, crowdfunding, incentives, green certificates, and carbon credits.

Fourth, the business models of the projects matter fundamentally for their long-term sustainability. The business model of the Efforce project appears to be sound. On the contrary, it is unclear how the SolarCoin could sustain itself by simply giving away their custom tokens to green energy producers.

VII. Conclusion

In this paper, we investigated industry-led blockchain projects in the field of smart grids. Our findings showed that only a few projects are still active, and many have been terminated when the funding was exhausted. Nevertheless, the few active projects provided good examples that sustainable technical approaches in conjunction with sound business models could lead to long-term successful blockchain-based projects in smart grids. Most of the active projects are targeting energy trading and using custom tokens to incentivize the production of green energy and energy savings. Furthermore, it appears that layer-2 blockchains are becoming the practical solutions for achieving high throughput with low transaction fees while preserving the security and trust of traditional large public blockchains.

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References

[1] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," https://bitcoin.org/bitcoin.pdf, 2008.

[2] G. Wood *et al.*, "Ethereum: A secure decentralised generalised transaction ledger," *Ethereum project yellow paper*, vol. 151, no. 2014, pp. 1–32, 2014.

[3] W. Zhao, *From Traditional Fault Tolerance to Blockchain*. Hoboken, NJ, USA: John Wiley & Sons, 2021.

[4] ——, "On blockchain: Design principle, building blocks, core innovations, and misconceptions," *IEEE Systems, Man, and Cybernetics Magazine*, vol. 8, no. 4, pp. 6–14, 2022.

[5] W. Zhao, C. Jiang, H. Gao, S. Yang, and X. Luo, "Blockchain-enabled cyber–physical systems: A review," *IEEE Internet of Things Journal*, vol. 8, no. 6, pp. 4023–4034, 2020.

[6] W. Zhao, S. Yang, X. Luo, and J. Zhou, "Dos and don'ts in blockchain research and development," in *Proceedings of the 4th International Conference on Blockchain Technology*, 2022, pp. 37–43.

[7] E. Akbari, Q. Wu, W. Zhao, H. R. Arabnia, and M. Q. Yang, "From blockchain to internet-based voting," in *2017 International Conference on Computational Science and Computational Intelligence (CSCI)*. IEEE, 2017, pp. 218–221.

[8] W. Zhao, S. Yang, and X. Luo, "On consensus in public blockchains," in *Proceedings of the 2019 International Conference on Blockchain Technology*. Honolulu, Hawaii, USA: ACM, 2019, pp. 1–5.

[9] T. Alladi, V. Chamola, J. J. P. C. Rodrigues, and S. A. Kozlov, "Blockchain in smart grids: A review on different use cases," *Sensors*, vol. 19, no. 22, NOV 2019.

[10] E. Kapassa and M. Themistocleous, "Blockchain technology applied in iov demand response management: A systematic literature review," *Future Internet*, vol. 14, no. 5, MAY 2022.

[11] W. Hua, Y. Chen, M. Qadrdan, J. Jiang, H. Sun, and J. Wu, "Applications of blockchain and artificial intelligence technologies for enabling prosumers in smart grids: A review," *Renewable & Sustainable Energy Reviews*, vol. 161, JUN 2022.

[12] V. K. Mololoth, S. Saguna, and C. ahlund, "Blockchain and machine learning for future smart grids: A review," *Energies*, vol. 16, no. 1, JAN 2023.

[13] M. Casquico, B. Mataloto, J. C. Ferreira, V. Monteiro, J. L. Afonso, and J. A. Afonso, "Blockchain and internet of things for electrical energy decentralization: A review and system architecture," *Energies*, vol. 14, no. 23, DEC 2021.

[14] T. Qiu, N. Chen, K. Li, M. Atiquzzaman, and W. Zhao, "How can heterogeneous internet of things build our future: A survey," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2011–2027, 2018.

[15] G. Wang, Y. Liu, C. Zhang, and Y. Zhang, "A review of energy internet research considering interactive energy: The blockchain perspective," *Froniters in Energy Research*, vol. 10, SEP 26 2022.

[16] S. Bielecki, T. Skoczkowski, L. Sobczak, and M. Wolowicz, "Electricity usage settlement system based on a cryptocurrency instrument," *Energies*, vol. 15, no. 19, OCT 2022.

[17] W. Zhao, I. M. Aldyaflah, P. Gangwani, S. Joshi, H. Upadhyay, and L. Lagos, "A blockchain-facilitated secure sensing data processing and logging system," *IEEE Access*, vol. 11, pp. 21 712–21 728, 2023.

[18] I. M. Aldyaflah, W. Zhao, H. Upadhyay, and L. Lagos, "The design and implementation of a secure datastore based on ethereum smart contract," *Applied Sciences*, vol. 13, no. 9, p. 5282, 2023.

[19] D. Kirli, B. Couraud, V. Robu, M. Salgado-Bravo, S. Norbu, M. Andoni, I. Antonopoulos, M. Negrete-Pincetic, D. Flynn, and A. Kiprakis, "Smart contracts in energy systems: A systematic review of fundamental approaches and implementations," *Renewable & Sustainable Energy Reviews*, vol. 158, APR 2022.

[20] S. Gawusu, X. Zhang, A. Ahmed, S. A. Jamatutu, E. D. Miensah, A. A. Amadu, and F. A. Junior Osei, "Renewable energy sources from the perspective of blockchain integration: From theory to application," *Sustainable Energy Technologies and Assessment*, vol. 52, no. B, AUG 2022.

[21] M. Nour, J. P. Chaves-Avila, and A. Sanchez-Miralles, "Review of blockchain potential applications in the electricity sector and challenges for large scale adoption," *IEEE Access*, vol. 10, pp. 47 384–47 418, 2022.

[22] W. Zhao, Q. Qi, J. Zhou, and X. Luo, "Blockchain-based applications for smart grids: An umbrella review," *Energies*, vol. 16, no. 17, p. 6147, 2023.

[23] M. Mihaylov, I. Razo-Zapata, and A. Nowe, "Nrgcoin—a blockchain-based reward mechanism for both production and consumption of renewable energy," in *Transforming climate finance and green investment with blockchains*. Elsevier, 2018, pp. 111–131.

[24] L. Orsini, S. Kessler, J. Wei, and H. Field, "How the brooklyn microgrid and transactive grid are paving the way to next-gen energy markets," in *The energy internet*. Elsevier, 2019, pp. 223–239.

[25] G. Zheng, L. Gao, L. Huang, and J. Guan, *Ethereum smart contract development in solidity*. Springer, 2021.