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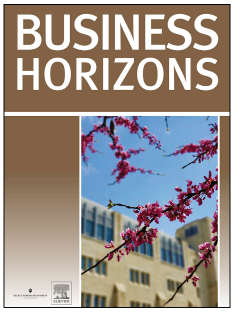

When digitalization pervades, business models converge: A conceptual model for the electricity industry

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**When digitalization pervades, business models converge:
A conceptual model for the electricity industry**

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Abstract
While decarbonization in the electricity sector has been studied extensively, there has been less attention paid to the digital transition. Not only can digital technologies improve efficiency and reduce operational costs in this sector, but they also can enable new energy ecosystems, create new business models, and accelerate the energy transition itself. We present a conceptual model that offers insights into three key areas: industry structure, end products, and pricing strategies. Our recommendations are tailored to help energy firms, startups, and digital companies navigate these evolving dynamics. While the focus is on the electricity markets, these insights hold broader relevance and can be effectively applied to other industries in response to digital transformation.

KEYWORDS: Digital transformation; Electricity markets design; Transaction costs; Strategy

1. The digitalization transition

While the decarbonization of electricity has been thoroughly studied (see for example, Blazquez et al. 2020 among many others), there have been fewer studies that analyze the wider impacts of digitalization on the energy and the electricity sector. Digital applications—such as digital platforms, artificial intelligence, big data, robotics, Internet of Things—have the potential to change how the economic sectors operate and how their products are made. In the electricity sector, digital technologies play a transversal role as they can not only improve operational efficiency and reduce production costs, but they can also enable new energy ecosystems, create innovative business models, and accelerate the energy transition itself. We provide insights into this question by focusing on three aspects: industry structure, ultimate products, and pricing.

While these insights are applied to the electricity industry, their implications are relevant further beyond. Most of the digitalization transformative innovations, such as blockchain and digital platforms, originated not in the field of electricity but in computer science. These technologies have been effectively applied to diverse industries, from banking and fintech to music. Although the electricity sector has unique features, such as regulated segments, the underlying digital technologies are essentially the same and are applied to problems with a common problem structure across industries. This allows us to draw parallels with the experiences of other industries and hypothesize not only the potential evolution of the power sector but other sectors as well.

Digitalization can be understood as a process that enhances the connection and merging of the digital and physical worlds. This transformative phenomenon comprises three core components, as identified by the International Energy Agency (IEA, 2017):

- Data: The proliferation of data stems from the reduced costs of sensors and data storage, resulting in large volumes of information flows.

- Analytics: Significantly advancing analytics and computational capacities facilitate the extraction of valuable knowledge and meaningful insights from raw data.

- Connectivity: The exchange of data between humans, devices, and machines, including machine-to-machine communication, occurs through digital communication networks.

Data, analytics, and connectivity are transforming sectors beyond electricity, including healthcare, manufacturing, and transportation, among many others. In healthcare, electronic health records and telehealth services have improved patient care and increased patient volume (Chilukuri and Van Kuiken, 2017). Manufacturing benefits from Industry 4.0 technologies such as IoT sensors, enabling smarter production and predictive maintenance, thus reducing costs and increasing productivity (Gregolinska, et.al. 2022). The transportation sector is benefiting from smart logistics and autonomous vehicles, optimizing routes and reducing inefficiencies (Heineke, et.al. 2023). In the electricity sector, digitalization's impact has focused primarily on efficiency, cost reduction, and renewable energy integration (Usman et al., 2021; Shahbaz et al. 2022). Across all these sectors, the primary focus has been on cost efficiency and productivity. While significant improvements are evident, the full potential of digitalization to reshape business models remains unrealized, suggesting future changes in how these sectors operate and deliver value.

In response to that, in this paper, we take a different but complementary strand to these approaches and analyze the extent to which digitalization can bring about new structures, actors, and regulatory practices that potentially can change, replace, or complement the existing ways that electricity firms compete, and the entire industry operates (Holmström, 2022; Hinings et al., 2018; Osmundsen et al., 2018). For instance, digitalization in electricity can remove long-standing constraints in these industries, such as the need for unused assets. Organizations would need to adapt their business processes in this evolving digital landscape (Lawton and Vassolo, 2022).

This study presents a conceptual model that establishes propositions in the electricity sector, given digital penetration in this industry. This paper aims to provide a coherent framework for understanding how digitalization can transform the electricity industry. Grounded in economic theory, this conceptual model offers a new perspective that raises broader theoretical questions regarding the relationship between business models and industry structures concerning the underlying technology—an idea referred to as the 'mirroring hypothesis' (Colfer and Baldwin, 2010). It also lays the groundwork for future practical implications and the evolution of companies in alignment with these theoretical foundations. Furthermore, this paper contributes to a more comprehensive approach to global energy issues, ensuring that the sector's transformation supports both sustainability and energy security in a rapidly changing world.

The structure of the paper is as follows. In section 2 we present the process to conceptualize the potential impacts of digitalization in the electricity sector. The framework assumes that companies emerge and evolve in line with economic principles. We explore this theoretical reasoning in section 3. Section 4 presents a conceptual model consisting of three propositions and how they each could impact industry structure, ultimate products and pricing in the electricity industry. Section 4 presents a series of recommendations for energy firms, startups and digital firms. Section 6 concludes.

2. Our approach

Although conceptual modeling lacks a predefined methodology per se, we adhered to a standard modeling-building approach. We first start by establishing theoretical boundaries and defining specific problems within that framework. Our theoretical framework is based on the concept of industry convergence and the mirror hypothesis. These two concepts are related yet with distinct implications in business strategy. Industry convergence observes traditional industries' boundaries blurring due to technological advancements, resulting in synergies and new markets. A prominent example is the convergence between telecommunications and media, with telecommunications companies offering content services and media companies entering the telecommunications market. The mirror hypothesis suggests that as industries converge, they tend to borrow business models from their counterparts. Driven by technology and changing consumer preferences, firms borrow elements such as ideas, strategies, and practices (Choi and Valikangas, 2001; Bröring and Leker, 2007).

Data collection involved observing the digital transition in various global industries-- like music, fintech and fast food (Geum et.al. 2016; Geurts and Cepa, 2023; Gomber et al., 2018)-- distilling these observations into key components and causal variables, and applying economic principles for synthesis. These synthesized components were then tested under extreme conditions, i.e., what would happen if their value were zero or infinitum for example. These scenarios allowed us to establish our conceptual model's boundaries and observe salient features, which allowed us to craft a meaningful representation in an analytical framework, represented by propositions.
By following this process our conceptual model offers utility for both analytical and prescriptive purposes in scenario planning and strategy development. This process is summarized in Figure 1.

[Insert Figure 1 Here]

3. Interpreting digitalization through economic principles

Historians of technology have pointed out that emerging technologies, which later become dominant, determine new ways to organize economic and social activity (Castells, 1996; Brynjolfsson and McAfee, 2014). Not all technologies have these transformative powers. For example, the OECD (2005) distinguishes four different types of innovation:

- Product innovation is a novel implementation or significant improvement of a well-known product or service. For example, an innovation that makes it easier to maintain a solar panel.

- Process innovation is the development of a new technology to perform a well-known task. For example, demand forecasting is a known activity, but with better tools such as big data and sophisticated algorithms.

- Innovations can also create new business models, an innovative redefinition of products and services, and their monetization. For example, in the UK, Energy Systems Catapult is pioneering the idea of business models around electricity uses such as heating services.

- Innovations can also alter industry structure. A new industry structure might arise when new technologies lead to a change in the supply chain, with either new actors emerging or old actors becoming obsolete. For example, a peer-to-peer market in which prosumers trade electricity (Fuentes et al., 2023).

This paper focuses on how the electricity industry is likely to be transformed due to the emergence of increasing digitalization (the third and fourth innovation types above). When faced with challenging questions such as these, economists often tend to revert to key economic principles that can help characterize the effect in question. One of the main theoretical concepts to analyze this problem is transaction costs. Coase (1988) argued that transaction costs determine the organization of an industry. The criterion for organizing commercial transactions is assumed to be in two parts: minimizing production costs and minimizing transaction costs.

Scholars have argued that the rise of information technology and the internet would reduce transaction costs (Brynjolfsson, et.al 1994). For instance, thanks to big data and connectivity, transaction costs—such as search costs and bargaining costs (digital platforms), or policing or enforcement costs (blockchain)—can be drastically reduced. This raises the question of the impact this would have on the way the electricity sector is organized.

The traditional business model in the electric power sector is relatively straightforward. Utilities generate electricity and feed it into the grid so that customers can consume it and pay for volume. In a stylized model, the organization of the electricity sector could be characterized around the following constraints. The industry structure is comprised of 1) a small number of players with 2) large assets. A large proportion of these assets remain 3) idle for long periods. The challenge is to minimize its operational costs by taking advantage of 4) economies of scale. Digitalization can relax some of these constraints which are analyzed next. The first three points establish the framework for analyzing changes in the industry structure and value chain, while the latter two provide the theoretical foundation for discussing business models in this evolving environment.

First, digitalization can reduce barriers to entry which allows the participation of more players with smaller assets (Brynjolfsson et.al. (1994). Indicative of this effect in the electricity sector is the emergence of multiple startups around the world in an industry that had traditionally been dominated by a handful of firms (see more on startups in the electricity sector in Fuentes et al., 2023).

Digital platforms can enable new markets by connecting these smaller players (Hagiu 2014, Hagiu and Wrights 2015). For example, startup Tempus Energy connects customers with the cheapest flexible energy source using AI, while Next Kraftwerke is a digital platform facilitating flexible power exchanges between producers and consumers (see more about electricity startups in Fuentes et al., 2023). These interfaces facilitate transactions, enabling parties like buyers, sellers, or complementary users to create value (McIntyre and Srinivasan 2017). Without the intermediation of these platforms, transaction costs would simply be too high for these new smaller players to participate in the electricity market.

This change can transform the power sector into one based less on economies of scale, and more on a modular structure that can be scaled up or down in granular and additive steps. Modularity occurs when interfaces between components allow interchangeability, and these interface specifications remain standardized throughout a product's commercial lifespan (Sanchez & Collins, 2001). This leads to increased product variety, faster technological advancements, cost reduction, lower prices, and important for the electricity sector, a more agile industry structure. Technologies like blockchain could help observe, design, and tune the activity and signaling of each modular unit.

Second, digitalization can increase the flexibility of the entire system by enabling integration across the different parts, including supply and demand. Interoperability would allow the exchange of operational information in real time between equipment anywhere in the energy system, reducing inefficiencies, improving reliability, and lowering costs. What is different is that flexibility allows consumers and producers to respond instantaneously to changing market conditions. For example, when the energy price is too high, the demand for energy will reduce, which in turn would reduce not only prices but also quantities. If flexibility is limited to infinitum, it has the potential to alleviate the constraint of underutilized assets in meeting peak load demands, which occur for brief periods throughout the year.

In this way, digitalization can change the way in which grid maintenance costs are covered. If tariffs are set at a specific rate of return, having less capital expenditure would reduce overall tariffs. Also, digital grid-enhancing technologies could increase the utilization of existing capacity without putting operations at risk. This is important at a time when physically increasing capacity is becoming more difficult. However, this could raise new concerns about cybersecurity.

Third, the electricity sector is organized upstream and downstream in segments of the value chain that follow the flow of power: generation, transmission, distribution, and retail. The boundaries between these activities are clear. Digital innovations emerge at the intersection of clearly defined industry boundaries and have the potential for a broader and deeper impact (Hacklin et al., 2009), causing a blurred value chain within the electricity sector (IEA, 2017). New segments could arise, such as prosumers, while others could emerge, such as aggregators. Since a firm exists to internalize transaction costs, the interplay of these two forces will determine the extent of vertical integration of the new electricity industry, which in all probability will be more fragmented as there are fewer transaction costs to absorb. But as digitalization also breaks down the boundaries of silos, for instance, the boundaries between electricity and transport, this can lead to a new horizontal integration of firms, to take advantage of economies of scale. For instance, startup CrowdCharge offers solutions to easily access and optimize renewable energy for EVs, while startup EVs.Energy provides applications to charge EVs when tariffs are low or when it is optimal to use a home's solar panel system.

Fourth, digitalization can redefine the ultimate products of the electricity sector and launch new ones (OEF, 2016). Economic theory establishes that transaction costs determine what a firm should produce internally, and what it should purchase in the market. When transaction costs are negligible, buying rather than making (firms versus markets) will normally be the most effective means of procurement (Williamson and Masten, 1999). Observations of the effects of digitalization on other industries show that the value proposition of some new firms is to take out of the firm some activities that can now be standardized due to digitalization. This leads to firms engaging in more relational contracting with other companies (Lamoreaux, Raff, Temin 2004; Langlois 2002, 2004) rather than absorbing those activities within the organization. Unbundling of a firm's activities can lead to an electricity sector where new firms offer hyper-specialized products and services (Giustiziero et.al., 2023).

The fifth element concerns costs and pricing. Digitalization shares the same cost structure with some renewables: large upfront costs, and negligible marginal costs afterward. How to deal with close to zero marginal costs is problematic in economic theory. For instance, it can break down the criteria of profit maximization, where prices are equal to marginal cost. Having prices equal to zero is an anomaly though, as the role of prices is to signal scarcity. The zero marginal cost structure of digitalization is even more problematic. While the physical network is constrained by congestion, digital networks are not. This characteristic makes digital networks prone to network effects, which can lead to concentration and market power. A zero marginal cost service can therefore lead to an industry structure with market power.

4. Three fundamental propositions shaping the electricity sector

Based on the economic characteristics of digitalization, we put forward the following propositions on how digitalization would change the value chain and redefine products and pricing.

4.1. Proposition 1. Digital transition will bring about a tension between fragmentation and aggregation in the value chain

Digital technologies like blockchain can help smaller players enter the electricity market by reducing costs and making it easier to participate. This opens up new business opportunities that were once too expensive or difficult to pursue. As a result, the electricity sector will likely see more companies with specialized roles rather than a few big players doing everything. However, for these smaller companies to succeed, they need to handle a larger number of transactions to make enough profit. This is where digital platforms can help by coordinating and connecting these smaller companies, allowing them to work together effectively.

Digital platforms would change the way electricity sector firms make money and create value. They would do this by bringing together different groups of users, consumers, and energy producers, and facilitating real-time communication between them. In the electricity sector, an aggregator (a company that brings together smaller players) could reshape the industry by reversing some of the fragmentation caused by digitalization. This would depend on whether the benefits of aggregation outweigh the costs for each participant. Even with this, the sector will still be more fragmented than it was before, with new participants now playing a role.

For example, the startup Meinergy is creating an "energy internet" that includes systems for managing both home energy and grid assets. Another company, Limejump, uses its Virtual Power Platform to connect renewable energy sources and batteries, enabling real-time management of renewable energy. On the other hand, Lumio's peer-to-peer electricity market allows individuals to trade solar energy directly, adding more fragmentation to the market.

One key advantage of these platforms is the network effect. This means that as more people use the platform, it becomes more valuable to everyone involved. However, as the platform grows, it could dominate the market, making it harder for new companies to enter—a situation that digitalization initially facilitated.

The tension between fragmentation and aggregation in the digitalized electricity sector can be exemplified by several innovative companies. The Brooklyn Microgrid in the USA, developed by LO3 Energy, uses blockchain to enable peer-to-peer energy trading, allowing individual homeowners to become energy producers (fragmentation) while the platform aggregates these transactions. Similarly, Germany's Sonnen Community has created a virtual power plant by connecting thousands of residential battery systems, aggregating distributed resources to provide grid services. These examples showcase how digital technologies are simultaneously driving market fragmentation by empowering individual participants and facilitating aggregation to harness the collective potential of these distributed resources.

4.2. Proposition 2. Digitalization can lead to a modular electricity sector versus an economy of scale

Digitalization can reshape the physical infrastructure of industries. Traditionally, the electricity sector relied on large-scale assets to achieve cost savings by spreading expenses over substantial output (known as economies of scale). With digitalization, the electricity system can become more modular, allowing infrastructure to be easily scaled up or down. This modular approach could be cheaper, quicker to implement, and better tailored to meet specific needs. For example, Enphase Energy's microinverters enhance the modularity of solar panel setups by providing each panel with its own inverter, facilitating easier scaling and improving reliability.

Fuentes et al. (2024) suggest that to avoid missing the nearshoring wave, Mexico could close its electricity infrastructure gap by deploying solar panels in homes instead of relying on large-scale generation projects. The installation of Tesla Powerpack in South Australia showcases the power of modular energy solutions; it implemented the world's largest lithium-ion battery in just 100 days, illustrating flexibility and quick deployment compared to conventional power plants. These concepts transform the way we conceive electricity challenges, shifting the focus from building large infrastructure to emphasizing manufacturing and logistics.

The move towards more flexible and smaller-scale electricity production would enable smaller producers to enter the market while maintaining cost efficiency. These cost savings arise not only from lower unit costs but also from the ability to increase capacity in smaller, more manageable increments, which reduces the total capital needed. As a result, large companies would no longer have a significant advantage solely due to their size.

In the past, signals in the electricity sector traveled only one way—from power plants to consumers. Today, thanks to increased connectivity, data availability, and automated responses, signals can now move in both directions. This two-way communication is often referred to as "flexibility". For example, the startup Amp X has created a digital energy assistant that uses AI to optimize household energy use for both environmental and cost benefits. Users can even earn money by being flexible with their energy use. Similarly, Bamboo Energy's platform helps aggregators manage energy assets, while Next Kraftwerke connects flexible power producers and consumers through a digital platform. Equiwatt uses AI to reduce demand across multiple homes, improving flexibility for network operators and energy companies. Furthermore, Enel-X's demand response solutions empower commercial buildings to dynamically adjust their energy usage, reinforcing the concept of modularity by enabling real-time scaling of energy resources. Collectively, these examples illustrate how digitalization enables a flexible and decentralized approach to energy production and consumption, ultimately transforming the electricity landscape. If digitalization continues to promote greater flexibility in the electricity sector, it could significantly impact the physical infrastructure of the industry. Specifically, there would be less need for excess capacity, allowing the industry to operate more efficiently with fewer resources. This streamlined approach could result in lower electricity bills for consumers. However, there is a trade-off: as the system becomes leaner, the potential for cybersecurity risks also increases, since there is less room for error.

4.3. Proposition 3. Digitalization leads to unbundling of products and hyper-specialization
One effect of digitalization seen in other industries is the breaking down of products into smaller, standardized parts that can be sold separately. For example, in education, traditional degrees like an MBA signal a range of skills and experience to employers. But now, digital platforms like edX and Coursera offer individual courses, such as programming in Python, that can be taken on their own. This allows the MBA to be broken into smaller, more focused pieces, emphasizing specific skills rather than the broad experience a full degree represents.

The examples of OhmConnect, Tibber, Bulb Energy's Smart Tariff, Enbala's water heater management, and Octopus Energy's Agile Tariffs illustrate the unbundling of traditionally integrated services. These companies offer hyper-specialized products focusing on specific aspects of energy consumption and management – from incentivizing demand reduction (OhmConnect) to automating procurement (Tibber) and implementing real-time pricing (Bulb and Octopus). This unbundling, enabled by digitalization, allows for greater consumer choice and control, and creates opportunities for new, niche energy service providers.

Another trend is the value found in removing unwanted features from products. Digital technologies often convert physical products into digital formats, making them intangible—meaning they can't be touched. This transformation can be seen in the food industry with ghost kitchens. These are commercial kitchens that operate entirely online without a physical dining area. By removing the need for a traditional restaurant space, ghost kitchens can be located in cheaper, industrial areas, saving on rent and utilities. They also offer greater flexibility in their menu options, allowing them to switch between different cuisines or concepts easily, which helps them adapt quickly to changing customer preferences.

In the electricity sector, a similar concept is the virtual power plant (VPP). A VPP is a cloud-based system that brings together multiple small-scale power sources—like solar panels, wind turbines, and battery storage—to operate as if they were a single, large power plant. This allows utility companies to better manage supply and demand on the electricity grid. For example, Evergreen Smart Power's VPP controls domestic energy loads, such as heating and electric vehicles, to match specific customer needs and market conditions. Instead of focusing on generating more power, they aim to reduce consumption, a concept known as selling "negawatts." This means they help decrease energy use, which can be just as valuable as producing more electricity.

Digitalization also uncovers new consumer preferences that were previously difficult to track. For instance, Octopus Energy has developed a smart grid platform that uses AI to balance the electricity grid efficiently and eco-friendly. Their platform offers products like Intelligent Octopus Go, which schedules electric vehicle charging during the cheapest and greenest hours, and Agile Octopus, which adjusts pricing based on daily wholesale costs, encouraging off-peak electricity use. These super-tailored products can better meet consumer needs but also raise concerns about potential demand discrimination, where some customers might pay more than others. Therefore, regulations are needed to ensure fair competition.

The impact of digitalization on pricing and cost structures is particularly relevant to the renewable energy sector. Both digitalization and renewable energy can lower costs and introduce new pricing strategies. However, digital products often have very low marginal costs (the cost to produce one additional unit), making them hard to fit into traditional pricing models that assume costs increase with production. As a result, new pricing models might rely on transaction fees, subscriptions, or two-part tariffs that separate fixed costs from production costs. This would support long-term fixed-price contracts, which are valuable in electricity markets where reliability is crucial.

Examples of this shift include electricity startups that use subscription-based models. Companies like Allume Energy in Australia offer grid-sharing and solar-as-a-service, allowing multiple users to share a single grid. Similarly, Moixa provides smart battery hardware and software for energy storage and sharing. These companies package their services into recurring payments, reflecting the changing cost structure in the energy sector. Table 1 summarizes the key points of our propositions.

[Insert Table 1 About Here]

5. Action plan for energy companies, startups and tech firms

Digitalization is reshaping the electricity sector by fostering increased competition, innovation, and a redefined competitive environment. Understanding the dynamics between fragmentation and aggregation, as well as modularity and hyper-specialization, enables industry participants to thrive in this rapidly changing landscape. As companies adapt to these shifts, a structured framework is crucial for effective decision-making and for navigating the evolving challenges and opportunities that lie ahead.

Following Holmström (2022) a robust framework must meet three essential criteria (Crossan et al. (1999). First, it should clearly define the phenomenon of interest, such as the impact of digitalization on industry structure, ultimate products and pricing. Second, it must articulate the key premises or assumptions underpinning the framework. Our framework assumes that companies emerge and evolve in line with the theoretical reasoning here. Finally, the framework must detail the relationships among its elements to provide a comprehensive understanding of how they interact. These are developed in Table 2. Based on this framework, we provide recommendations for energy companies (incumbents), startups (disruptors) and tech firms (established firms that could enter the sector).

[Insert Table 2 About Here]

For energy companies, startups, and digital firms, the shift toward more modular and fragmented systems presents both opportunities and challenges. Energy companies may face heightened competition from smaller players, prompting the need for strategic partnerships to maintain market share amid the tension between fragmentation and aggregation. Energy firms will need to adjust their operational strategies to accommodate modular production, investing in new technologies that support decentralized energy generation, which could alter their cost structures and lead to more flexible investment strategies. Furthermore, the shift towards unbundling products will require energy firms to focus on core competencies by outsourcing non-core activities, creating opportunities for collaboration with specialized providers. This hyper-specialization will increase competition not only from established players but also from new entrants offering niche solutions, compelling firms to innovate and differentiate their offerings to thrive in this dynamic environment.

With lower barriers to entry, startups can seize opportunities to create niche markets and develop innovative services that challenge established firms. They can leverage the modular nature of digitalization to introduce smaller-scale solutions, such as localized renewable energy systems or energy storage options, without needing substantial capital investment. By focusing on specific niches—like community solar projects or demand response services—startups can deliver tailored solutions that address localized needs. Their agility and capacity for rapid innovation enable startups to quickly adapt to changing market demands and consumer preferences, positioning them to disrupt traditional energy models. Through hyper-specialization, startups can produce targeted solutions like energy management software and renewable energy integration services, driving further innovation in the industry.

Tech firms have opportunities to create platforms that enhance market efficiency by facilitating interactions among various market participants. By integrating modular energy solutions, tech firms can improve coordination between producers and consumers and utilize data analytics to provide insights into modular system performance, helping energy companies optimize operations and consumers manage their energy use. Additionally, tech firms can develop technologies that ensure interoperability among systems and create specialized platforms that allow consumers to pay for only the services they need, such as energy monitoring or renewable sourcing. Leveraging data analytics also enables a deeper understanding of consumer behavior, leading to hyper-specialized products that cater to specific segments. Ultimately, by offering tailored solutions, tech firms can enhance consumer engagement and satisfaction, fostering loyalty and long-term relationships.

Flexible pricing models that reflect the real-time value of electricity, such as time-of-use pricing, should be considered an important theme for all types of firms in the electricity sector. As the sector evolves, energy companies, startups, and tech firms entities must stay alert to the impacts of digitalization. Collaborating to shape a regulatory environment that promotes innovation while addressing potential market power concerns is essential for their success. Lastly, the integration of digital technologies raises cybersecurity concerns that must be addressed to protect both grid infrastructure and consumer data. A proactive approach to risk management in this domain will be vital as the sector continues to undergo transformative changes.

6. Conclusions

This paper examines how digitalization can introduce new structures, actors, and practices that may change, replace, or complement existing competitive practices among electricity firms and the overall operation of the industry. It specifically focuses on the impact of digitalization on industry structure, product offerings, and pricing mechanisms.

The framework presented in this paper addresses key questions that stakeholders must consider while navigating the changing energy landscape. These questions include: what kind of companies would be emerging in the electricity sector? What implications arise for energy companies, startups, and digital firms as the industry shifts toward modular or fragmented systems? Additionally, how does digitalization impact traditional pricing strategies and cost structures within the electricity sector?

One of the key changes is the scope and nature of new entrants into the energy sector. As market fragmentation continues to accelerate, a wave of small innovators, modular players, and hyper-specialized firms will be reshaping the industry. These diverse new entrants not only would enhance competition but also bring niche innovations tailored to specific market demands, contributing to overall industry growth.

Traditional energy companies must adopt new technologies and innovative business models to remain competitive. To effectively respond to market shifts, they should consider flexible models like subscription services for energy management or pay-as-you-go systems, which align with consumer preferences and help established players compete with emerging startups. Partnerships with tech firms can facilitate access to innovative digital solutions, while investments in digital platforms, modular energy systems, and data analytics are crucial for adaptation.

Startups can take advantage of newly accessible markets by focusing on digital solutions that address challenges in the energy sector, creating substantial value with niche offerings, such as peer-to-peer energy trading platforms that disrupt traditional business models and engage consumers. Strategic alliances with traditional energy companies can enhance startups' viability by providing essential resources and market access. Meanwhile, tech firms can apply advanced technologies to improve operational efficiency and consumer engagement. By prioritizing user-friendly interfaces and seamless integration into existing energy systems, they can foster widespread adoption and leverage data-driven insights to develop personalized services, significantly enhancing customer satisfaction and engagement.

This framework for analyzing the impact of digitalization on the electricity sector is compatible with the rise of renewables. The digitalization of the sector helps manage and integrate renewable energy sources, supports modular and specialized approaches, and aligns with new pricing and cost structures emerging from increased renewable adoption. The insights derived from this framework will serve as a valuable resource for policymakers and practitioners alike, informing strategies for electricity market design and encouraging adaptability in business models and product offerings.

[Insert Declaration Here]

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Figure 1. Roadmap to develop our conceptual model

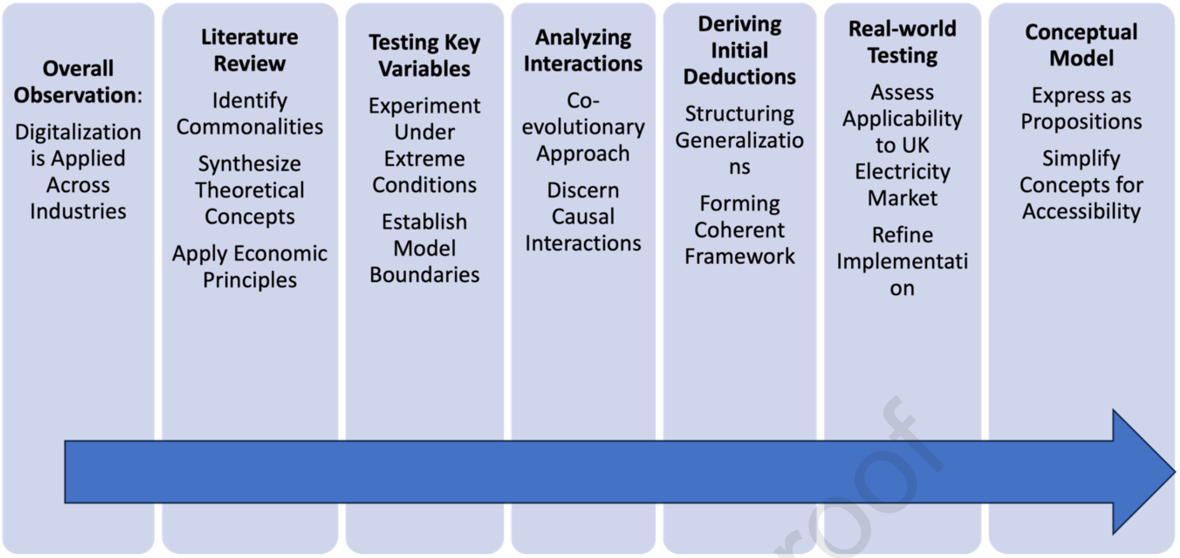

Table 1. Key takeaways

Proposition	Description
1. Tension between Fragmentation and Aggregation in the Value Chain	Digital transition enables smaller actors' participation but also leads to further fragmentation, countered by aggregation through digital platforms.
2. Modular Electricity Sector versus Economy of Scale	Digitalization shifts the electricity sector from large assets to a modular architecture, enabling smaller producers and bidirectional flexibility, potentially reducing excess capacity.
3. New Ways to Price Electricity Services	Digital technologies challenge traditional pricing models, suggesting alternatives like transaction fees and subscriptions to reflect the willingness to pay for reliability.
4. Unbundling of Products and Hyper-specialization	Digitalization enables the unbundling of products and hyper-specialization, observed in education and food & beverage industries, leading to innovative solutions like virtual power plants, while regulation ensures competition and prevents demand discrimination.

Table 2. Propositions and their effects on industry structure, products, and pricing

Proposition	Implications for industry structure	Implications for ultimate products	Implications for pricing mechanisms
1. Fragmentation vs. Aggregation	- Increase in the number of smaller players entering the market. - Potential for consolidation through aggregators as they grow.	- Emergence of specialized products tailored to niche markets. - Bundling of products by aggregators to offer comprehensive solutions.	- Development of diverse pricing models reflective of competition. - Evolution of pricing strategies that consider network effects.
2. Modular vs. Economies of scale	- Shift from large, centralized utilities to modular and flexible structures. - Reduction in barriers for new entrants, enabling innovation at various levels.	- Proliferation of modular products that can be easily integrated. - Increased customization and customer choice in product offerings.	- Lower tariffs as costs are distributed over smaller, scalable operations. - New dynamic pricing strategies that adapt to real-time conditions.
3. Unbundling and hyper-specialization	- Formation of new market segments (e.g., prosumers and aggregators). - Greater industry fragmentation as firms focus on niche markets.	- Creation of hyper-specialized products and services that cater to specific needs. - More emphasis on service-focused products rather than just energy supply.	- Introduction of more complex pricing mechanisms accommodating specialized products. - Change in pricing structures to reflect the unbundled nature of offerings.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT in order to copy-edit some parts of the text. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.