Article

Blockchain Platforms in Energy Markets—A Critical Assessment

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Abstract: Compared to other applications of distributed ledger technologies, for example, in decentralized finance, non-fungible tokens, and logistics, Blockchain applications in the energy industry have not found widespread dissemination and fell short of market expectations during the Blockchain hype in the late 2010s. In semi-structured qualitative interviews with leading providers in the energy industry, conducted from 2019 to 2021, hurdles in energy applications are compared with a control group of additional interviews with representatives of companies operating in IT and FinTech. The analysis uses a framework covering technical feasibility, desirability, and economic viability, as well as the role of regulatory frameworks. The interviews reveal that the first Blockchain applications suffered from a combination of technological constraints and inter-platform competition. Due to the permissionless configuration of the early energy Blockchains, they were slow in terms of transaction speed compared to existing platforms and prices per transaction were high, in addition to high degrees of complexity related to requirements from both critical-infrastructure systems and financial market regulation. The analysis further points to the slow adoption of Blockchain applications in the energy sector being related to business models rather focusing on products and platforms as well as on transactional rather than procedural use cases, with a high degree of standardization of the offering and low levels of inclusiveness concerning processes. The move from transaction platforms to innovation platforms and the emergence of Blockchain as a service provider—plus technical advances with regards to high-frequency transactions combined with the increasing importance of use cases, such as proof of origin for fuels or e-charging—may induce a shift from pilot applications to commercialization within the larger innovation ecosystem. While the involvement of Blockchain solutions in energy markets increases with pilot projects and with this, the acceptance of players and stakeholders in the energy ecosystem, a big hurdle for innovation remains the regulation of energy markets to allow for peer-to-peer trading, a usage-driven distribution of network costs, and bottom-up pricing markets.

Keywords: Blockchain; distributed ledger technologies; energy markets; platforms; energy transformation; disruptive innovation

1. Introduction

Distributed ledger technologies (DLTs) allow for synchronously storing and sharing data in a decentralized, transparent digital format that enables users to undertake transactions without the need for an intermediary. The idea is expressed in late 2008 in a White Paper outlining the concept of a cryptocurrency that would allow for peer-to-peer transactions of electronic cash (Nakamoto 2008). The first cryptocurrency is called Bitcoin and initiates a surge in other cryptocurrencies.

Blockchain and decentralized ledger technologies become known to a broader public when Bitcoin as a cryptocurrency is perceived as a complement, or counter-model, to the global financial system by establishing a parallel FinTech universe without the power asymmetry between banks, trading companies, and global financial institutions on the one side and atomistic and unorganized individuals on the other side. Blockchain promises
an approach based on the principles of consumer empowerment and self-determination, without the interference of a rent-seeking central player, such as a bank. Trust would be shifted from an institution to the process itself by creating a framework of maximum transparency and based on the decisions of its members.

Over a similar period, the electricity supply industry experiences a fundamental change. Regulatory incentives, such as feed-in tariffs or net metering, trigger household-scale investments in solar panels and wind farms owned by local cooperatives in countries, such as Australia, Germany, and states, such as California, Arizona, and New England states, in the United States. Decentralized renewable generation technologies, in particular solar photovoltaic cells, and local storage via stationary household batteries or electric vehicles become affordable, even for the mass market.

As the idea of DLTs spreads from FinTech to other sectors, such as logistics, telecommunications, and any type of transaction platform, Blockchain’s normative connotation of consumer empowerment resonates also in the energy sector. It is perceived as the ideal mechanism to literally empower private residents to engage in direct peer-to-peer trading. So-called prosumers are envisaged to become mini-traders without the interference of an intermediary, which—in analogy to banks in the financial sector—would be, of course, the energy utility or the local grid operator (Martin 2018). In addition, crowdfunding via tokenization and initial coin offerings (ICOs) serves as a warranty for participatory decision processes and a vision of a grassroots, anti-establishment movement. Blockchain would become an instrument for coping with the complexity of the decentralized structure and provide, for example, hedging tools against fluctuating electricity prices (ibid.).

With the launch of Ethereum in 2015, more complex applications within DLTs are introduced. So-called Smart Contracts allow for automated, trackable, and irreversible actions based on pre-defined conditions and executed within fixed rules and software code. Their ability to automate minor transactions reduces the level of complexity and offers security.

In the mid-2010s, the first real-world, energy-specific applications of DLTs emerge, including the SolarCoin movement, which tries to assign a cryptocurrency value to each kilowatt hour produced by renewable energy installations (Gogerty and Johnson 2018; Johnson et al. 2015; Nehai and Guérard 2017), and the Brooklyn Microgrid, which facilitates peer-to-peer transactions in an urban mix of consumers and producers of distributed energy (Mengelkamp et al. 2018b; Orsini et al. 2019; Zia et al. 2020).

Blockchain startup GridSingularity and the Colorado-based non-profit organization Rocky Mountains Institute (RMI) launched the Energy Web Foundation (EWF), with the mission of “analyzing use cases and organizing task forces to push the most promising use cases into proof of concepts and commercial applications, while incubating an ecosystem of application developers, and cooperating with regulators and standardization bodies to facilitate deployment” in an “open-source approach of eliminating energy market entry barriers” (Zeranski 2017). Corporate players, such as utilities Centrica (United Kingdom), Engie (France), Sempra Energy (United States), Tokyo Electric Power Co (Japan), transmission grid operator Elia, and E&P-focused Royal Dutch Shell and Statoil ASA, belong to the first consortium members of the EWF (ibid.).

Meanwhile, governments started funding applied research projects for potential Blockchain applications in the energy sector, establishing regulatory “sandboxes” as instruments of innovation that do not have to fully comply with the existing regulatory framework. For example, within the “Smart Service World” framework, the German Federal Ministry of Economic Affairs finances four distinct consortia (BlogPV, SMECS, ETIBLOGG, and Pebbles) to investigate the use of Blockchain in testing peer-to-peer trading (Kasanmascheff 2020).

Despite all these bottom-up and top-down efforts, Blockchain initiatives in the energy sector fail to gain traction and, to date, only selected pilot projects and model regions, often financed by respective governments, start to implement Blockchain-based solutions, whereas DLT applications in other industry verticals attract substantial private and in-
Institutional investments, most notably in the areas of non-fungible tokens (NFTs) and decentralized finance (DeFi).

Exacerbated and accelerated by the global lockdowns during the COVID-19 pandemic, NFTs emerged as an alternative to real-world art fairs and auctions. The basic idea of an NFT is a unique identifier for (typically) a digital piece of art, for example, a file in jpeg or gif format. Since digital art can be replicated an infinite number of times, NFTs create an artificial scarcity of a certain art object. In a two-sided market of sellers and buyers of art, all involved parties share a consensus on the validity of the market mechanism and the underlying assumption that an NFT is an adequate representation of the value of a digital file.

Until May 2021, the trading volume of NFTs reached more than USD 34 billion (Wang et al. 2021), but it plummeted sharply in the transition phase to a post-pandemic global economy, with real art events opening up again and temporary visitors (“tourists”) leaving the market (Craig 2022). Nonetheless, NFTs are core elements of future metaverses, such as “The Sandbox” and “Decentraland.” This is because they allow users to acquire unique accessories for their avatars, such as virtual shoes or a property, and potentially transfer them from one metaverse to another via Blockchain connector and bridge services, such as Polkadot, Polygon, or the Harmony Foundation (Chan 2022). Citi, an investment bank, estimates that the prospects for the metaverse potentially reach USD 8–13 trillion by 2030 (Morris 2022).

Similarly, DeFi applications and business models have emerged as increasingly popular alternatives to the traditional banking system (Chen and Bellavitis 2019, 2020; Katona 2021; Schär 2021). Startups, such as Berlin-based Bitbond, for example, operate in peer-to-peer lending markets (Noreikaite and Ambrazaite 2017) and as service providers for bank-grade tokenization and digital assets technology, thereby challenging the business models of established players but also providing DLT-based solutions for them in an uncertain market environment.

This paper investigates the underlying reasons why DLTs have so far failed to experience widespread implementation in the energy sector and why the initial enthusiasm of moving toward a more decentralized, Blockchain-oriented configuration has faded.

2. Literature Review

With a certain delay compared to the initial articles in the grey literature, including code-sharing websites, such as Github, and web-based publication tools, such as Medium (for example, Tual 2016), the scholarly literature on Blockchain in the energy sector reflects a very pragmatic, yet sometimes fairly narrow, approach to the topic, with proof of concept, descriptions of concrete applications (or plans thereof), simulations, and the identification of use cases. In particular, the reasons for the failures in implementing real-world projects are hardly addressed. After an analysis of the evolution of the scholarly focus on Blockchain and DLTs in the energy sector, other strands of the academic literature are included in this review, most specifically the literature on platforms and inter-platform competition.

Early academic publications reflect the enthusiasm related to the emerging technology, ranging from improving smart grid cyber resiliency and secure transactive energy applications (Mylrea and Gourisetti 2017) to the usage of green certificates within a micro-grid (Imbault et al. 2017). Mannaro et al. (2017) developed a modular Blockchain-based software platform for extending the features of cryptocurrency exchanges to the renewable energy market, including a “robo-advisor”, which will suggest strategies to prosumers. Green and Newman (2017) foresaw a new “citizen utility paradigm” using new Blockchain support systems, with the concrete example of Perth, Australia. Noor et al. (2018) proposed a game theoretic approach for a demand-side management model incorporating storage components.

One recurrent theme of the early literature is the facilitation of peer-to-peer trading—equivalent to the initial Bitcoin idea for financial markets—without any intermediary, such as a bank or, in the case of electricity, the local utility or grid operator. Later publications
integrate more sophisticated simulation approaches, for example, Lüth et al. (2018) and Sousa et al. (2019), who simulate and analyze local market designs that facilitate peer-to-peer trade. Mengelkamp et al. (2018a) presented a comprehensive concept, market design, and simulation of a local energy market between residential households, including an economic evaluation of the market mechanism. Pop et al. (2018) described a prototype for demand response implemented in an Ethereum platform.

Concrete security aspects also become increasingly relevant in the literature. Li et al. (2018) proposed a secure energy-trading system based on consortium Blockchain technology while addressing security and privacy challenges and Aitzhan and Svetinovic (2018) provided a proof of concept, providing transaction security in decentralized smart grid energy trading without reliance on trusted third parties. Diestelmeier (2019) analyzed first-use cases of Blockchain applications in the electricity sector and identified policy implications from an energy law perspective. Hackbarth and Löbbe (2020) estimated regression models to identify the most prospective customer segments and their preferences and motivations for participating in peer-to-peer electricity trading.

The connection between Blockchain and the Smart Grid is explored by a further strand of literature (see e.g., Agung and Handayani 2022; Gajić et al. 2022; Kameshwaran et al. 2023; Yapa et al. 2021), which addresses the advantages of distributed ledgers when the energy system becomes increasingly decentralized, with a high share of intermittent renewable energy intake from wind or solar radiation. Hrga et al. (2020) identified four potential use cases of Blockchain in the energy sector, namely energy tokenization and investments, peer-to-peer trading, charging of electric vehicles, and e-mobility.

A number of meta-studies on Blockchain applications in the energy sector have appeared, including bibliometric analyses (Ante et al. 2021; Wang and Su 2020; Wu and Tran 2018), a survey among corporate decision-makers (Burger et al. 2016), and a comprehensive compendium of use cases in the innovation ecosystem, including business models of startups and a categorization of 140 Blockchain research projects and initiatives undertaken by companies and research organizations (Andoni et al. 2019). The authors of this latter meta-study mention, at least, “significant barriers in the adoption of the technology” with respect to the legal and regulatory spheres (Andoni et al. 2019, p. 167). However, none of the meta-studies provide a plausible explanation for the persistent failure of energy Blockchain applications to gain traction.

In order to better understand why Blockchain and DLTs have not found widespread dissemination in the energy sector, a larger platform ecosystem view provides valuable insights. In their least sophisticated configuration, Blockchains and DLTs are platforms for storing, sharing, and exchanging information. Many academic publications related to Blockchain applications in the energy sector focus on the micro-management and optimization of the platform technology (for example, Esmat et al. 2021; Kang et al. 2018; Khatoon et al. 2019). However, Blockchain platforms compete for users in a larger innovation ecosystem. Their overall commercial success or failure not only depends on the quality of internal settlement mechanisms or information exchange, but also on the macro-characteristics of the market in which they operate, and of the platform ecosystem that they nourish (Tiwana 2013, p. 3).

Platform economics have different underlying theoretical concepts than, for example, regulatory economics. One of the basic features of platform economics is network effects. A platform becomes more valuable and attractive for each user if more users participate in the platform (Baldwin and Woodard 2008; Gawer 2021). If it succeeds to attract a critical mass of users, a digital platform may enter into a positive feedback loop and become the dominant platform in a given market (Cusumano et al. 2019). Platforms typically compete with other platforms that offer comparable functionalities—a phenomenon called inter-platform competition.

Once a dominant platform is established, barriers to market entry for other platforms remain high because of user stickiness. Cennamo and Santalo (2013) questioned the “winner-takes-it-all” hypothesis, though, by analyzing corporate strategies in the US
video game industry. In a market with competing platforms, the strategy of a distinctive positioning or identity, or a niche market, may lead to commercial success despite other dominant platforms (ibid.).

Platforms can be either characterized as one-sided platforms, for example, by providing a marketplace for peer-to-peer trading, or they function as multi-sided platforms, such as for information exchange between various stakeholders in a global supply chain (Cusumano et al. 2019) or—more closely related to the energy sector—enabling access to information related to a specific megawatt hour produced by a wind turbine in the Baltic Sea to its final customer, who needs to prove its emission-free generation using a so-called Certificate of Origin (Giegling 2022).

Cusumano et al. (2019) elaborated on two types of platforms—transaction platforms and innovation platforms—where the former “serve as intermediaries for direct exchange or transactions, subject to network effects,” while the latter “serve as a technological foundation upon which other firms develop complementary innovations” (Cusumano et al. 2019, figures 1–2). Examples of transaction platforms include social media platforms, such as Facebook, but also service providers without own physical assets, such as Uber and AirBnB (ibid.). Most importantly, the individual users of these platforms use the service without adding new features or functionalities. By contrast, innovation platforms create the foundation for an ecosystem of applications developed by third parties, often with minimal in-house investment. Google Android and Apple iOS, but also Siemens MindSphere and Microsoft Azure, belong to that category (Carroll et al. 2017; Fortino et al. 2022). While many digital tech companies have started offering hybrid platforms that allow for transactions as well as innovations, the basic paradigm of inter-platform competition remains relevant in the quest for market dominance.

The objective of this paper goes beyond collecting and presenting findings about the diffusion and dissemination of individual Blockchain applications in the energy sector for the period from 2017 until 2022, since there have been other studies, most notably Andoni et al. (2019) and Ante et al. (2021), which explained them in great detail and with scholarly rigor. The objective is rather to locate Blockchain in the energy sector within the more fundamental and generic theory of platform economics by describing the underlying mechanisms of technology adoption and entry barriers over the course of time and by seizing the insights of qualitative interviews with key players and stakeholders in the movement.

3. Methodology

Any quantitative analysis of Blockchain innovations in the energy sector fails because of the lack of a sufficiently large number of valid data points that would match the requirements of statistical methods. However, even if large-scale deployment information was available, quantitative methods might not provide the causal insights for the phenomenon this paper investigates. Instead, a qualitative approach based on semi-structured interviews was chosen. The authors investigate the hurdles energy Blockchain solutions faced in 2019/2020 in four interviews with representatives from energy market players, such as a German IT company that released a Blockchain-based energy wholesale trading platform (A), an international energy and Blockchain foundation (B), a UK-based Platform-as-a-Service Blockchain developer (C), and a European energy mid-stream player (D). This last interview took place in 2021. They are complemented by three interviews with a control group, more specifically with executives of companies operating in the IT and FinTech sectors, including a permissioned peer-to-peer (P2P) DLT platform focusing on financial services (E) and a European IT corporation (F), plus an additional interview with a joint venture between two European banks targeted at digital innovation, which was conducted in early 2022 (G). As Blockchain applications in other industries have been implemented more successfully, this control group provides a larger perspective and spectrum of corporate strategies and allows for comparisons across industry verticals.
In academic research, there tends to be a positive selection bias (Heckman et al. 1998; Hernán et al. 2004; Winship and Mare 1992), but the interviews assembled in this paper are intended to provide a sound basis for a scholarly root-cause analysis of potential reasons for the failures of large-scale commercialization.

The following analysis is structured around the triad of technical feasibility, economic viability, and desirability—that means a valid, implementable, and relevant use case—to the empirical results of the interviews. This approach has been applied by the scholarly literature that propagates the perspective of user-centric innovation (Bocken et al. 2022; Brenner et al. 2021; Chasanidou et al. 2015; Dennehy et al. 2019; Goldsby et al. 2017). Given the intersection between DLTs as financial vehicles with cryptocurrencies and tokenization and their application in a critical-infrastructure sector, a fourth dimension—the regulatory framework—complements the other three dimensions.

4. Results and Discussion

The following sections analyze the four above-described dimensions of successful innovations and the use of the respective platform types based on expert and practitioner interviews in order to provide an assessment of the evolution and current state of Blockchain in the energy sector.

4.1. Technical Feasibility

Because of their distributed data storage features and their decision-making processes, Blockchain and DLTs have a high degree of inherent complexity in the software architecture and infrastructure.

However, the promise of Blockchain in the mid-2010s is still engrained in its technological capabilities. Instead of a centralized system of dispatch, many local or regional nodes would emerge. Data storage is organized in a decentralized way—as opposed to a single profile provider with a central repository, which may be more vulnerable to theft of confidential data. This disintermediation may also increase transparency and trust between parties, for example, between a power generator selling renewable energies and an industrial customer that intends to use the proof of origin to publicly verify that it meets certain sustainability targets. The attractiveness of Blockchain solutions is mainly attributed to the promise of a transparent and irreversible ledger of transactions among micro-agents (Andoni et al. 2019).

The Brooklyn Microgrid is one of the earliest role models in the sector (for a discussion of the case, the publication by Andoni et al. 2019, p. 155, is recommended). The initiators aim to achieve a high degree of autonomy via decentralized settlement mechanisms, thus, making the grid more ecological and sustainable—because supply is primarily based on local renewable energies—as well as resilient. In the US context, this is an important feature of a future energy system, because micro-grids may better withstand blackouts provoked by natural catastrophes, such as hurricane Sandy in New York in 2012 (Pyper 2013).

From a technological perspective, though, early applications in the wholesale markets suffer from the technically and organizationally complex validation system. According to the founder of an IT service provider, Blockchain-based marketplaces face a technical limitation related to the speed of the transactions (interview (A)): “Blockchain won’t work for the execution in a high-frequency market, because there is always a delay—the latency of a trade execution on a high-frequency trading system is in the range of microseconds, and here we are talking about a second. For a marketplace with hundreds of transactions per second, Blockchain won’t work.”

The decentralized nature of the validation process not only reduces the transaction speed inherent to public Blockchains, but also creates high mining costs. From an environmental perspective, the so-called Proof of Work acts as a validation mechanism, which consumes substantially higher amounts of energy than conventional tools and, therefore, produces high CO₂ emissions. In this constellation, miners secure the network by purchas-
ing and running the mining hardware. They consume electricity in exchange for block issuance and a portion of the transaction fees.

Because of these constraints, practitioners confirm that the use cases on transaction platforms tend to low-frequency applications (interview (B)): "The use cases [that are being developed partially by us or our affiliates] generally tend to use the Blockchain as little as possible, because it costs money to use the Blockchain. Typically, it is used for coordination purposes, for access rights, for value transactions, for a recording of provenance, and so forth. As little as possible, and generally for the coordination of rights or of ownership of assets.". This observation is confirmed for markets with lower-frequency applications (interview [A]): "If we talk about less liquid markets or low liquidity markets, with a couple of transactions per day or a couple of hundred or even thousands of transactions per day, then this limitation doesn’t really materialize anymore."

Business cases related to low-frequency transactions are, for example, asset ownership, billing and settlements, or proof of origin, as mentioned above, for example, a green certificate that testifies to the source of one particular kilowatt hour of power supplied to a buyer. In all these examples, information is stored in a database, often protected with pseudo-anonymous identifiers, and secured with private or public keys. If certain conditions are fulfilled, the information is released to the counterpart in a transaction.

In these low-frequency applications, another challenge emerges related to identity management, asset registers, and certificates of origin, which are typical use cases for low-frequency transactions (interview (C)): "The big problem you encounter when you want to trade on an asset ID basis is how to get all that information in a reliable format in a way that works for the different products. And we firmly believe the best way to coordinate those data sets is not through some big large centralized data project, but it’s basically through a thin coordinating, decentralized data permissioning layer."

One way of increasing speed and reducing costs is to establish a private or "permissioned" Blockchain, which allows only selected members to engage in trading or the exchange of information. This strategy contradicts the normative claim of universal access but enhances efficiency. The advantage of a public infrastructure may be partially offset by concerns of data security and privacy (interview (B)): "We developed a couple of features around privacy, but of course, it’s easier in a private chain.". This statement characterizes the trade-off between public and private (or permissioned) Blockchains, which has been an on-going debate in the Blockchain community and questions the fundamentals of Blockchains as a universally accessible means of communication.

One of the most prominent examples of how a permissioned Blockchain can be implemented successfully stems from logistics: Maersk, a global logistics player, and IBM, an IT services company, set up TradeLens as a permissioned Blockchain that tracks shipping containers and related documentation in global supply chains (Jensen et al. 2019) and claims to handle more than 700 million events, for example, the shipping of containers, and 6 million documents annually (TradeLens 2022).

In 2022, Ethereum, as the second-biggest chain behind Bitcoin, changes the validation mechanism to Proof of Stake to reduce energy consumption. In this model, the network is secured by validators who must own significant portions of the Ether cryptocurrency. Other chains, such as Solana, Cardano, and Polkadot, also use Proof of Stake to reduce carbon emissions. Hence, the technical deficits of early Blockchain application seem to have been overcome.

### 4.2. Desirability and Use Cases

From the Design Thinking perspective, desirability takes on the central role in the triad of technical feasibility, desirability, and commercial viability, because if the innovation does not address a “human need,” it is not likely to succeed commercially (Schraven et al. 2021).

First, there must be a valid use case from the perspective of the organization that is considering deploying Blockchain technology. In the case of a European energy mid-stream company, the Blockchain solution reduces transaction costs (interview (D)): "The reason to use a technology such as Blockchain was to simplify commodity flow management in a market
characterized by extensive manual and paper-based transactions and high processing costs. At the same time, small-scale liquefied natural gas (LNG) was supposed to be developed as a new business. However, both these markets were comparatively small and complex for a big energy player such as [our company]. Thus, it became clear that scalability and simplification were key, and we saw a use case for the new technology.

Another example of a unique value proposition is expressed by a Platform-as-a-Service provider (interview (C)): “Today’s existing power exchanges were designed for forward trading of a fungible commodity, here the kWh, in large chunks. But we want to build an exchange on which you can trade other things beyond the kWh that are more valuable on this new decentralized, zero marginal cost grid. We call those attributes. An attribute could be I want generation at this time, which is what you can already do, but then also in this location or with these specific properties. You can pay a premium for green and or local for example.”

Second, the users themselves must be convinced that the new solution yields haptic benefits, either monetary or in terms of convenience. In the case of the company that has established a wholesale energy-trading platform, substantial savings are promised (interview (A)): “The value proposition is on making obsolete the intermediary, and this is not just a technical optimization, it is an organization optimization. [...] It can be compared to a small commodity market with 50 market participants. A broker or an exchange with 20 employees and high IT costs organize that market. It may cost €5 million. This implies that every market participant would cover €100,000 on average of these costs. And if this organizational cost can be brought down to 10%, then that’s significant. It’s not just 20% technical optimization, it is 90% cost reduction, because this organizational cost disappears.”

However, typically, the user interface—respectively, the ease of use by customers of Blockchain solutions—is burdensome and unfamiliar to users who expect a seamless user experience (UX). In contrast to applications provided by large corporate players, such as Apple, Amazon, and Facebook (Meta), so-called digital wallets must be generated, seed phrases have to be remembered and stored safely, and changing between different Blockchains asks for separate wallets. Fiat currency must be transferred via a specialized online bank, such as Kraken, into a cryptocurrency, with a risk of failure of performing the appropriate actions and losing the money.

While this is an alternative for a customer segment typically classified as “innovators” (Rogers 1995), other segments prefer to have access via known channels. As the example of a Swiss banking innovation hub suggests, customers benefit from Blockchain innovation while leaving the complex implementation to service providers (interview (G)): “We developed a prototype and went to customers to validate our idea. Around 80% of the customers responded with, ‘What is a wallet? Why do I need a wallet? I don’t want a wallet. I just want to get the digital assets.’ We were stunned, asking ourselves, ‘What is the problem with this wallet?’ First of all, most of the customers did not even know what a wallet is. We learned that we needed to make more of an effort in the knowledge transfer to the customers so that they understood the function of a wallet. We decided to change our strategy. We kept the same validation process, but we avoided showing a wallet to the customers. We instead just presented the depot as they were used to with their other shares, allowing them to simply make a transfer to that particular depot. This turned out to be no problem for our testers.”. For energy solutions to gain momentum, it becomes essential that corporate customers and private users are not aware of the underlying technology, but rather appreciate the flexibility of the solutions via a normal app.

In the 2010s, public perception of the Blockchain is mainly framed by illegal transactions and money laundering via cryptocurrencies (van Wegberg et al. 2018). In the energy industry, skepticism vis-à-vis the technology can be observed (interview (G)): “We expect in the future that utilities don’t want to hold tokens. This is not a business model.”.

Yet, Blockchain’s advantages of enhancing cybersecurity in critical infrastructures experience some appreciation (Hasanova et al. 2019; Zhuang et al. 2021). Over the last few years, Blockchain solutions have become part of everyday discussions. With financial companies, such as Blackrock, JPMorgan Chase, Morgan Stanley, and Goldman Sachs, entering the Blockchain market (Rooney 2022), energy and car companies are more likely
to integrate Blockchain solutions. With social acceptance increasing, especially among younger generations, political parties take into consideration their perspectives when regulating this technology (Gemini 2022; Perrin 2021), with stablecoins allowing for a seamless integration into established accounting standards.

4.3. Economic Viability

Over their relatively short existence, Blockchain-based business models in the energy sector differ in their competitive strategies. They have in common, though, that they operate as platforms in platform ecosystems. In the following sections, the most important models, their revenue structure, and potential pitfalls are described.

4.3.1. Transaction Platforms

Many Blockchain applications in the energy sector compete in already existing and well-functioning markets, for example, in the wholesale trading of power or carbon emission allowances. If established solutions—for example, in wholesale trading—already exist, the likelihood that individual players will switch to a new platform must be incentivized by benefits that the existing platform cannot provide. In the geographical context of the European Union (EU), several power markets have been established since the late 1990s. For example, the European Energy Exchange in Leipzig was founded in 2002 and has since then expanded its portfolio of services.

If newly established platforms aim to attract users by motivating them to leave existing marketplaces, they must either provide services that other platforms do not offer—commonly called competitive differentiation—or attract new users by providing, for example, a substantial reduction in process costs. The attempt to establish the company of founder and interviewee (A) as a new trading platform was driven by the cost savings for players (interview (A)): “We can offer this at a quite low cost, and market participants will pay €500 per month, including the first 500 transactions per month, which as you can calculate is €1 per transaction.”

Despite potential cost advantages, Blockchain-based platforms experience challenges that are similar to those of other platforms. They have to attract a sufficiently large number of market participants to achieve positive network externalities and ideally reach a winner-takes-it-all status (interview (A)): “There have been brokers who attempted to establish a new platform and they all failed in dragging liquidity from the existing platforms, because the retaining effects of a marketplace which has already a high liquidity is quite high. So, they have to use a high budget to direct liquidity to the new platform, and this budget must be very high for a long time.”.

By contrast, some Blockchain applications in the energy sector target emerging markets with no dominating platform, for example, in roaming and charging of electric vehicles, or the market for green energy certificates. One successful example of a niche strategy is Australian startup PowerLedger, which offers peer-to-peer trading solutions for real-estate developers. Their revenue model is composed of two components: a B2C component via fees for each individual transaction and a B2B subscription model consisting of a daily fixed supply charge as a service provider for the developers or independent power producers (Burger et al. 2020).

4.3.2. Innovation Platforms and Blockchain as a Service

Innovation platforms serve as the operating software foundation for other applications (“apps”) to be developed by third parties, such as Apple’s iOS and Google’s Android systems. However, most companies that are running innovation platforms also offer the option of co-creating or supporting third-party providers with technical expertise. This approach can also be observed in the energy Blockchain ecosystem. For example, the foundation (interview (B)) provides the platform and also offers programming services that are legally separated in a similar fashion to Linux, providing the not-for-profit software and Red Hat serving as its commercial consulting practice.
As opposed to transaction platforms, innovation platforms typically target different user segments with different value propositions. For example, the members of the foundation of interviewee (B), are evenly split into three main interest groups: large corporations, startups, and financial investors. Their motivations for entering the foundation also diverge, according to a founding member of the foundation (interview (B)): “For the corporate clients, it is cheaper to join a foundation because of the joint research. Instead of doing research by themselves, they can build on a knowledge basis and exchange experience. By contrast, the startups are interested in access to potential clients. The foundation is also developing frameworks which help innovators to shorten the development cycle and the way to a minimum viable product.”. In addition, users of the platform have a value proposition in becoming so-called validators; they can receive financial rewards when they run a server to contribute to the network by mining (interview (B)).

Innovation platforms organized by consortia are competing with private platforms offered by large IT companies. Some of the industry-owned innovation platforms attempt to imitate their not-for-profit counterparts by establishing transparent governance mechanisms, for example, in the financial sector (interview (E)): “We have a [...] network which we’re going to be shifting responsibilities to a democratically elected governance board, facilitated through the [...] network, which is its own entity. They’re going to do all the work figuring out who’s allowed to join the network and also different business networks. The groups that manage the applications are going to have rights in who they let into their groups as well. So right now, functionally [...] it acts as a doorman, or an identity operator.”.

Similar to the foundation, innovation platforms run by industry players can be separated into two organizational entities, with one providing the platform infrastructure and the other offering services. An example from the financial sector reflects this organizational structure (interview (E)): “The open source version of the platform and the enterprise version of the platform really have the same set of users; the enterprise version is just used by those willing to make the investment into upgrading to enterprise and it’s usually those institutions that are about ready to either—if you’re a app builder—go into production with your app or—if you’re a customer—start going live with your transactions, because on all blockchain networks most of the activity right now is piloting. A lot of that is done on open source, because we want a lot of activity and because it’s basically the top of the funnel, to get people down the line to sign up for our enterprise.”. The company charges a licensing fee for the enterprise version, whereas the open-source version is free for anyone to use.

As opposed to consortia offering platform services, the IT company of interview (C) follows a Platform-as-a-Service business model: “We are working with network utilities in order to develop them offerings that better serve their customers. This means that we work with a huge range of parties from system operators to distribution network operators, suppliers to aggregators, and original equipment manufacturers to new service providers.”. Revenue generation on innovation platforms may follow different strategies: “The model for the coordination platform [...] is basically a kind of Platform-as-a-Service model, where we operate it on behalf of the partners that need to coordinate and have it under the license conditions. They pay us the fees to manage it, and we handle on-boarding and off-boarding customers and other functionality. The model for the market or service products can range from a fee per trade, for example if we operate the market such as the curtailment market, to a licensing fee” (ibid.).

Another strategy of some larger players in the IT industry is to abstain from the risky platform business and offer solutions to corporate clients, such as a multinational, European-based IT company (interview (F)): “We don’t have a Blockchain application at the product level but we offer Blockchain-as-a-Service capability. We take over the application management service of well-known open source technologies; today we have in the portfolio three types of technologies, permissioned Blockchains: hyperledger fabric, multi-chain as a Bitcoin fork, and [name] as an enterprise permissioned Blockchain. In some of the industries, depending on the expectations of our customers, we are developing also Blockchains, so one example is the pharma Blockchain for fake medicines. [...] There is no low-hanging fruit to develop regarding Blockchain that fulfills all the requirements of our clients.”.
Based on a framework by Linz et al. (2017) that suggests a taxonomy of digital business models along four categories—product, project, platform, and solution—corporate players and startups seem to try and overcome the pitfall of network externalities by moving from product and platform business models with a high degree of standardization to project or solution business models that offer individualized, comprehensive, and integrative services.

4.3.3. The Innovation Ecosystem, Participation, and Tokenization

Many innovations fail to gain market traction because they are technically advanced but do not provide an ecosystem for complementary services and applications. Prototypical examples are Apple’s Newton device, which was launched in 1993, at a time when very few “apps” for this early form of tablet computer existed, or the “Symbian” cell phone operating system by Nokia (Adner 2006; West and Wood 2014). Apple learned from this commercial failure and created an innovation ecosystem for the iPhone, in which individual programmers were incentivized to write apps that users could download onto their smart phone.

Consortia and single-provider platforms have the communality in the quest to generate positive network externalities. Hence, they compete for participants and members from different stakeholder groups (interview (E)): “The way I see the partner ecosystem and also the way the company sees it is really in three groups. You have application builders, those would be the startups or existing FinTech companies that are issuing or creating applications on […] You also have the big IT builders that have partnered with us; a group of customers who want to build an application and don’t want to lend their developer resources to, will go to one of these partners and they can help build up the application. Those tend to be large, IT-focused consultancies, new Blockchain design shops, things like that. The third group would be infrastructure providers, cloud companies, for example AWS, Google Cloud, or Microsoft Azure.”.

Independent innovation platforms see one of their advantages in the attractiveness for startups (interview (B)): “In the corporate Blockchain space, most applications are running on completely closed chains, private chains. The public aspect of our chain has a very big advantage that it enables innovation—a lot of startups came because of this reason to us.”.

A crucial point is the business model for the network participants. One option is the example of IBM/Maersk’s TradeLens. It stays within current solutions, does not offer a tokenization, and founders participate via a share of the venture and income, respectively, while participants pay a monthly subscription fee and/or transaction fees.

Tokenization is an alternative option. The organization of interviewer (B) was financed by tokens at the very beginning: “Every affiliate had a flat minimum fee for entry. They could join the whole network, our events, and receive token vouchers against the payment. Now the tokens are gone, and we have started a dedicated subscription fee for different types of clients. But for startups, membership is basically free.”.

A cryptocurrency solution needs a decentralized structure, though, in order not to be treated as an equity and then allows founding members to participate via the token and via running a node earning staking rewards. Transaction fees are channeled to the foundation to develop or support new solutions. Moreover, it becomes important that participants in the network can develop their customized solutions. This implies easy updates that do not require a hard fork of the respective chain. Interoperability allows customized solutions to be transferred between suppliers or phrased differently to enable seamless options for customers.

4.4. Regulatory Framework(s)

Blockchain innovations in the energy sector face a dual regulatory challenge: On the one hand, electricity and natural gas networks, in particular, are part of the critical infrastructure, with some parts of the value chain serving as competitive elements, in particular supply and retail, whereas, typically, grid-based distribution and transmission operations are regulated and controlled by a governmental agency or commission. On the other hand, Blockchain and other DLTs belong to the area of financial regulatory control. A
A combination of these regulatory spheres creates a high degree of complexity for market agents, because two networks interact: the first one consisting of electrons and the second one consisting of bits and data.

Consequently, early Blockchain-based trading mechanisms experienced multiple hurdles during their actual implementation in the electricity sector. For example, agents trading energy products among each other on a Blockchain transaction platform are confronted with certain regulatory requirements specific to competitive practices in the energy sector (interview (A)): “If the decision to match two orders, one from the buy side and one from the sale side in the order book, is located in the middle or at a third party—who is not party to the trade—then such a party has, according to financial regulation [in Germany], a status which is called an MTF or multilateral trading facility, corresponding to an exchange. With the status as MTF, multiple regulatory requirements have to be fulfilled.”. One solution that reduces regulatory complexity is to detach the informational content from the actual energy units, thereby acting as a pure information channel, not as an energy-trading entity. However, the role of Blockchain is mainly related to the exchange of information between market participants: “If we think of this in a decentralized way based on Blockchain, that is just a communication channel. You can compare that with a chat service, for example with the Yahoo Messenger” (ibid.).

Because of the novelty in the emerging Blockchain technology, many market elements are not yet defined from a regulatory and legal perspective, including the tokenization (interview (B)): “There are unlimited regulatory obstacles around the utility token, unclear field around responsibilities and liabilities for validators in the public chain. I can’t even imagine a place where we don’t have regulatory problems, so the company is on each side of its activities, if it’s company structure, and if it’s releasing of funding structure or product structure, there’s hardly any benchmarks we can draw from. So it’s very difficult to grow the company when you don’t have any benchmarks on utility token, company structure; you can’t survive only from sending tokens, you need to have cash flow-based income, a huge problem in a foundation.”.

Beyond regulatory hurdles specific to the energy sector, all Blockchain models suffered from legacy systems and the incomplete digital transformation of administrative transactions, as a representative of the FinTech industry explains (interview (E)): “What’s a more interesting question is once you consider all the different applications being run—because for example, a trade finance-supply chain application that requires a digital document in many jurisdictions digital documentation is in effect—I’m pretty sure all over the world you would need a physical piece of paper to accompany a good. So that is where regulation is behind, but it’s also not necessarily a Blockchain problem. It’s not that the regulations won’t allow for Blockchain, so they won’t allow for digital transfer and Blockchain is a way of doing digital transfer.”.

Regulatory red tape often prevents use cases from materializing (interview (C)): “I can think of some really specific use cases that would take off if a piece of regulation was changed. The classic one for example: peer-to-peer trading being enabled by allowing multiple service providers to supply one meter. Another is around flexible connections and who has the right to what part of the grid and how that is determined. As more and more of these new use cases open up new ways to use the grid, our coordinated model becomes more and more relevant to the network utilities vs. continuing with whatever kind of bilateral arrangements they already have. That’s our main competition right now! Invisible, bilateral contracts.”.

Regulation has been developed to protect the customer. The EU recently released the MiCa (Markets in crypto-assets regulation) and CASP (crypto asset service providers) regulations, which shall become effective in 2024 (European Council 2022). Yet, for digital assets, worldwide regulation is necessary, and the question is: how little needs to be regulated to allow for innovation while still protecting consumers? In addition to cryptocurrency regulation, energy regulation is changing due to renewables, storage solutions, prosumers, and e-vehicles. The EU directive has imposed a right for consumers to be part of the energy system. The urge for energy security due to the Ukraine crisis and increasing climate incidents provide additional momentum for a global energy transformation (Birol and IEA 2022). ESG (Environmental, Social, and Governance) may become another driver to track transparency, with Blockchain applications providing low-cost solutions.
5. Conclusions

Blockchain applications in the energy sector have not materialized in the way expected in the late 2010s, while other Blockchain ecosystems have flourished, even under current economic conditions—and despite regulatory constraints and uncertainties. The last section of this paper summarizes the three main shortcomings derived from the findings of the interviews.

First, inter-platform competition: early applications suffered from a combination of technological constraints and platform competition. Due to the permissionless configuration of the early energy Blockchains, they were slow in terms of transaction speed compared to existing platforms and prices per transaction were high. Existing electricity markets are asking for high-frequency validation though. Such fast validation is difficult to offer on permissionless Blockchains. Permissioned Blockchains, which are initiated by industry consortia or individual companies for niche applications, such as the small-scale trade of liquefied natural gas, achieve significant cost reductions. Even the second-largest DLT in terms of market capitalization, Ethereum, moved from Proof of Work to Proof of Stake in 2022, thereby also significantly reducing energy consumption and making it more attractive for market participants to deploy Blockchain technology.

Second, value proposition and business strategy: founders in the early energy Blockchain innovation ecosystem focused on products and platforms as well as on transactional rather than procedural use cases, with a high degree of standardization of the offering and low levels of inclusiveness concerning processes. From the perspective of corporate customers, the disruptive Blockchain technology suffered from the lack of a seamless user experience. With new Blockchain-as-a-Service and Platform-as-a-Service offerings, products and platforms are moving toward project and solution-based business models with a higher degree of individualization as well as a higher level of inclusiveness of transactions.

Third, regulatory complexity: energy-related Blockchains and DLTs operate in a legal and regulatory environment that must reconcile both critical-infrastructure and financial-system requirements. This increases the level of administrative and organizational complexity and reduces incentives for private players to participate. In comparison with two commercially successful Blockchain applications, DeFi and NFTs are “digital by nature”—they rely on interactions that are governed by bits and pixels, whereas transactions in, say, peer-to-peer energy trading must respect not only the data layer, but also the conditions of the local grid, for example, with respect to temporary supply-and-demand bottlenecks, and comply with the respective regulatory framework. If digital artists mint their works on NFT platforms, they do not interfere with a physical artefact or large technical system. By contrast, if residential producers of rooftop solar power intend to sell surplus electricity to their neighbors using the existing grid, in many jurisdictions, they qualify as full-fledged traders of energy and, hence, must comply with the multiple commercial regulations—as if they participated professionally in the supra-regional wholesale markets.

The most likely innovations to succeed in energy Blockchain applications are the ones that meet the requirements of all three conditions, which means that they operate in emerging—not consolidated—markets, they offer a clear value proposition, and they cope with regulatory complexity. For example, the abovementioned Certificates of Origin score highest in the category “economic benefits” in an analysis of Blockchain use cases carried out by the German Energy Agency dena (Richard et al. 2019, p. 14). As companies are required to increase their carbon-free energy consumption, Certificates of Origin provide a means to enable end-to-end authentication that meets stricter regulatory requirements, for example, in the EU, and the number of companies has been continually growing in that region since 2016 (Lorenz et al. 2022). Individual European energy utilities already offer Certificates of Origin on a Blockchain platform (EnBW 2021). They are not hampered by high-frequency trading, as they can be sold as a packaged solution to corporate customers and they will be required to be provided from corporate players in a carbon-restricted regulatory framework.
The prospect of DLT innovations in the energy sector may not be as revolutionary as anticipated in the heydays of the Blockchain hype in the 2010s, but in a move of mimetic and normative isomorphism (DiMaggio and Powell 1983), commercially viable applications will emerge.

The development of a permissioned Blockchain is necessary to succeed in the marketplace. Validation mechanisms must be developed and agreed by the community of foundations and consortia, be this Proof of Authority or Proof of Stake. Integrating company players into the foundation requires time, even more so due to the fact that the concept of Blockchain is still not well understood in management nor accepted by society and customers. Giving up power as an energy incumbent to develop an industry platform co-owned with competitors and companies outside of their own industry is a further hurdle—in terms of corporate culture in the sector.

6. Policy Implications and Further Research Directions

Blockchain applications in decentralized finance, logistics, and NFTs in art and gaming have experienced significant adoption rates over the last couple of years. In particular, NFTs have gained traction since the beginning of global COVID-19 lockdowns in early 2020. By contrast, energy use cases are lacking substantially behind and often do not leave regulatory sandboxes or pilot projects. Our investigation suggests, though, that some of the hurdles may be overcome in the coming years.

Further research in this field should, therefore, be directed towards the following developments that can be observed:

— The technical feasibility of Blockchain solutions with the move to proof of stake and the development of permissioned platform solutions;
— Desirability and acceptance of use cases, such as proof of origin for Bitcoin mining, aviation fuel, and e-charging;
— Integration into standard accounting systems, which might be the trickiest hurdle, because many companies are shying away from having cryptocurrencies on their balance sheet; research hints towards introducing stable-coins and, thus, a fiat-like interface to Blockchain solutions, which might lower this hurdle;
— The evolution of regulatory frameworks with regard to the integration of prosumers in energy markets.

The implications of this study are restricted by two important limitations that further research can at least partially compensate, once more quantitative data is publicly available. Primarily, the methodology of conducting qualitative interviews can only shed light on very selective aspects of the implementation of Blockchain in the energy sector and in other industries. Even though the authors chose a sample of leading players and pioneers in the field, the corporate narratives might diverge if other representatives had been interviewed. The relatively small number of interviews prevents any generalization or testing of hypotheses. Second, the market environment is changing very dynamically, and any interview is already outdated when it is published. Predictions about future developments have to remain vague and are subject to the authors’ interpretation of the findings.

Keeping these limitations in perspective while drawing implications from the analysis, the race for an energy-only Blockchain platform has started again. Many applications are triggered under regulatory conditions of sustainable supply chains and fossil-free primary fuels. A fundamental change might be expected if energy markets allow for regional markets, compared to national markets where the merit order is setting the price. Future lines of research should, therefore, focus on the trade-offs of local versus supra-regional energy markets. In both settings, Blockchain and related DLT applications might cater for an increasingly decentralized user base or for industrial customers who rely on verifiable certificates testifying the origin of carbon-free energy produced.

In the context of policy-making and multi-level governance, such as in the European Union, countries are moving towards more innovative energy regulation. The next step
might be to auction permanent Blockchain regions, asking community bidders to test not only P2P trading, a usage-driven distribution of network costs, but also proof of origin. The scope might even be broadened to include mobility solutions, payment, and financing solutions. Changes in the environment may foster energy Blockchain adoptions, although a long road is still ahead to move from pilot projects to establishing niche markets and beyond.

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