Digital Energy Platforms Considering Digital Privacy and Security by Design Principles

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ABSTRACT

The power system and markets have become increasingly complex, along with efforts to digitalize the energy sector. Accessing flexibility services, in particular, through digital energy platforms, has enabled communication between multiple entities within the energy system and streamlined flexibility market operations. However, digitalizing these vast and complex systems introduces new cybersecurity and privacy concerns, which must be properly addressed during the design of the digital energy platform ecosystems. More specifically, both privacy and cybersecurity measures should be embedded into all phases of the platform design and operation, based on the privacy and security by design principles. In this study, these principles are used to propose a holistic but generic architecture for digital energy platforms that are able to facilitate multiple use cases for flexibility services in the energy sector. A hybrid framework using both DLT and non-DLT solutions ensures trust throughout the layers of the platform architecture. Furthermore, an evaluation of numerous energy flexibility service use cases operating at various stages of the energy value chain is shown and graded in terms of digital energy platform technical maturity, privacy, and cybersecurity issues.

EICC 2023, June 14–15, 2023, Stavanger, Norway

ACM ISBN 978-1-4503-9829-9/23/06.
https://doi.org/10.1145/3590777.3591405

KEYWORDS

Flexibility markets, digitalization, distributed ledger technology, cybersecurity, privacy.

ACM Reference Format:
Umit Cali, Marthe Fogstad Dynge, Ahmed Idries, Sambeet Mishra, Ivanko Dmytro, Naser Hashemipour, and Murat Kuzlu. 2023. Digital Energy Platforms Considering Digital Privacy and Security by Design Principles. In *European Interdisciplinary Cybersecurity Conference (EICC 2023), June 14–15, 2023, Stavanger, Norway.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3590777.3591405

1 INTRODUCTION

Over the last decades, modern power systems have become increasingly decarbonized, decentralized, democratized, and diverse [8]. The rate of change in the power market has also accelerated, along with the investment of advanced digital technologies in power grid infrastructure. Emerging Information and Communication Technologies (ICT) are facilitating the process of digitalizing power systems, which aims to improve both the system's effectiveness and level of safety. Many aspects of power systems and markets are amenable to digitalization. The platformization of flexibility services, in particular, has piqued the interest of academics and industry in recent years [4, 21]. Flexibility can be defined as the ability of resources, both on the consumption and production side, to rapidly respond to the system operator's requirements [25].

The advantage of creating digital platforms for this purpose is the ability to coordinate the services, thus streamlining and improving the operation of such markets. The most prominent ICTs that have the potential to shape the future digital power systems and markets are Distributed Ledger Technology (DLT), big data analytics, cloud computing [23], Artificial Intelligence (AI), Internet-of-Things (IoT), next-generation communications (5G and beyond) and quantum computing [8]. The study [7] reviews emerging technologies (blockchain and IoT) and investigates how to improve the current power grid ecosystem for better monitoring services. It also states the importance of ICT in the future of modern power grids and markets. Cybersecurity threats, on the other hand, are growing in lockstep with the increased use of digitalization technology in power grids, which occurs at the same time that entire economies are transitioning to digital economies on a large scale. The primary motivation for this paper is that next-generation digital power market platforms will play an important role in these large transition phases by taking cybersecurity and privacy concerns into account. As a result, there is a need for technologies that can address these cybersecurity and privacy concerns.

The contributions of this paper are as follows:

- Systematical review of existing digital platforms in the energy domain, with a focus on flexibility services.
- Proposing a new holistic architecture for future digital energy platforms to support flexibility services.
- Integrating cybersecurity and digital privacy aspects of such digital energy platforms by design.
- Using a hybrid framework that incorporates both DLT and non-DLT solutions via Oracles.

2 DIGITALIZATION OF POWER MARKETS AND DIGITAL PLATFORMIZATION

This section first provides an overview of the research's main idea, which is the platformization and digitalization of electricity markets. The study's conceptual underpinning for investigating the issues associated with the transition of electricity enterprises to the digital platforms model is then introduced as service platforms in the context of electrical energy services. Digitalization and digital transformation have become critical components of modern marketplaces and enterprises. The use of novel digital methods has not only facilitated trading but has also resulted in new forms of economic exchange and institutional structures [15].

In the literature, the term platformization has given rise to several definitions of service platforms. Researchers have explored the concept of service platforms as a modular structure encompassing physical and intangible resources that simplify and increase interaction between actors and resources [16]. According to [30], platforms typically serve three functions as businesses: providers, sponsors, and users. The first is a platform provider who provides infrastructure and thus connects users.

The primary goal of platformization is to integrate all services and products to improve efficiency and lower costs while enhancing the concreteness and comprehension of the service. Service platforms facilitate processes on three levels: services, procedures, and organization, and as a result, service platforms that improve the consumer experience have been developed [5]. According to [32], a platform-based ecosystem comprises two main components: a platform and complementary apps. A software platform is a software-based product or service that serves as a foundation for third-party goods or services. As a result, a software platform is an expandable software-based system that offers fundamental functionality shared by "apps" that interact with it, as well as the interfaces through which they interact. Platforms, both digital and multi-sided, are sets of digital resources, including services and information, that enable the creation of value and interaction between external consumers and prosumers. Furthermore, digital platforms can be viewed as an extensible codebase to which third-party modules can be added. They are also services, technologies, or products that allow various groups of customers or participants to interact directly with one another [14].

The ecosystem is another key term, which is defined as a collection of add-ons (apps) to the core technical platform, the majority of which are provided by third parties. Ecosystem participants are natural or legal entities that provide platform modules, services, or sales channels and are any social and economic agent who contributes to and benefits from value co-creation [10]. According to Ilieva et al. [**?**], a digital ecosystem for flexibility can entice customers by providing enhanced billing, marketing, peer-to-peer operations, community benefits (lock-in strategy), and big data. Local prosumers, consumers, DSOs, and service providers support a global ecosystem that connects regional and local ecosystems. Greater market power, resilience, revenue streams, and enhanced branding and data management are among the projected benefits of the ecosystem serving as a partner of partners, product innovator, and value-added facilitator

The rise of the platform economy has made digital platforms commonplace in the electricity market, altering the nature of electrical energy suppliers. Several platform-based startups have been formed in recent years to catch up with the platform economy (e.g., Power Ledger), and many electricity incumbents have heavily invested in converting to platform-based business models [17].

When more vital infrastructures, such as energy grids, are linked via networks, greater quality network connections will be required. As a result of such diversity of entities and networks, security threats are rising. Privacy and security remain major concerns in the digitization and platformization of electrical energy services. As a result, security and privacy must be handled at separate levels, while still approached in a holistic manner in the design phase. As data is pooled and shared across the value chain and across multiple ecosystem participants, privacy and end-to-end security solutions should be handled based on local logic and trust, validating unique business models [33].

3 PRIVACY AND CYBERSECURITY ASPECTS OF DIGITAL ENERGY PLATFORMS

To ensure proper privacy and security measures are in place in digital energy platforms, a holistic design-thinking perspective is required. This means that both privacy and security measures should be embedded into every part of the design process and platform architecture. Digital privacy should be enforced through the seven principles of privacy-by-design [9]:

- *Proactive not reactive; preventative not remedial:* Before a privacy risk even arises, the platform design should systematically take proactive and preventive measures.
- *Privacy as a default setting:* The platform users should not need to take individual measures to protect their privacy, as privacy is already built into the system. The collection of as

little data as possible, along with precise purpose definitions and data disclosure restrictions, can help achieve this.

- *Privacy embedded into design:* The platform's functionality should include privacy protections as a core feature that cannot be easily compromised by misuse, incorrect configuration, or technical or human error.
- *Positive-sum, not zero-sum:* The platform's technical functionality should not be compromised while privacy is integrated. Additionally, it should support rather than undermine other objectives, such as cybersecurity measures.
- *End-to-end security - full data lifecycle protection:* Confidentiality, integrity, and availability must be guaranteed at all stages of the platform's functionality, leaving no gaps in either protection or accountability.
- *Visibility and transparency - keep it open:* Users of the platform should have access to all pertinent details regarding data management and procedures. Emphasis should be placed on accountability, transparency, and compliance in the design of the platform.
- *Respect for user privacy - keep it user-centric:* Users must consent to the platform's use of their personal data, and this consent may be withdrawn at any time in the future. Users should be able to access their data at any time, and the data should be kept up-to-date and accurate.

In parallel with the privacy-by-design principles, platform design should systematically incorporate cybersecurity safeguards at all stages. As stated, the privacy measures taken in the platform design should not conflict with its cybersecurity measures; rather, they should support one another. Designing for cybersecurity involves minimizing the impact of potential attacks and increasing the difficulty of compromise and disruption while facilitating their detection [1].

To fulfill the purpose of digital energy platforms, an increased number of IoT devices must be deployed throughout the energy system, particularly in the distribution system and at the end-user level. Thus, attackers may find large amounts of data in the form of real-time measurements and interactions to be an appealing target for weakening the grid's resilience. Both the data sources and the data transfer process may be jeopardized. Most IoT devices are incapable of running sophisticated encryption and authentication algorithms to protect the system [22]. For this reason, the data must be stored in a tamper-proof and immutable manner while still preserving the user's privacy, e.g., through DLT frameworks. Because of its decentralized and distributed nature, DLT support for digital energy platforms provides a certain level of resiliency on its own. As all transactions are stored on the distributed ledger and verified and recorded across all nodes on the platform, it is nearly impossible to submit malicious data without the supervisory node becoming aware of it and rejecting it [11].

Many of the intended functionalities of digital energy platforms necessitate the participation of previously passive end-users, such as households or small enterprises. The resulting information flow triggers new and complex privacy discussions. While the DSO, for example, wishes to interact with the end-users or aggregators to access flexibility services, the user's identity or other sensitive personal data must not be revealed. In addition to storing data in an immutable manner through DLT, a more sophisticated IMS should be deployed to ensure user privacy. The IMS solutions should give each user control over their identity data and who has access to it [11]. More sophisticated IMS solutions are also beneficial in terms of their own data management systems for commercial entities that use and interact with information from the digital energy platform. If the digital platform is already able to manage sensitive data, the other entities are not required to comply with separate data protection schemes such as the European Union's GDPR [2].

The importance of ensuring the physical and digital security of the power market and its systems is rapidly increasing. As the energy system is such an integral part of modern society, the consequences of both physical and digital attacks could be severe. The potential attack surface for cyberattacks is growing in tandem with the rapid digitalization of the energy sector. Implementing precautionary measures and infrastructure to prevent, mitigate, or minimize cyber-attack risks is thus critical for a safe digital transition. Therefore, at the early stages of digitalization in the power sector, additional security measures linked to physical communication protocols are required to ensure the safety of smart meters and other IoT devices [24].

Furthermore, the rest of the broader value chain of power markets and systems includes several extremely volatile components that must be secured by cybersecurity measures. It should come as no surprise that several wireless communication protocols include encryption methods that have the potential to make the system safer. However, additional cybersecurity measures integrated into digital platforms used in the power sector, whether centralized or decentralized, are also required. As a result, the comprehensive architectural framework proposed in this paper has prioritized safety measures.

4 POWER MARKET DESIGN SPECIFICATIONS

The growing integration of renewable resources into power systems increases the need for flexibility in the system. Therefore, a market clearing platform capable of sending dispatch signals and settling the market is required to reap the numerous benefits of renewable resource deployment and demand-side flexibility, such as the postponement of distribution grid expansion [26]. Implementation of such a platform would strongly depend on the digitalization of the power system from the top down to the end-users. Thus, in order to fully reap the benefits of energy flexibility, the following section will discuss the importance of holistically integrating different agents in the energy domain into the platform architecture. Examples of features such as Transmission System Operator (TSO)-Distribution System Operator (DSO) coordination and regional flexibility trading will be discussed in more detail to illustrate the complexity of embedding these services into digital platforms. Therefore, modularity in the platform and DLT architecture is required in the context of electrical energy services to decrease system complexity or boost scalability [18].

Furthermore, several impact variables influence such platform models, including data where the value proposition is strengthened by increased use, communication, and analysis. Policy and legislation, relationships with actors, customers, and stakeholders, pricing that modifies pricing schemes, and partnerships that expand market reach through open and collaborative innovation are all critical considerations. The aforementioned factors must undoubtedly be considered when developing and presenting a platform business model for energy trading [?].

4.1 The application of digital platforms in TSO-DSO coordination

Utilizing flexibility to match local output with local consumption more frequently has the potential to minimize grid losses. Nevertheless, this does not necessarily lower system-wide losses, and this possible advantage must be examined on a case-by-case basis. Moreover, changes in marginal losses can be recorded by the overall tariff design, which can capture such impacts in both the entire system and a specific sector. As a result, possible grid loss savings from a specific area's activities should be examined in the context of overall tariff system signals (current or planned) [3].

Flexibility can help balance the grid and alleviate congestion. In this case, the TSO is in charge of deploying the system's flexibility potential. Some flexibility providers, primarily small-scale distributed resources, are linked to distribution grids. In the ideal case, the TSO would include all distribution system constraints in the market clearing problem. However, this is not an institutionally acceptable solution because the distribution grid is operated by a separate entity from the TSO, namely the DSO. Moreover, such a problem would be very large-scale and difficult to solve in near real-time. The hierarchical TSO-DSO coordination proposed by [25] and [26] appears to overcome the challenges mentioned. In this design, the grid-secure aggregation of the DSO-side bids, performed by the DSO or the aggregation-disaggregation system (ADS), plays a central role. The aggregated bid, namely the residual supply function (RSF), is then sent to the balancing market operated by the TSO. At the distribution system level, the market outcome is then disaggregated to individual flexibility providers. In fact, by setting prices at the distribution level based on the marginal cost of the marginal unit, the disaggregation step eliminates gaming opportunities.

It should be noted that this approach reduces the amount of data exchange between TSOs and DSOs in both directions. In the first direction, i.e., from DSO to TSO, RSF is the only information that must be transmitted. In the opposite direction, after clearing the market, the distribution systems' net position is returned to the DSOs. As previously stated, ADS is in charge of constructing RSF and disaggregating the net positions of the DSOs. Another distinguishing feature of the hierarchical structure is that, unlike many other known decomposition methods, such as Alternating Method of Multipliers (ADMM), it does not rely on iterative information exchange between the TSO and DSOs. This feature makes the hierarchical approach compatible with balancing market platforms such as MARI, as they are expected to match the bids and offers in closed-gate auction form.

4.2 Operation of flexibility trading platforms

On the consumer side, revealing the flexibility potential of local power generation and flexibility assets necessitates the development of novel market designs and digital flexibility trading platforms. The flexibility market aims to provide access to a large number of small-scale assets in the distribution grid. The market participant, known as an aggregator, will be responsible for combining the flexibility of multiple small-scale energy users and involving them in flexibility trading for this purpose. DSOs and TSOs are the primary buyers and recipients of flexibility services. Communication and coordination between TSOs, DSOs, aggregators, and consumers are critical to ensuring the market's efficient operation.

The operation of the flexibility market is based on the use of smart metering, control, and digital technologies that enable secure communication between flexible assets and power utilities. It is impossible to integrate local flexibility services into the market without this communication. Furthermore, processing a large amount of information and microtransactions from small-scale flexibility assets will be an important feature of the operation of a flexibility trading platform [27]. It should be noted that local flexibility assets can differ significantly. They can have different sources, sizes, and amounts of flexibility that can be extracted, different response times, and different activation periods. Therefore, the digital flexibility trading platform should be designed to work with a wide range of assets while taking into account their key characteristics. In Europe, the flexibility market mechanism is still being developed. Due to regulatory and technical constraints, only a small number of pilot flexibility market programs engage in actual flexibility trading.

The NODES platform, which began in Norway and is now extended to several other countries, is an example of a successful implementation of flexibility trading [6]. This platform primarily acquires flexibility assets for grid congestion problems, capacity management, and power system balancing. The platform functions as an intraday market, continually setting prices and activating different flexibility assets at different times. The flexibility provider aggregates the NODES platform's available flexibility. Portfolios are included in the offers, taking into account ramping capability, source, production, consumption, activation time, duration, and so on. DSO and TSO are flexibility buyers and define their willingness to pay for flexibility activation at a specific grid location and continuously feed this information into the platform. The platform values flexibility and allows buyers to change consumption or production in accordance with a contract. Long-term and short-term flexibility trading are both available in the NODES marketplace. In the short-term flexibility market, flexibility is traded near real-time in a continuous market [6]. The platform processes bids from various flexibility providers who are available in the right location at the right time to meet the DSO's flexibility needs at the lowest cost [13]. The long-term flexibility market includes availability contracts that ensure that a DSO has access to flexibility resources when necessary [6]. These contracts include both a price for availability and a price for activation.

5 HOLISTIC ARCHITECTURE OF DIGITAL ENERGY PLATFORMS

In this section, a holistic architecture for digital energy platforms is proposed. Although the focus of this paper is on flexibility market platforms, the generic architecture can be applied to a variety of energy services, both standalone and combined services.

Platforms are complex systems that have been purposely created to have an underlying structure that determines how they

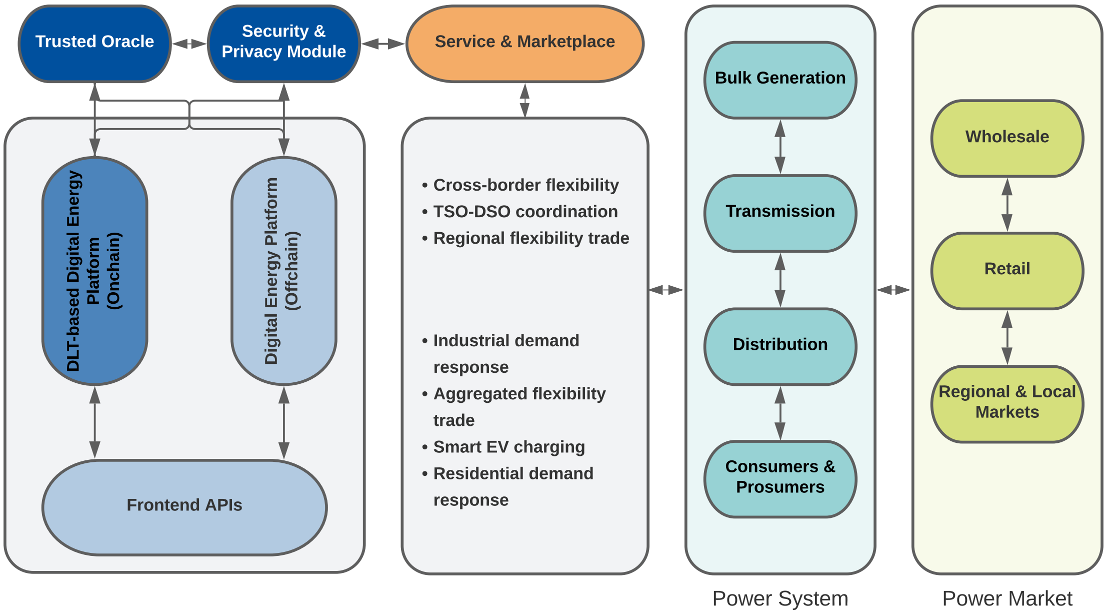

Figure 1: Digital energy market architecture with DLT technology

behave, function, and grow over time. A platform ecosystem, like any other complex system, is made up of several interacting subsystems. The design of the platform ecosystem determines how various subsystems interact [31].

According to concepts from platform ecosystem literature, architecture is only meaningful in relation to the other parts that make up the entire ecosystem. Platform architecture is a hierarchical concept, which means ecosystems can be decomposed into interconnected subsystems, such as apps, which have architectures as well [32]. In the same context, [32] noted that while the platform has a consistent design that all apps/services see, the architecture of different apps/services within the same platform may vary. Many aspects of app architecture are linked with platform architecture because platform design limits all applications in a platform's ecosystem. According to [16], the platform architecture and marketplace design are influenced by openness, governance, stakeholder and actor management, and standardization. Each of these difficulties may be viewed as a complicated system. The findings of[16] also demonstrate how such problems might impact the quality of services provided and how current technologies must interact with decentralized DERs. As a result, platform architecture must remain adaptable in terms of being receptive to new and dynamic business models [16].

The core platform and its interfaces are part of the platform architecture. Remember that a platform is a collection of basic functionality and common assets that are made available to apps via a set of interfaces. Platform architecture should inform apps about what the platform does as well as how to use it. The latter is a role that is directly fulfilled by the platform's interfaces, and as such, it must be viewed as an inherent element of the platform's design [31].

Figure 1 depicts a DLT-enabled digital energy market architecture where the DLT use is controlled by using a Trusted Oracle as a type of switch. The power market is divided into three levels, beginning with existing market mechanisms such as wholesale and retail markets. A local and regional market mechanism is envisaged that can facilitate client-to-client, client-to-business, or business-to-business interactions. Adjacent to that is the structure of power systems, which begins with bulk generation and progresses to consumers or prosumers via transmission and distribution systems. The service and marketplace, exemplified but not limited by the figure, is located in the center of the figure. At a higher level, cross-border flexibility trading can be accessed by larger entities in the energy system, such as large-scale power producers and TSOs. Furthermore, the proposed platform framework can facilitate TSO-DSO coordination, as explained earlier in this paper, as well as regional flexibility trade. However, the generic design should also be able to accommodate flexibility services at lower levels in the energy system, from industry to residential demand response services. These services are enabled by the DLT platform. The service layer is linked to the DLT layer via a secure digital switch. The DLT layer hosts on-chain and off-chain platforms interfaced with front-end Application Programming Interfaces (APIs). The APIs enable clients to interact. The client can be consumers, prosumers, or other stakeholders such as aggregators. The trusted oracles are on the top left.

DLT enables fast, secure, and decentralized storage of information, such as transactions. However, external data, such as market

Table 1: Rating of technological maturity, privacy and cybersecurity concerns of digital energy platform use cases.

Scale	Use Case	Technological Maturity [20]	Degree of Privacy Concern	Degree of Cybersecurity Concern
Cross-border	European Cross-Border Intraday (XBID) Solution	●●●●○	●○○○○	●●●●●
National	TSO-DSO coordination [29]	●●◐○○	●●◍◍○	●●●●●
Regional/	Regional flexibility trading (e.g. NODES)	●●●○○	●●◍◍○	●●●●○
Local	Industrial demand response reserves	●●●●◐	●●◍○○	●●◍◍○
	Aggregators providing demand-side flexibility [28]	●●◐○○	●●●◍○	●●◍◍○
	Smart charging EVs at commercial buildings and public places	●◐○○○	●●◍○○	●●●○○
	Smart charging EVs at residential houses	●◐○○○	●●●●○	●●●○○
	Residential smart appliance demand-side flexibility [12]	●●○○○	●●●●●	●●●●○

prices, is often needed to validate a transaction. This information must be gathered from a credible, accessible, and verifiable external source. Oracles serve as trusted nodes for acquiring, validating, and communicating real-world records to the distributed ledger. The proposed architecture includes a trusted oracle to facilitate the communication of such information into and out of DLT platforms.

In addition, the use of DLT eliminates various unnecessary intermediates that increase the economic and technical efficiency of the systems and platforms. For example, if DLT is aimed to be used to develop a Renewable Energy Certificate (REC) trading platform, some third parties such as intermediate REC traders can be eliminated from the ecosystem. Moreover, the roles of certificate generation and retirement roles and functions shall be automatized and thus increase the system efficiency by reducing the needed manpower and resolving the double count problem of used/retired REC certificates.

6 DISCUSSION AND CONCLUSION

Table 1 rates the privacy issues pertaining to various use cases that can be embedded into the proposed digital energy platform architecture. The potential harm from a sensitive data leak is taken into account when rating the level of concern. The level of concern over digital privacy increases as a use case requires closer interaction with end users. The shaded rating range in some use cases demonstrates how the privacy concern also varies with the type of data exchanged. Using the example of TSO-DSO coordination, a various amount of end-user data or other sensitive information could be shared depending on the overall objective of the coordination. The same is true for aggregators providing demand-side flexibility, as the granularity of personal data provided by the aggregator varies depending on the platform solution. To adhere to the privacy-by-design principles outlined earlier in this article, this type of mapping is crucial during the early stages of platform design. A comprehensive, end-to-end privacy-preserving framework for flexibility trading will be made possible by combining knowledge of the case-specific risks connected with the platform service and the architectural elements suggested in this article. The technological maturity of the different use cases is also rated in Table 1, based on a 2019 report from the International Renewable Energy Agency (IRENA) [20].

The degree of cybersecurity concern of the different use cases is also rated in Table 1. The ranking is based on the severity of a potential attack on the platform's users. In terms of broader societal consequences, an attack on a cross-border flexibility trading platform can be considered more severe than on local demand-side flexibility providers. However, attacks compromising the integrity and functionality of the platform may have severe implications on the individual users and their long-term trust in the system. In use cases with industrial demand reserves and aggregated demand-side flexibility, the impact can also vary depending on the size or severity, as illustrated by the shaded rating range. Even though an attack on an industry with a smaller demand response reserve may have severe computational consequences, it may have limited societal impact, as it may not disrupt the energy system operation of the area.

Demonstrators and developing local energy systems play an important role in the supply of critical future digital energy services and platforms, and digital energy platforms are a major component. They are, however, only useful if the value they provide is realized. If digital energy platforms provide a market path and assign value to the services they provide, they have the potential to liberate distributed energy resources. Along with other digitalization technologies, the application of DLT in the energy sector is a suitable alternative. Since some end-users and stakeholders may prefer not to use DLT, or because on-chain data storage may cause scalability issues in some use cases, the Trusted Oracle solution may be able to address this issue. Furthermore, with the support of cutting-edge legislative frameworks such as the EU Digital Single Market Strategy, which aims to remove virtual obstacles, increase digital connectivity, and simplify access to cross-border online content for consumers, integrating cybersecurity and data protection aspects of such digital platforms by default is gaining importance. Consumers and prosumers have the potential to play a variety of roles, given that they are the owners of both significant data and valuable assets. Nonetheless, it is essential that consumers have faith in and trust the platforms. The potential of distributed energy resources, aggregators, consumers, and prosumers can be unleashed by digital energy platforms. This potential, however, cannot be realized unless the platforms provide security, trust, functional go-to-market strategies, and added value. The system's operation is expected to become more difficult in the future, and the provision of the critical power market and systems services will entail the participation of a great number of additional parties. The functions that electricity generators and DSOs perform will change, though it is not yet obvious where the responsibilities will be determined. The proper balance between local and national levels has yet to emerge. Also, the design and integration of DLT in such platforms require a certain level of alignment with operators and regulators.

ACKNOWLEDGMENTS

This paper has been partially supported by the PowerDig project (Digitalization of short-term resource allocation in power markets), funded by the Research Council of Norway through the ENERGIX program (p-nr: 320789). We are also grateful to industrial partners Statnett and Statkraft for supporting the PowerDig project.

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