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Review

Impact of Digital Transformation on the Energy Sector: A Review

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Abstract: Digital transformation is a phenomenon introduced by the transformative power of digital technologies, and it has become a key driver for the energy sector, with advancements in technology leading to significant changes in the way energy is produced, transmitted, and consumed. The impact of digital transformation on the energy sector is profound, with benefits such as improved efficiency, cost reduction, and enhanced customer experience. This article provides a review of the impact of digital transformation on the energy sector, highlighting key trends and emerging technologies that are transforming the sector. The article begins by defining the concept of digital transformation, describing its scope, and explaining two conceptual frameworks to provide a deep understanding of the concept. This article then explores the benefits of digital transformation, examines its impact, and identifies its enablers and barriers. Each source examined was analyzed to extract qualitative results and assess its contribution to the researched topic. This paper also acknowledges the challenges posed by digital transformation, including concerns about cybersecurity, data privacy, and workforce displacement. Finally, we discuss the potential developments that are expected in the future of digital transformation in the power sector and conclude that digital transformation has the potential to significantly improve the energy sector's efficiency, sustainability, and resiliency.

Keywords: digital transformation; digitalization; energy sector; power industry

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1. Introduction

Digital transformation (DT/DX) is a phenomenon introduced by the transformative power of digital technologies. This trend has gained significant attention in academic and business settings, including education, government, banking, and manufacturing, especially during the fourth industrial revolution (4IR). For more than 20 years, scholars have been studying the different aspects of digital transformation, including its enablers, barriers, and how it creates value [1,2].

The rapid advancement of society, the economy and industry depends on digital transformation. Today, digitalization and globalization are inseparable and shape human life. By 2030, the European Commission (EC) predicts that the "transformative industrial and technological revolution" will be a major global theme. As technology continues to progress, it will have an impact on various aspects of society, such as lifestyle, education, politics, research, collective intelligence networks, governance, the establishment of open systems, and even health, including the alteration of the human genome [1,3,4].

Similarly to other institutions and nations, the EC has made digital transformation a top priority for both businesses and society. To measure progress across European countries, the EC has introduced a digital transformation monitor and scoreboard as part of its initiatives [5]. The Organization for Economic Cooperation and Development (OECD) also launched a new global project in 2017 called "Going Digital: Making the Transformation Work for Growth and Well-being". The objective of the project is to help policy makers understand the digital transformation taking place and create a policy framework that promotes economic and societal growth in a world increasingly driven by data and digital technologies [6].

Digital technologies have also become integral to our daily lives, influencing our work, communication, and behavior as consumers. In addition, digital technologies, in order to connect the physical and digital worlds, are rapidly catering to the individualized needs of consumers. Consequently, businesses across industries are experiencing a diversification of rapidly changing demands, now affecting areas that have always been dependent on physical materiality [7].

Numerous organizations and businesses have integrated modern technologies such as Big Data analytics, the Internet of Things (IoT), cloud computing, and social media to enhance their day-to-day operations. Failure to adapt to the digital world may result in being a victim of "Digital Darwinism", whereby established players may fade away. Only the most adaptable and responsive companies that keep up with technological advancements will remain competitive in the market. These digital technologies are transforming commercial activities, and the term "digital transformation" is frequently used to describe these changes. However, there is currently no standardized definition for this term. While some consider digital transformation and digitalization to be synonymous, most studies show that they differ and require distinct definitions [8,9].

Historically, the energy sector has been at the forefront of embracing novel technologies. As early as the 1970s, electricity providers and oil and gas companies were pioneers in utilizing emerging technologies to streamline grid management, as well as to simulate exploration and production assets. This digital transformation has been underway in the energy industry for several years, and it has led to significant changes related to the fourth industrial revolution or Industry 4.0 [10,11].

Given the significance of digital transformation in shaping the future, it is imperative to assess the current status and impacts of this trend on diverse industries and anticipate future developments and their potential consequences. Accordingly, this article aims to examine the impact of digital transformation on the power industry. The power industry is undergoing a rapid digital transformation, changing how electricity is generated, transmitted, and distributed. Digital technologies are improving the power system's efficiency, reliability, and safety. In addition, the power industry is facing challenges such as increasing demand, the need for renewable energy sources, and aging infrastructure. Digital transformation is seen as a way to address these challenges and improve the overall performance of the power system. In Section 4, we will provide a literature review and examine the impact of digital transformation on the power industry, focusing on its effects on energy consumption, economic aspects, and social dimensions.

To reach the objectives determined above, we have organized this contribution as follows. First, we begin by introducing the research questions and methodology. We continue by defining digital transformation and showing that it is distinct from digitization and digitalization. Then, we review the different definitions of this term and introduce two conceptual frameworks that facilitate a better understanding of this phenomenon. Next, we move on to discuss digital transformation in the energy sector in general and the electric power industry in particular. In the following, we discuss drivers and barriers to digital transformation in the energy sector and its economic and social impacts. Finally, we present our main findings and discuss the expected impacts of digital transformation on the power industry.

2. Methodology

This study investigated what digital transformation is and how it has affected the energy sector, specifically the power industry. To identify relevant articles for our study, a keyword search was performed based on the following questions and queries:

Questions:

- What is digital transformation and why is it essential for an organization?
- How has digital transformation changed/affected the energy sector (power industry)?
- What are its economic and social impacts?

Queries:

- "Digital transformation" and ("definitions" or "conceptual frameworks").
- "Digital transformation" and ("challenges" or "barriers" or "issues").
- "Digital transformation" and ("enablers" or "drivers").
- "Digital transformation" and ("importance" or "necessity").
- "Digital transformation" and ("impacts on power industry" or "impacts on energy sector" or "benefits for industries").

To ensure the relevance of the paper, a rigorous selection process was implemented to identify suitable papers. Initially, the abstract, introduction, and conclusion of each paper were assessed, and those with a strong link to the research topic were shortlisted for detailed examination. Following this, a comprehensive analysis of each paper was undertaken to evaluate their qualitative findings and their potential contribution to the research topic. The study aimed to incorporate a wide range of relevant papers and thus did not rely solely on factors such as citation count or impact factor for selection.

3. What is Digital Transformation?

Over the past few years, the widespread adoption of digital technologies has significantly impacted various aspects of our society. This phenomenon, commonly referred to as digital transformation, has captured the attention of scholars, managers, and businesses alike. Despite its growing importance, the exact meaning and scope of digital transformation remain unclear, and there is no widely accepted definition of this term among academia, industry pioneers, and practitioners [12–14].

3.1. Digitization, Digitalization, and Digital Transformation

In the course of our in-depth search and analysis of the phenomenon of *digital transformation*, we observed that the terms *digitization* and *digitalization* were used side to side, sometimes interchangeably and inferrably for the term digital transformation. Therefore, before discussing digital transformation, it is necessary to grasp what digitization and digitalization mean because the three terms are often used together and sometimes interchangeably, which is a mistake.

There are several definitions for "digitization," which differ depending on the context. According to [15], "digitization essentially refers to taking analog information and encoding it into zeroes and ones so that computers can store, process, and transmit such information". Converting handwritten or typewritten text into digital form is an example of digitization, and it is the information you are digitizing, not the process—that is where digitalization comes in [15,16].

The first use of digitalization can be found in an essay published in the North America Review in 1971 [17]. I-SCOOP [18], a digital business consultancy, has offered the following concise definition: "Digitalization means the use of digital technologies and of data (digitized and natively digital) in order to create revenue, improve business, replace/transform business processes (not simply digitizing them) and create an environment for digital business, whereby digital information is at the core" [18,19].

Digital transformation encompasses a broader scope and significance than digitalization (automation). When comparing these three terms, it becomes apparent that they are distinct: we digitize information, digitalize processes and roles, and digitally transform businesses and their strategies. Each stage is necessary but not sufficient for the next. Crucially, while digitization and digitalization pertain to technology, digital transformation centers around the customer [15]. Westerman et al. define digital transformation in a Capgemini Consulting and MIT Sloan Management article as "the use of technology to radically improve the performance or reach of enterprises" [20]. While this definition highlights the widespread application of digital transformation, it fails to include the essential components required to achieve this transformation. Emphasizing the key elements necessary for digital transformation is vital, as it is unattainable and impractical

without them [12]. Table 1 outlines the critical factors that differentiate the concepts of "digitalization/automation" and "digital transformation" [21].

Table 1. Key indicators characterizing the notion "digitalization" and "digital transformation" [21].

Indicator Classification	Automation/Digitalization	Digital Transformation
Goal	enhancement of operational productivity and efficiency	fundamentally enhancing the company's competitiveness and boosting its worth.
Objectives	operational, solution of tactic problems	strategic and sometimes marketing
Role	user, software, and system maintenance	innovative concept generation for addressing business requirements
Features	solution and technology with a well-understood set of functions and outcomes, measurements, time limits, and examples of their implementation in other organizations without altering business processes.	solutions based on innovative technology that are exclusive to the firm; There are few instances of introductions; Not usually are the introduction periods well established; The implementation follows the agile development paradigm; It results in changes to corporate procedures or models.
Dependence on IT	stoppage of information systems does not result in the cessation of the company's physical operations. Therefore, it is feasible to switch to the use of hardcopy data carriers.	physical company activity is theoretically impossible without enabling the functioning of the physical reality digital twin.
Relation to physical reality	the physical reality is somewhat reflected in the company's information space.	a digital twin/digital platform is established as the company's information area.
Management	Head of IT department, Chief Information Officer (CIO), etc.	Digital transformation programs are headed by the Chief Digital Officer (CDO), etc.

Implementing technologies into business processes is only a small part of digital transformation. Technologies must generate additional value and synergy for the customers, the business, and other key stakeholders. "To succeed in digital transformation, leading companies focus on two complementary activities: reshaping customer value propositions and transforming their operations using digital technologies for greater customer interaction and collaboration" [19,22].

Over the past 20 years, there have been many discussions regarding digital transformation and its various components, including factors that drive or hinder it, strategies for implementation, and its effects on different industries and businesses. Despite this, the concept of digital transformation is complex and can be interpreted differently depending on the context. As a result, there is no single definition of digital transformation that is consistently applied, and sometimes no definition is provided at all. When a definition is provided, it may be unclear due to being mixed with information about project success or cautionary notes. Alternatively, there may be a clear definition, but it differs from those found in other sources [1,19,23].

Hence, many researchers have worked to formulate a comprehensive and commonly accepted definition for this buzzword. The following examples show that tens of definitions have been proposed for digital transformation [19,23]:

- "Digital transformation applies digital technology to an existing business".
- "Digital transformation aims to create new businesses".
- "Digital transformation is the application of Cloud, Mobile, Social and Analytic technologies".
- "Digital transformation is about changing the company. However, it is not just a change due to the application of new digital technologies and services. It is much more than that".
- "Digital transformation is not only a technological change but also as an organizational, cultural and managerial one. Digital transformation is about reworking strategies, products and processes by leveraging digital technologies. Digital transformation is really business transformation".

- "Digital transformation is the deep transformation of business models and competencies, organizational models, business processes and practices".

These definitions of digital transformation reflect many perspectives on the topic. Technology, customer value, and expected organizational values are some main points that are highlighted in the above definitions. Some focused on digital transformation's aims, while others addressed the related organizational changes. Therefore one can conclude that the digital environment has undergone numerous changes. Additionally, there has been a variety of digital transformations in various domains. Digital transformation of computer hardware and software, communications, commerce, products, relationships, humans, industry, and digital transformation of society are some types of digital transformation that have been addressed by different researchers [19,24,25].

3.2. Digital Transformation Framework

The prior section presented various interpretations of digital transformation, which differ significantly in language usage, prompting some authors to recommend distinguishing between the different definitions. The absence of a consistent theoretical foundation to integrate all aspects of digital transformation is also evident from this lack of clarity. As a result, some scholars have suggested conceptual frameworks to elucidate the concept of digital transformation, identifying its fundamental constituents, facets, and groupings, which reconcile the disparate definitions and aspects of this phenomenon.

For this purpose, Verina and Titko [1] used text extracts from scientific databases, reports, surveys, papers published by non-governmental organizations, and concept-related text segments to analyze definitions of the term "digital transformation" put forth by various researchers, government officials, and business experts. Applying the frequency analysis process within the content analysis approach, the analysis was carried out, and the inter-rater reliability was assessed using Cohen's Kappa coefficient. The expert survey was also conducted to assess the elements influencing the effectiveness of the digital transformation process and to increase the validity of the results that had already been received. Figure 1 presents a visual conceptual model that visually represents the study's final findings. The model that illustrates factors enabling digital transformation processes as well as the potential outcomes. Table 2 also presents the categories of the concept "digital transformation" and the elements within.

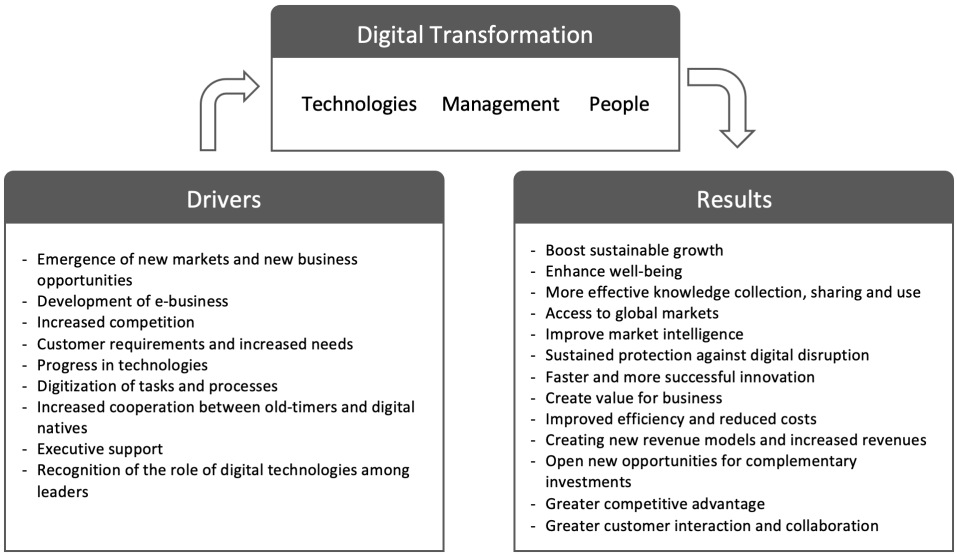

Figure 1. Conceptual model of digital transformation (adapted from [1]).

Table 2. Categories of the concept "digital transformation" and the elements within [1].

Technologies	Management/Processes	People
Data	Strategies	Customers
Mobile devices	Business models	Executives
Cloud	Operating models	Talents
Social media	Business activities	Employees/workforce/people
Big Data	New services	Managers
Artificial intelligence	Operational processes	Suppliers
IoT	Coordination mechanism	Owners
Software	Products	Competencies
Analytics	Organizational culture	Stakeholders
Cybersecurit	Organizational structure	Partners
Embedded devicesy		
App marketplaces		

Veldhoven and Vanthienen [26] have formulated a conceptual framework that harmonizes the discrete definitions and facets of digital transformation. Moreover, they have formulated a new, all-encompassing definition of digital transformation. Their approach entailed an inductive analysis of the definition of digital transformation to construct a conceptual framework. They exclusively examined exclusive and distinctive explanations of this concept, deconstructing them into recurring, vital constituents to identify the fundamental aspects of digital transformation.

The following key components are the ones that are most frequently obtained from definitions: utilizing digital technology, developing a new business model, internal operations, customer experience, society transformation, organizational transformation, digital innovation, the digital economy, the change process, value creation, and products and services are just a few of the topics covered. Figure 2 demonstrates how all of the previously mentioned key elements are arranged around a conceptual framework to balance the many aspects of digital transformation [26].

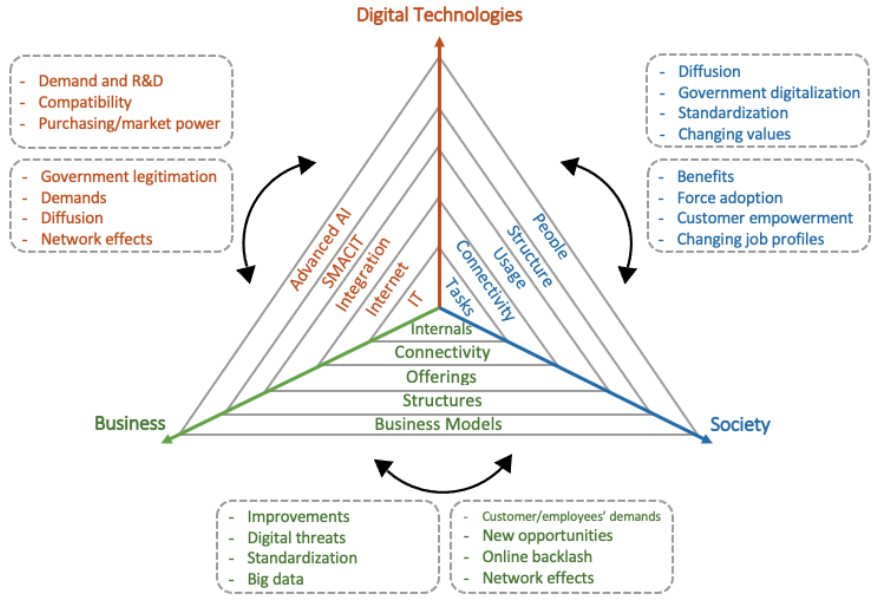

Figure 2. The interaction-based framework for digital transformation (adapted from [26]).

The framework shown in Figure 2 condenses the most important elements and the literature on digital transformation into three axes, their segments, and interactions between the axes. The axes depict the three transformations that can be derived from the components:

the transformation of digital technologies (digital innovation), business transformation (goods, services, organizational transformation, internal operations, and new business models), and societal transformation. Table 3 lists the definitions of the key elements shown in the conceptual framework [26].

Table 3. Definition of essential components in conceptual framework.

Dimension	Segment	Definition
Society	Tasks	modifications to discrete tasks and activities
	Connectivity	alterations in the network, information, and communication
	Structure	alterations to routines, habits, and the work-life balance
	People	changes in people's values, notion of ownership, identity, and way of living
	Usage	adjustments to the everyday goods and services
Business	Internals	internal operational, technological, and labor changes
	Offerings	new or enhanced products and services
	Connectivity	alterations in the relationships between entities, businesses, and procedures
	Business model	modifications to the business's scope, management, and strategy
	Structure	changes to the culture, responsibilities, and organization
Digital technologies	Internet	affordable, universal connectivity, and information sharing
	IT	automating discrete tasks and doing problem calculations
	SMACIT	social media, mobile, analytics, cloud computing, and IoT
	Advanced AI	actions that typically demand human intelligence
	Integration	more accessible, ubiquitous, and available computational power

- Digital technologies transformation—Figure 2's vertical axis serves as its representation. There are numerous digital technologies that are responsible for digital transformation; five important waves from the previous five decades are shown in Table 3 in chronological sequence. Despite the fact that advanced artificial intelligence (AI) is still in its infancy, it is included since many organizations consider it as a possible technology for digital transformation in the near future [26].
- Business transformation—the left axis depicts organizational changes that lead to appreciable gains in performance or value. A growing variety of business-related issues are evolving. Using the keywords and associated terms as a basis, they are categorized into five groups. The categories are listed in chronological order since this is the most common way that they change [26].
- Society transformation—the right axis shows the evolution of civilization (digital maturity), which can be interpreted as the evolution of individuals, groups of people, and societies over time. The right section of the framework illustrates the changes brought on by the greater use of digital technology in the context of digital transformation. Digitalization is the process through which people gradually incorporate digital technologies into every aspect of their lives. This affects their adoption of digital trends, identity, and privacy concepts, as well as their employment, communication style, and way of life [26].

Therefore, it can be seen as the circular movement toward the outer reaches of the digital transformation framework where digital technologies incrementally advance further changes in business, society, and their linkages, as depicted in Figure 3. By proposing that the enhanced interactions between these advancements, as seen by the two-headed arrows connecting the framework's axes, are causing and steering the digital transformation, Veldhoven and Vanthienen [26], elaborated on this theory. As a result, there is a significant rise in the speed, scope, and influence of the many transitions as they become interconnected. Consequently, the following definition is suggested:

> "Digital transformation is the continuously increasing interaction between digital technologies, business, and society, which has transformational effects and increases the change process's velocity, scope, and impact".

In this section, we discussed two conceptual frameworks of digital transformation. Researchers have utilized different definitions proposed over time for digital transformation and constructed conceptual frameworks that help to understand this phenomenon on a deeper level. If we compare the extracted categories and elements, they are almost identical; however, the methods differ.

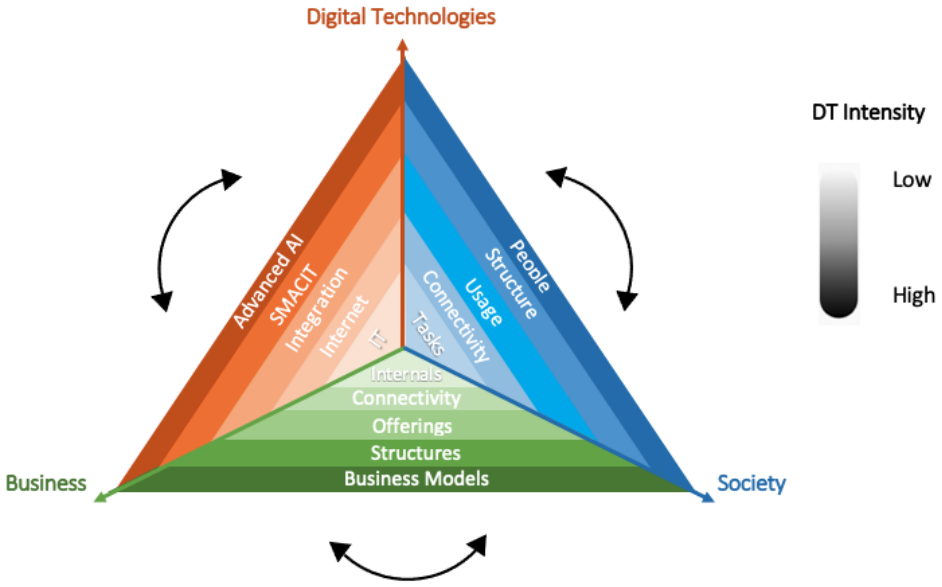

Figure 3. The digital transformation process (adapted from [26]).

3.3. Why Digital Transformation?

The fourth industrial revolution, or Industry 4.0 scenario, led society towards a fundamental change. Digital technologies enhance the quality of people's lives and facilitate work in numerous industries. Digital transformation enables an organization to keep up with emerging customer demands and, consequently, to survive in the future. It also enables businesses to compete more successfully in a continually changing economy due to technological advances. Effective digital transformation management provides organizations with operational and productive advantages [7,27].

Prior to the outbreak of COVID-19, the main emphasis of digital transformation was on enhancing the customer experience. However, the pandemic wrought widespread changes, accelerating the pace of technology adoption and expanding the scope to encompass other stakeholders, including users, administrators, managers, and the like. While COVID-19 was responsible for creating a global crisis and disrupting the activities of people worldwide, it also triggered a surge in digitization. The pandemic-induced factors such as reduced social interaction, social isolation, lockdowns, travel restrictions, and business reorganizations have caused significant disruptions to our daily lives and necessitated our acceptance and adaptation to the "new normal". To continue personal and professional services and interactions, information and communication technologies (ICT) have become essential tools in both social and business contexts [28–30].

Although organizations started to address the digital transformation of the workplace before the COVID-19 epidemic, employers did not anticipate such a quick confrontation with the digital age's impact on the personal, professional, social, and financial dimensions of human capital. Now, digital transformation is the focal point of operational efficiency and innovation for all businesses. Change comes in shorter waves across sectors than ever before, and CEOs are aware that digital transformation and fluency are crucial to their future survival and success [28,31].

When discussing digital transformation, it is essential to note that it involves a vast array of changes to business models and business core, organizational culture, employee

work habits and activities, and the delivery of products or services to customers, all with the full support of digital technologies [28,32].

Numerous organizations engage in digital technology implementations that support business model transformation. Advanced manufacturing, Big Data, blockchain, AI, robots, IoT, and other technologies herald the emergence of a new age in the IT industry. Digital transformation is altering the appearance of industry, the structure of the economy, and the way people work and live. It is ubiquitous, and no sector is immune to its advantages [28].

The post-pandemic environment in which we exist is fostering a "digital fever" attitude. Successful businesses will design intelligent experiences and customer journeys that facilitate and/or enhance the lives of their customers. In contrast, those that do not strive to gain from emerging AI technologies and do not use data to forecast demand patterns, inform regulations, or make workforce-enhancing choices will fail [27]. Digital change in the sector offers the chance to merge practices and methods, resulting in new approaches, skills, and revenue streams. The following are some of its primary benefits:

- It decentralizes manufacturing by promoting distant communication and mobility.
- It increases operational productivity and efficiency.
- It decreases expenses as a consequence of process time reductions.
- It enhances integration and internal cooperation by easing departmental communication.
- It creates new business prospects and income sources, allowing for the development of new goods and services.
- It facilitates decision-making by enhancing data analysis (Big Data).
- It accelerates the reaction time to changes in market demand.
- It creates a competitive advantage for the business by improving the quality of the produced goods.
- It encourages the identification of systems and piques the curiosity of specialist experts, hence attracting fresh talent.
- It drives the innovation culture and prepares the business for any disruption.

Today, digital transformation is a need; we must leave our comfort zones, reinvent ourselves, and compete in a world dominated by technology advancements; otherwise, the utopia humankind was longing for would turn out to be our dystopia.

3.4. Enablers and Barriers

Digital transformation is not a simple project but a complex phenomenon combining technological and organizational challenges [33]. The complexity of the digital transformation process results in the creation of various concerns and problems that must be resolved in order to develop creative business models that allow the full use of an organization's potential. In this part, we detail the many hurdles associated with digital transformation and identify the primary challenges, problems, and barriers that organizations encounter while pursuing digital transformation, as well as the facilitators for this turnaround, [28,34] as shown in Table 4. In addition, different resources are required for a successful digital transformation. Consequently, it is crucial to identify internal and external elements that directly affect success or failure and feasibility [28,35,36].

Table 4. Enablers, challenges, problems, and barriers to digital transformation.

	Digital Technologies	**Business**	**Society**
Challenge	The complexity of the logistics system and core processes Adoption of new and complex technologies Legacy systems	Lack of industry-specific transformation guidelines Poor organizational environment Organizational structure Traditional business model and processes Lack of expertise to lead the digital transformation initiatives	Mistrust in digital transformation in general Resistance to change
Problem	Poor technical / IT skills Technological compatibility Poor data quality	Lack of clear vision The inadequate strategic vision of top management Lack of coordinated digital strategy (unclear strategy) Misunderstanding of the digital transformation process Lack of change management strategy	Lack of training on new digital tools Unidentified benefits from the digital transformation Lack of required digital skills (digitally skilled employees) Lack of coordination between different stakeholders in public and private industry
Barrier	Security concerns	Budget constraints Complexity	Lack of national standards and policies Lack of infrastructure and connectivity Poor legal framework Inadequate legislation for digitization
Enabler/Driver	AI and machine learning Big Data Cloud computing Cybersecurity VR and AR	Clear integrated strategy Put people in the right places Agile way of working Commit to leadership from the top through the middle management	Customers' demands Employees' demands Increasing awareness and building digital skills Standards and legal frameworks Creation and promotion of digital competences

4. Digital Transformation in the Energy Sector and Power Industry

Digital transformation is rapidly changing the energy sector and the power industry, bringing significant benefits to companies and customers alike. The energy industry was a pioneer in adopting digital technology. Power utilities and oil and gas companies were digital pioneers in the 1970s, using new technology to simplify grid administration and operation or to model exploration and production assets [10,37,38].

It has been several years since the global digital revolution of the energy industry began. Decades ago, this sector was a pioneer in the use of emerging technology, such as IT. Industry 4.0, sometimes known as the fourth industrial revolution, has ushered in substantial developments in recent years. Companies in the energy industry have invested heavily in digital technology, and the pace of digitalization in this industry is growing [39–41]. Since 2014, according to the International Energy Agency (IEA), worldwide investments in digital power infrastructure and software have increased yearly by more than 20%, reaching USD 47 billion in 2016. In 2016, digital investments were almost 40% more than worldwide investments in the natural gas power industry (USD 34 billion) [42]. Deregulation of the power industry and the adoption of new policies for renewable energy formed the basis for these changes in several nations, mostly in European Union member states [41].

In recent years, the power industry has been experiencing a wave of digital transformation driven by the adoption of digital technologies such as the Internet of Things, AI, Big Data analytics, and blockchain. In the power industry, digital transformation is having a profound impact on the way electricity is generated, transmitted, and distributed. This literature review explored the impact of digital transformation on the power industry and the benefits and challenges associated with this transformation [41].

The power industry has traditionally been characterized by large centralized power plants that generate electricity and transmit it to consumers through a network of high-

voltage transmission lines. However, the emergence of digital technologies is changing the way electricity is generated, distributed, and consumed. The power industry is now moving towards a more decentralized model, where electricity is generated from renewable sources such as solar and wind, and distributed through microgrids and smart grids. Digital technologies are also being used to improve the efficiency of power generation, transmission, distribution systems, and customer experience resulting in lower costs, customer satisfaction and reduced carbon emissions [41,42].

- Impact on power generation: one of the most significant impacts of digital transformation on the power industry has been in the area of power generation. Power generation is the process of converting various sources of energy into electrical power that can be distributed to homes and businesses. Digital technologies have been used to improve the efficiency and reliability of power generation. Predictive maintenance using Big Data and machine learning algorithms is being used to identify potential equipment failures before they occur. This approach helps power companies to reduce downtime and improve the reliability of their power plants. Another impact of digital transformation on power generation is the use of renewable energy sources. Digital technologies are being used to integrate renewable energy sources such as solar and wind into the power grid. Although the unpredictable and intermittent nature of these variable energy sources can lead to challenges for maintaining the stability and reliability of the grid, digital technologies can support the integration process through enhancing grid visibility and providing tools for coordination and learning. In addition, digital technologies are being used to optimize the use of renewable energy sources. Machine learning algorithms are being used to predict when renewable energy sources will be available and when they will need to be stored for later use [38,41].
- Impact on power transmission: digital transformation has also had a significant impact on power transmission and distribution. Power transmission and distribution is the process of transmitting electrical power from power plants to homes and businesses. Digital technologies are being used to improve the efficiency and reliability of the power grid. Sensors and IoT devices are being used to monitor the health of power lines and transformers. This information is then used to identify potential issues and prevent power outages [38].
- Impact on power distribution: digital technologies are also being used to improve the distribution of power. Smart grids are being used to balance the supply and demand of power. This approach helps to reduce the cost of electricity and improve the reliability of the power grid. In addition, digital technologies are being used to optimize the use of power during peak demand periods. Machine learning algorithms are being used to predict when power demand will be high and when it will be low. This information is then used to adjust the distribution of power to meet the needs of customers [38].
- Digital transformation is also having a significant impact on customers. Digital technologies are being used to improve the customer experience. Mobile apps are being used to provide customers with real-time information about their energy consumption. This information helps customers to better manage their energy usage and reduce their energy bills. In addition, digital technologies are being used to improve the billing process. Digital billing and payment systems are being used to reduce the cost and time associated with the billing process. Another impact of digital transformation on customers is the emergence of new business models. For example, some power companies are now offering customers the ability to generate their own power using renewable energy sources such as solar panels. This approach allows customers to reduce their dependence on traditional power sources and save money on their energy bills [43,44].

Therefore, emerging technologies need particular consideration because they facilitate the development of other technologies and uses, are broadly adaptable, and contribute to the energy sector's stability, efficiency, and environmental sustainability. Tables 5 and 6 detail digital applications, their usage, their advantages in the energy sector,

and the effects of digital transformation on the energy sector and the power industry, respectively [41,45,46].

Table 5. Digital applications and their use and benefits in the energy sector [41].

Main Benefits of Digital Transformation	Application of Digital Technology in the Energy Industry	Types of Digital Technology Most Used in the Energy Industry
Environmental protection System security and stability and cost reduction	Smart grids and optimized operations	Big Data Blockchain Cloud computing Machine learning (ML) Artificial intelligence (AI) Artificial neural network (ANN) Robotic process automation (RPA)
System security and stability and cost reduction Environmental protection	Smart market and flexibility integration	Big Data Blockchain Cloud computing Internet of Things (IoT) Artificial intelligence (AI) Artificial neural network (ANN)
Cost reduction System security and stability	Anomaly detection and prediction	Big Data Cloud computing Machine learning (ML) Artificial intelligence (AI) Artificial neural network (ANN) Robotic process automation (RPA)
Cost reduction	Process efficiency	Big Data Blockchain Cloud computing Machine learning (ML) Artificial intelligence (AI) Artificial neural network (ANN) Robotic process automation (RPA)
Customer satisfaction Environmental protection	Smart home	Big Data Blockchain Cloud computing Internet of Things (IoT) Artificial intelligence (AI)
System security and stability Customer satisfaction	Trust and transparency	Big Data Blockchain Cloud computing

Overall, digitalization can save the power industry around USD 80 billion per year, or 5% of total annual power generating costs. These cost savings is the consequence of digitalization's advantages, which include a reduction in operating and maintenance expenses, a reduction in unexpected outages and downtime, an improvement in power plant and network efficiency, and an extension of the operational life of assets. Using drones to monitor tens of thousands of kilometers of transmission cables across rugged terrain is one example. Digitalization also has the ability to trigger more fundamental, system-wide changes by dismantling conventional demand and supply limits [47–49].

4.1. Drivers of Digital Transformation in the Energy Sector

Economic benefit and revenue growth through introducing new products, services, and customers are the primary goals of all businesses; digital technologies have the potential to provide economic benefits for all types of businesses. Energy companies have recognized the potential of digital technologies and taken steps to become digital [50].

Moreover, digital transformation in the power industry is being driven by a combination of factors. Increased demand for renewable energy, customer satisfaction and changed expectations, aging infrastructure, industry disruption, regulatory requirements, renewable energy, energy efficiency, cost reduction, increased competition, and the emergence of new technologies are some of the key drivers of digital transformation in the energy

sector, and power industry. However, renewable energy is the most significant driver of digital transformation in the power industry. Digital technologies can enable power companies to optimize the placement and operation of wind turbines and solar panels which reduces costs and improves efficiency. The transition to renewable energy sources is also necessary to achieve environmental goals and lessen the carbon footprint of the power industry [51,52].

Table 6. Ways digital transformation has impacted the power industry.

What?	How?	Results
Smart grids	Implementation of digital technology in the energy grid enables real-time monitoring and control of power distribution	improve efficiency reduce costs increase reliability
Predictive maintenance	Digital technologies are being used to monitor the health of power equipment and predict when maintenance is required.	reduces downtime reduces maintenance costs increasing the reliability of the power grid
Renewable energy	Digital technologies such as predictive analytics, machine learning, and IoT sensors are being used to optimize the performance of renewable energy sources, such as wind and solar.	more efficient cost-effective
Energy storage	Digital technologies are also playing a key role in energy storage solutions. Advanced battery storage systems use data analytics to optimize the use of stored energy	reducing costs increasing reliability
Energy efficiency	The use of digital technologies in buildings and industrial processes can help improve energy efficiency. Building management systems, for example, use sensors and data analytics to optimize heating, ventilation, and air conditioning systems.	reducing energy consumption
Customer experience	Digital technologies are enabling a more personalized and interactive customer experience in the energy sector. Smart home systems, for example, allow customers to monitor and control their energy usage from their smartphones, while chatbots and virtual assistants can provide instant support and advice.	Customer satisfaction Better customer engagement
Data analytics	Digital transformation enables companies to better data collection, analysis, and management in the energy sector.	make more informed decisions optimize their operations.

Customer satisfaction is another critical driver for going digital. Customers' needs and expectations have changed through the years, and companies compete to provide better services and achieve higher satisfaction. For decades, customers have wanted cheaper and more accessible electricity, and consumers from highly developed countries have had even higher expectations. The importance of climate-friendly energy, its use, and cost transparency have increased. Smart meters and smart homes are digital applications that can assist in meeting the goals of decreased costs, increased transparency, and increased usage of renewable energy [53–55].

The smart home solution allows the daily measurement and invoicing of energy use, as well as the visualization and display of the energy consumption of particular household appliances [56]. This technology creates transparency and provides the opportunity to identify energy-saving potential. The utilization of artificial neural networks in such systems can help adapt to consumer preferences. As most interactions can be completed through online consumer portals, these solutions boost customer satisfaction while reducing costs [41,57].

4.2. Barriers to Digital Transformation of Energy Sector

The application of digital technologies that result in transformative change involves many challenges in the energy sector and in all other sectors. A qualified and skilled (mainly

digital skills) workforce is the first and foremost need from a managerial perspective. All employees need digital knowledge and skills at different levels, regardless of their organizational roles (forecasting, designing, transmitting, producing, selling, and using energy). A clear managerial vision and a well-defined digital strategy are other vital requirements for an organization to take steps toward the digital [41,51]. Recent studies of success stories about different organizations' digital transformation have shown that a successful transition does not depend solely on the adopted technologies but, more importantly, builds on the digital strategies that its leaders deploy [58,59].

The capital to invest in purchasing, implementing, and using digital technologies is another vital requirement. The transformation of organizations, processes, and technologies is forced by digital transformation. Such reforms are often faced with resistance at various levels of management. Change management, which is mainly focused on overcoming employees' resistance, is a critical managerial skill for businesses that cannot expand without ongoing transformation [60].

Legacy systems, poor data quality, and cybersecurity are some of the technological barriers to digital transformation in the power industry. Many energy companies are still using legacy systems that are not compatible with new technologies, which can slow down the adoption of new systems. The quality and consistency of data are also critical for digital transformation, but most energy companies struggle with poor data quality and siloed data sources. The energy sector is one of the most critical infrastructures, which makes it a high-value target for cyberattacks, and digital technologies can increase the risk [59].

Even if organizations overcome internal barriers and meet the requirements, and the need to implement them is justified, prioritized, and feasible, difficulties in the application and use of digital technologies may arise from external conditions. Poor legal frameworks, a lack of national standards and policies, government limitation of investments in this area, the resistance of social groups, and a lack of industry-specific transformation guidelines are some examples of external barriers to the energy sector's digital transformation [41]. Although many national and regional governments have defined digitalization as a strategic priority and undertaken large-scale initiatives to support the digital transformation of science, industry, and society, the swift and effective digital transformation in the energy sector is impossible without support from the government and social groups that are associated with this sector. They must be aware of the vital changes that may occur due to sector transformation, especially the layoffs [41]. Figure 4 illustrates the main drivers of and barriers to digital transformation in the energy sector.

4.3. Social and Economic Impacts of the Digital Transformation on the Energy Sector

The impact of digital transformation on our society and economy is complex, and it is important to understand the dynamics, interactions, models, actors, and influencing factors involved. Investigating these aspects can provide insight into the profound impact of digital transformation [52].

Macías [61] identifies three key factors that will transform work and employment in the digital age. The first factor is the *automation of work*, which involves the replacement of human labor with digitally enabled machines for certain tasks within production and distribution processes. While the concept of machine automation has been around for centuries, advancements in AI and other digital technologies have vastly expanded the possibilities for automation, meaning that a wider range of tasks can now potentially be automated.

The second factor that [61] identifies is the *digitalization of processes*. This involves using sensors and rendering devices to convert physical aspects of the production process into digital information (and vice versa), taking advantage of the enhanced processing, storage, and communication capabilities of digital information. Digitalization is the primary mechanism by which the characteristics of the digital economy are extended beyond the ICT sector to other industries and sectors.

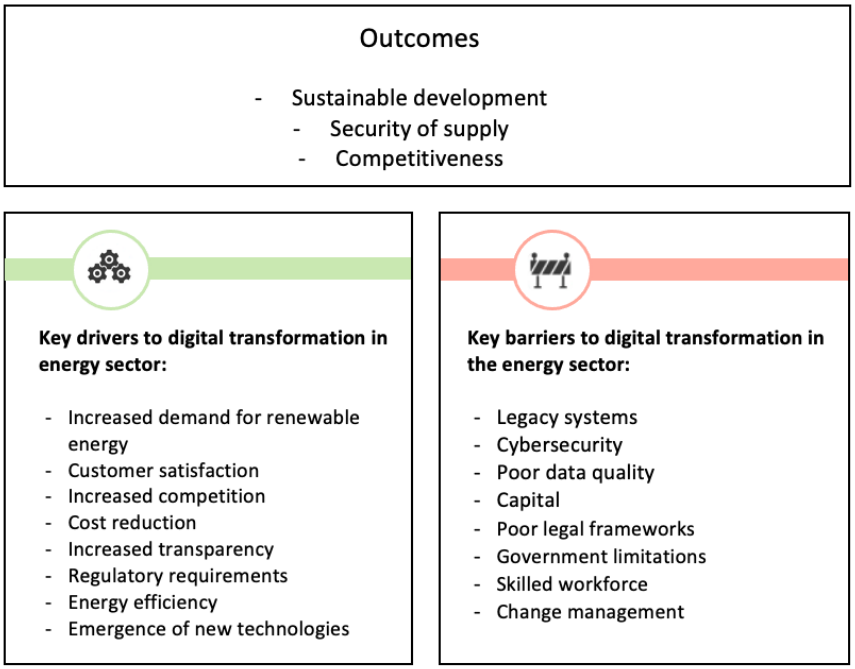

Figure 4. The key drivers of and barriers to digital transformation process in the energy sector.

The third factor is *coordination by platforms*, which refers to digital networks that algorithmically coordinate economic activities. Platforms are digital networks that facilitate transactions through algorithmic coordination. This definition encompasses two critical elements: the structured digital "space" where goods or services can be offered or demanded, and the set of algorithms that match and coordinate transactions in an automated way [61,62].

The vectors of change mentioned above of change can have a significant impact on the structure of employment, affecting both occupational and sectoral structures, as well as working conditions, industrial relations, and the social organization of production. As [52,61] notes, mid-skilled occupations in the energy sector that involve high levels of repetition, standardization, and limited social task content are at a high risk of being disrupted by automation as advanced robotics and AI-enabled machines, become more prevalent. However, digital transformation can also create new job opportunities based on high-value digital services and activities, as well as a new industrial value chain, which can mitigate job loss [5,52,61]

The digitalization of the grid through smart grids is a transformative development in the electricity sector. The World Economic Forum has highlighted that smart grids and grid-edge technologies, including smart meters, have resulted in cost reductions and enabled innovative business models that empower customers. Additionally, smart grids have led to a 60% improvement in the asset utilization of the electricity system. Digitalization has also facilitated increased data collection and analysis to optimize production processes, improve energy efficiency, and reduce waste, among other benefits that can be applied to all production processes [63,64].

Despite the advantages offered by smart grids and grid edge technologies, concerns related to privacy, safety, and loss of control have emerged in society. Therefore, the acceptance of consumers has become a critical factor in the digital transformation of the electricity sector [65]. To increase acceptance, it is important to raise awareness, educate consumers, and highlight the benefits of smart meters, such as providing precise billing, reducing energy consumption, and lowering costs by adjusting usage. A survey conducted by Smart Energy GB among individuals in the UK using smart meters found that 73% of respondents would recommend them, 82% believed that smart meters could help them

better understand their energy expenses, 81% considered their energy bills accurate, and 82% had taken measures to reduce energy waste [66].

Engaging consumers and using microgrids (local energy communities) can enhance demand-side management (DSM), which is crucial for managing losses in transmission and distribution systems and improving energy efficiency for end-users. In addition, microgrids can contribute to the transition to future electricity systems by adding resilience and inclusiveness. As of 2014, over 3.5 billion euros had been earned annually by the local economy through demand response, increasing interest in DSM in the energy sector[5].

Digitalization, according to the International Energy Agency, has the potential to save approximately USD 80 billion per year, which is equivalent to 5% of the total annual power generation costs. This can be achieved through reduced operation and maintenance costs, improved efficiency of power plants and networks, minimized unplanned outages and downtime, and extended lifetimes of assets. For instance, using drones to monitor transmission lines over rough terrain can be a cost-effective way to monitor thousands of kilometers [47]. Overall, the digital transformation of the power sector has both positive and negative socio-economic impacts that are classified in Table 7. However, the impacts have been largely positive, with the potential to create significant benefits in terms of efficiency, reliability, cost-saving and environmental sustainability.

Table 7. Socio-economic impacts of digital transformation on power industry.

Social		**Economic**	
Positive	**Negative**	**Positive**	**Negative**
Energy access Energy efficiency Energy security Renewable energy Job creation Energy democracy Environmental impacts: to improve environmental sustainability, by enabling the integration of renewable energy sources and reducing energy consumption.	Job displacement Digital divide Cybersecurity risks Data privacy concerns Environmental impacts: increased production of electronic waste and carbon emissions from energyintensive data centers.	Improved reliability Increased flexibility in operations Environmental benefits Better customer experience Increased efficiency Increased competition New business models Improve sustainability of energy sector: enabling the integration of renewable energy sources and improving energy efficiency. Reduced costs Investment opportunities New revenue streams: sale of data and value-added services Supply chain optimization: improving logistics, reducing waste, and increasing transparency. Increased productivity: automating routine tasks and enabling faster and more accurate decision making.	Job displacement Regulatory compliance Infrastructure costs Data privacy concerns Cybersecurity risks Digital divide

5. Discussion

As we stated earlier, digital transformation is beyond digitalization. Hence it is not just the implementation of digital technologies. Instead, digital transformation changes the whole aspects of an industry, as it must generate additional value for its customers, business, and key stakeholders. Some believe that digital transformation has increased the demand for and consumption of electricity. However, others believe that it has not caused an increase but a decrease in demand, causing savings in electricity, less energy consumption and preventing energy losses. Because of new technologies and intelligent electronic devices, energy management can be more effective, sending electricity only where it is needed.

Digital technologies have also changed the process and speed of work, which, as a result, reduces the demand for and consumption of electricity. According to the existing definitions, "digital transformation" is a process that affects the business process, society, lifestyle, business strategy and culture, and most aspects of life. As a result, it may have a different effect than digitalization which only focused on automation.

The digital transformation process began decades ago, has altered multiple sectors, and is continuously accelerating. Energy, transportation, construction, health, education, government, and public administration are some sectors that have witnessed massive changes due to digitalization, and more radical transformations are expected in the future. Hence, the world population is expected to move increasingly from rural to urban areas due to this transformation. Consequently, the number of smart cities will increase to provide their growing population with the required utilities, including power. Therefore, there will be a growing need to adopt smart energy systems.

Numerous digital applications have been embraced in the energy sector, and many others are expected in the future. These technologies will make global energy systems intelligent, efficient, trustworthy, and sustainable in the coming decades. Big Data, analytics, and networking breakthroughs enable many new digital applications, such as smart appliances, shared mobility, and 3D printing. Future intelligent energy systems will identify who requires energy and deliver it at the appropriate time, place, and cost. However, it will not be easy to carry this out properly [67].

Various emerging technologies, including AI, blockchain, ML, and cloud computing, are extensively employed in various sectors, including the energy industry. Numerous studies suggest that blockchain technology can facilitate decentralized energy markets while also presenting numerous benefits, such as enabling direct peer-to-peer markets and the economically viable integration of small-scale generation and consumption units. It can also enhance transparency and consumer trust, and open up new business models for suppliers, provided that regulatory and technological obstacles are overcome. Furthermore, AI and ML can substantially improve energy security, accuracy in demand, generation, and price forecasting, and consequently, support the implementation of smart grids and the integration of more renewable energy [51,68].

Weigel and Fischedic [51] conducted a literature review, providing a comprehensive overview of potential digital applications, expected benefits, and stakeholders impacted by digitalization in the energy sector. They categorized the impact of digital applications into three categories: "customer orientation", "system balance", and "process optimization", each comprising various individual digital applications. Based on their findings, digitalization has primarily improved system stability through better balancing of generation, consumption, and grid capacity, and enhanced environmental protection by integrating more renewable energy. Additionally, digitalization has led to reduced energy demand through energy efficiency applications and reduced losses, cost savings due to more efficient and effective processes, increased revenue through new business models, products, and services, and higher customer satisfaction. The literature review revealed that cost reduction was the main benefit of digitalization in the energy sector, indicating that most digital applications, even those not primarily focused on cost reduction, have the potential to reduce costs [69].

In the energy sector, anomaly detection and prediction, smart grids, smart markets, and smart homes have been found to be the most important digital innovations. Digital applications have a wide range of effects on the energy value chain, including on the sale, environment, society, and the national economy. However, the main stakeholder that benefits greatly from digitalization is the grid, which can take advantage of monitoring, control, and communication technologies. Consumers are also significantly impacted, as their role has changed from passive to active customers who can now offer generation and flexible demand capacity to other participants or the market [69,70].

Digital transformation has also affected the efficiency, sustainability, and resilience of power systems. The efficiency has been enhanced by improving operational processes, reducing costs, and increasing productivity. The use of digital technologies such as sensors, analytics, and automation, enables power companies to optimize their operations, reduce downtime, and improve maintenance schedules. They also facilitate monitoring and analysis of data in real time, allowing their users to make informed decisions quickly and efficiently.

Recently, the power industry has undergone significant changes with a growing focus on sustainability and reduction of carbon emissions. Digital transformation has played a significant role in enabling the industry to achieve these goals. For instance, the use of renewable energy sources, such as wind and solar power, has increased significantly. Additionally, digital technologies have allowed power companies to manage these sources better, mitigating their intermittency and optimizing their output. Digital technologies have also enabled power companies to implement smart grids, enabling efficient and sustainable distribution of energy. The power industry is critical to the functioning of modern society, and disruptions in the industry can have severe consequences.

The digital transformation has significantly enhanced the resilience of the power industry by improving its ability to rapidly respond to disruptions. For example, digital technologies have provided power companies with capacity to better monitor their infrastructure, identify potential problems before they occur, and quickly respond to outages or other disruptions. They have also provided power companies with new tools for integrating distributed energy sources, reducing the impact of associated disruptions on the overall energy supply [71,72].

Finally, the future of digital transformation in the power sector is expected to be revolutionary due to ongoing technological advancements and a growing integration of renewable energy sources. Moreover, the power sector faces problems such as climate change, energy security, changing customer expectations, and increasing pressure to cut carbon emissions and improve efficiency. Hence, digital transformation will be vital to tackling these problems and driving growth, as it will help the power sector deal with these problems and meet changing customer expectations. Based on our discussions in previous sections, a list of potential developments in the future of digital transformation in the power sector is expected, which are as follows.

- Artificial intelligence and machine learning: The use of AI and machine learning is expected to increase in the power industry, enabling power companies to better forecast demand, optimize power generation and distribution, and enhance system performance.
- Blockchain-based systems: Blockchain technology has the potential to revolutionize the power industry by facilitating peer-to-peer transactions, improving energy trading, and enabling greater energy market transparency and efficiency.
- Advanced analytics: Due to the application of new technologies, the power industry is generating vast amounts of data, and advanced analytics tools will enable power companies to make better use of their data to optimize operations, improve reliability, and reduce costs.
- Internet of Things (IoT): The IoT enables the deployment of smart grids and connected devices, which will provide power companies with real-time information on energy consumption and enable them to manage their operations more effectively.
- Cloud computing: Cloud computing enables power companies to store and analyze large amounts of data more efficiently and is expected to become more prevalent in the power industry. Hence, power companies can optimize power generation, transmission, and distribution, and improve the customer experience.
- Smart homes and buildings: The integration of smart homes and building technologies enables customers to manage their energy usage more effectively and participate in demand response programs and this will become increasingly important.

- Decentralized energy systems: The growth of decentralized energy systems, such as microgrids and distributed energy resources, will require new digital technologies to manage and integrate these systems with the larger power grid.
- Electrification: The electrification of transportation, heating systems, and other facilities will create new opportunities and challenges for the power sector, as power companies seek to manage increased demand and optimize the use of renewable energy sources.
- Cybersecurity and data privacy: As the application of digital technologies is increasing in the power industry, cybersecurity, and data privacy will become increasingly important. Power companies will need to invest in robust cybersecurity and data privacy systems to protect their networks and customer data.
- The continued growth of renewable energy: New digital technologies are required to manage the variability and intermittency of renewable energy sources such as wind and solar and integrate them with traditional power generation sources.
- Policy and regulation: The development of policies and regulations that support digital transformation will be critical to enabling the power industry to realize the full potential of these technologies.

The future of digital transformation in the power industry will likely be shaped by a combination of technological innovation and policy and regulatory developments, focusing on addressing key sustainability, reliability, and customer engagement challenges. By addressing these challenges, the energy sector can drive growth and build a more sustainable and equitable energy system for the future. However, it will face challenges in cybersecurity, data privacy, and the digital divide. Ensuring the security of digital systems and data and addressing concerns related to data privacy will be critical to building trust and confidence in adopting new digital technologies. Additionally, the successful adoption of digital technologies in the power industry will require collaboration and coordination among stakeholders, as well as ongoing investment in infrastructure and talent development.

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