VILNIUS UNIVERSITY

KAUNAS FACULTY

INSTITUTE OF SOCIAL SCIENCES AND APPLIED INFORMATICS

International Business Management study program

MASTER'S THESIS

THE IMPACT OF DIGITALIZATION ON THE ENERGY MARKET

Kaunas 2025

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THE IMPACT OF DIGITALIZATION ON THE ENERGY MARKET

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Kaunas 2025

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ICT	Information and Communication Technology
IoT	Internet of Things
SG	Smart Grid
IEA	International Energy Agency
ANN	Artificial Neural Networks
RPA	Robotic Process Automation
ML	Machine Learning

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INTRODUCTION

The Relevance of the topic. Understanding the influence of digitalization on the structural, economic, and operational dynamics of the energy market is critical, especially in the context of a rapidly evolving global energy landscape (Singh et al., 2022). As energy systems become increasingly complex and decentralized, digital technologies such as big data analytics, artificial intelligence (AI), and smart grid infrastructure play a pivotal role in optimizing energy production, distribution, and consumption (Maroufkhani et al., 2022). This topic is particularly relevant due to the urgent need to enhance energy efficiency, reduce operational costs, and meet ambitious sustainability goals. Furthermore, examining how digitalization reshapes energy market paradigms provides valuable insights for policymakers, industry stakeholders, and researchers aiming to navigate the digital energy transition effectively.

Scientific problem – To what extent and in what ways does digitalization influence the energy market's future?

Object of the thesis is the role of digitalization in the energy market.

Aim of the thesis is to analyze the influence of digitalization on the structural, economic, and operational dynamics of the energy market by examining its impact on efficiency, cost savings, transparency, and sustainability while considering the role of smart grids, big data, and digital tools.

Objectives of the thesis:

1. To examine the role of digitalization in enhancing energy demand forecasting accuracy and market efficiency.
2. To assess the impact of advanced digital technologies on the transformation of energy market paradigms.

3. To evaluate the challenges and opportunities of digitalization in the energy sector transformation.
4. To analyze the contribution of digitalization to sustainability goals, including renewable energy integration.

Thesis and research methods. The researcher analysed the digitalization and the energy market's theoretical and analytical premises using standard scientific research methods, including analysis of scientific literature, synthesis, and classification. One hundred participants, including energy market analysts, digitalization and smart grid experts, policymakers and regulators within the energy sector, and technology providers specializing in digital energy solutions, were selected, and a questionnaire was administered. The survey findings analysis incorporated previous studies used to substantiate the results. The respondents were required to express their opinions on various aspects relating to the impact of digitalization in the energy market.

Structure and scope of the thesis. The thesis is organized into four sections. The first one presents the introduction; the second presents the theoretical aspects of digitalization in the energy market. Section three outlines the analytical research level of the impact of digitalization on the energy market, and the last part contains this study's research.

1. THEORETICAL ASPECTS OF DIGITALIZATION IN THE ENERGY MARKET

This chapter overviews key concepts associated with digitalization in the energy market. It focuses on digitalization in the energy sector. It examines key concepts such as renewable energy integration, demand response, and data-driven decision-making to address challenges and opportunities in modern energy markets. Two major theories are examined: the instrumental theory of technology and technological determinism. Theoretical analysis is essential for understanding the underlying frameworks associated with the implications of digitalization on the energy sector.

1.1 Concept of Digitalization and Its Current State in the Energy Sector

Problem Investigation Level: Energy is essential for modern production, consumption, and all human and economic activity (Sharma et al., 2022). The data from the IEA shows that global energy demand is constantly increasing (World Energy Outlook, 2024). This increase in energy demand has exacerbated existing inefficiencies in traditional energy systems. These inefficiencies include forecasting gaps, infrastructure vulnerabilities such as cyberattacks, and regulatory fragmentation. Digitalization promises robust solutions to these inefficiencies. It is evident that digitalization has led to significant shifts in production models and the economics of production, enabled the reconfiguration of production factors, and spurred new technological advances and industrialization revolution (Lim & Sun, 2022). Elements such as AI-driven demand forecasting, smart grids, and blockchain-enabled peer-to-peer trading, but adoption is uneven. While the EU prioritizes consumer empowerment, such as Germany's Energiewende, the U.S. and China focus on industrial scalability, revealing a global divide in strategic approaches. This study investigates how these disparities shape outcomes in efficiency, sustainability, and market accessibility.

The Concept of Digitalization: Digitalization is profoundly altering and transforming the fundamental assumptions of the way of life and organization of economic activities in the postmodern society, which is becoming more globalized and deeply digitalized than ever (Kohont & Gorensek, 2019). Kohont and Gorensek (2019) describe digitalization as the increase in the use of digital technology by organizations, industries, and nations. This process could be called digital transformation and involves how many domains of social life get remodeled around digital communication and media paradigms (Kohont & Gorensek, 2019). Similarly, Reis et al. (2020) define digitalization as a digital transformation process that incorporates digital technologies in a particular segment of an economic operation, sector, or industry, resulting in significant changes in operations.

Światowiec-Szczepańska and Stępień (2022) establish that the concept of digitalization could be used interchangeably with the term digital transformation. Thus, Światowiec-Szczepańska and Stępień (2022) define the concept of digitalization as the integration of digital technologies to enhance business operations, policies, and decisions in general in order to elevate the overall efficiency, security, and sustainability, as well as costs. The process aims to enhance a firm or an operation by activating considerable transformation to its features through information, communication, connectivity, and computing technologies. The International Energy Agency (IEA) outlines that the concept of digitalization involves the increasing interconnection of the digital and physical spheres as a result of the growing utilization of ICTs (Światowiec-Szczepańska & Stępień, 2022).

Digitalization in the Energy Sector: Digitalization plays a significant role in the energy markets by providing the desired interfaces and infrastructure that allow for efficient and smart functioning of operations and operators (Trzaska et al., 2021). Digitalization technologies, including artificial intelligence (AI), big data, cloud computing, and blockchain computing, allow for comprehensive data collection, processing, and analysis within the energy market (Światowiec-Szczepańska & Stępień, 2022). According to Xu et al. (2022), these digital technologies are starting to play an essential role in the energy industry and, shortly, will accelerate the decentralization of power generation, digitalization of the infrastructure, engineering, and intelligent control, and the development of novel opportunities for end energy consumers.

According to Światowiec-Szczepańska and Stępień (2022), the most frequently stated digital technologies that are starting to be applied within the energy sector include AI, artificial neural networks (ANN), Internet of Things (IoT), robotic process automation (RPA), big data mining, cloud computing and machine learning (ML). These technologies possess similar characteristics in their implementation within the energy sector. They are interconnected and support each other; they are universal, and their application often results in significant benefits (Światowiec-Szczepańska & Stępień, 2022). In addition to these standard features, these technologies have broad applicability and offer comprehensiveness in efficiency, stability, and sustainability when applied in the energy market.

International Perspectives on Digital Energy Perspective: Innovative technologies, such as smart grids, IoT sensors, and data analytics in the energy sector, can enhance energy production, transport, and usage. Therefore, multiple countries across the globe have started to emphasize energy digitalization. The European Union postulated an action plan for digitalizing its energy system to enhance interoperability and connectivity, promote coordination in smart grids and related technologies, empower consumers, elevate cybersecurity, and promote efficiency (Thanh et al., 2022). The United Kingdom established the ‘digital spine’ feasibility study, which involved a digital task force enabling the country to integrate digitalization into its energy system. UK companies such as National Grid ESO, Western Power Distribution, and Octopus Energy are developing AI platforms and running pilot programs (Charalampous, 2021). The major domains targeted by these companies include modeling and optimization, maintenance and security, customer-facing services, and markets and investments. The United States has constantly strived to digitalize its energy systems by integrating novel technologies such as smart grids and AI. China's energy sector is actively pursuing digitalization to boost efficiency, optimize capacity, and accelerate the transition to renewable energy (Zhang et al., 2023). In response to reduced gas supplies, Germany's “Energiewende” initiative, which accelerated its transition to renewables, was supported by advanced energy digitalization efforts. Technological adoption could lead to consequences such as using renewable energy, fewer energy losses, and more stable grids (Pakulska & Poniatowska-Jaksch, 2022).Further comparison of digitalization within the energy sector across different nations is provided in Table 1.

Table 1: Comparison of Energy Digitalization Across Different Countries

Country	**Focus of Digitalization**	**Key Initiatives**	**Outcomes/Challenges**
Germany	Renewable energy integration and smart grids	Energiewende program, Smart meter rollout, AI-supported grid management	High renewable share but challenges with grid intermittency and storage

China	Capacity optimization and AI-driven energy forecasting	"Energy Internet" strategy, massive smart grid investments, and AI forecasting systems	Improved grid efficiency, cybersecurity, and regional coordination issues
United Kingdom	Consumer empowerment and market flexibility	Digital Spine project; AI-enabled services by National Grid ESO and Octopus Energy	Better demand-side management; regulatory updates lag behind technological advances
United States	Smart grid modernization and decentralized energy systems	DOE Smart Grid Investment Program; AI, blockchain in energy trading	Significant grid upgrades, challenges with fragmented state-level regulations, and cybersecurity threats
Brazil	Grid reliability and rural electrification via digital solutions	ANEEL-led digitalization initiatives; investment in smart metering	Expanded rural grid access; difficulties in maintaining system stability and cybersecurity protection
France	Efficiency and grid decarbonization through smart grids	Linky smart meter project; Digital energy data hubs	Strengthened grid intelligence, consumer privacy concerns, and moderate adoption rates
Japan	Disaster resilience and decentralized energy systems	Smart Community Projects post-Fukushima: AI for grid management	Increased microgrid adoption and resilience; high costs and aging infrastructure pose obstacles

A comparison of how different countries implement digitalization depicts critical insights. The underlying difference in the digitalization of energy markets emerges from the country's individual needs and unique needs, the inefficiencies of existing infrastructure, and the objectives that the country is pursuing. Germany prioritizes digitalizing renewable energy integration, including integrating and expanding its smart grids. In contrast, China focuses on optimizing capacity and utilizing AI to achieve efficiency in energy practices such as grid forecasting. The UK emphasizes consumer empowerment through energy digitalization tools such as IoT and flexible energy markets, contrasting with the US policy, which focuses on smart grid modernization and forecasting. Brazil utilizes digital tools primarily to enhance rural electrification and grid reliability. France targets efficiency and grid decarbonization but faces adoption hurdles. On the other hand, Japan concentrates on building disaster-resilient, decentralized energy systems. Despite varying goals, all countries encounter cybersecurity risks and regulatory adaptation challenges.

1.2 Digitalization Theories

Technological Determinism Theory. Technological determinism posits that technology has an enduring effect on human thought processes, behavior, and attitude. A theme of modern society, it was initially introduced by Thorstein Veblen. Technological determinism seeks to illustrate that technology, or media is the reason for historical and social change (Hallström, 2022). It assumes that individuals have negligible free will and that society conforms to the chosen means of communication. Many hyperglobalists argue that such development must occur due to the availability of relatively easy technology for the global digitization of the energy industry (Hallström, 2022).

According to this view, technological developments are primarily responsible for large-scale shifts in social structure and more significant historical events. At the same time, it is accountable for smaller-scale shifts in the user's psychological makeup resulting from constant exposure to some of these instruments (Azam et al., 2020). Technology is entirely independent. Even though technological determinism is most frequently associated with the assumption that technology is neutral, it can also be related to the claim that humans have no means of getting over technology without using technology to exploit humans. However, one can verify very general statements of the effects of technology, and medium determinism is a version of technological determinism that focuses on the role of the communications medium. A slightly nuanced version of technological determinism claims that it may not matter what instruments we use daily. Still, the social setting in which we use the instruments does matter (Wyatt, 2008).

Philosophical, sociological, historical, design, and technological determinism studies of technology have focused on technology education (Hallström, 2022). Hallström attempted to put these studies back under construction. The research yielded three new insights about technological determinism. In the first part, technological determinism is a theory that explains the past and present status of technology, or a tangible structure, directing society in unobtrusive or demonstrative ways, according to some researchers. There is no limitation of technological determinism to studies of technology at the level of society or to those of a relatively macroscopic nature about technology and culture. Determinism might even manifest on the microscopic level. As design is somehow an inevitable compromise between desirable, socially and technically feasible goals, technological determinism, like social/societal determinism, becomes an unavoidable result of the design process. Thirdly, from a technically literate perspective, the greatest need is to disseminate the idea that when it comes down to it, technology is built and run by people (Hallström, 2022).

Others believe technological determinism to be too simplistic and neglect the close connection between technology and society. Their main arguments are that technology is not objective because it is subject to the pressures of monetary and social forces and does (or can) serve different functions in different sites (Hallström, 2022). Technological determinism, which some regard as technical fatalism, holds that people cannot do anything about technology changing culture and society. In truth, the interaction between technology and society is much more complex and dynamic. Technology influences society and culture, yet society and culture also influence technology (De la Cruz Paragas & Lin, 2016).

Technological determinism has been emphasized at multiple levels of evaluation. At the broadest level, the theory has informed most analyses of the transformation in socio-economic configurations: the transition from feudalism to capitalism, shifting the skill as well as occupational structure of the labor force in the 20th century, the occurrence of the post-industrialism after the Second World War, the eventual occurrence of the 'information world,' 'post-Fordism,' as well as globalization (Adler, 2006). For others, technological growth symbolizes the promise of the subtle emancipation of civilization from the challenges of unnecessary labor and sickness. For others, it represents a loss of individual humanity, embedding humans in an ever more elaborate, dangerous, alienating web. Another perspective of technological determinism argues that technology does not profoundly determine as perceived, especially in the modern world. Instead, this technological authority emerges only at particular historical moments. This involves determinism by default: 'capitalists' or 'industrial' societies have unleashed technological development but have not postulated the mechanisms necessary to provide it with requisite social direction (Adler, 2006).

Marx inspires one significant variant of technological determinism. According to Marx, the ‘forces of production (capabilities of the technology and the workers) form the substructure of relations of production and the superstructure of culture and politics (Adler, 2006). The general direction of this transformation mainly relies on the social structure, even though the latter can increase or decrease the transformation rate. Over time, the relations between production and the superstructure must adapt to accommodate further technological transformation.

Instrumental theory of technology. To instrumentalists, technology is simply an instrument used to accomplish a purpose. In this respect, technology represents no more than technological processes and products designed to achieve specific objectives (Gunkel, 2020). Instrumental theory rests on the idea that technologies are merely 'tools' that people can use to get things done. It is inherently valueless; thus, based on this perspective, technology is viewed as 'neutral' (Gunkel, 2020). This concept of neutrality implies multiple insights. Pure instrumentality technology does not care that it can accomplish various objectives. Given this, technological neutrality is ultimately only a special case of instrumental means' neutrality, with a dubious connection to the values they represent. This idea of objectivity is a common and obvious one. In today's world, it would seem that technology is politically apathetic towards capitalist and communist nations (Kynigos & Psycharis, 2013). A hammer works, as does a steam turbine, no matter the social setting. Here, the technology differs very much from traditional social institutions, such as those involving law or religion, which are intrinsic to the communities in which they arose and so challenging to transpose to other contexts. In contrast, technology transfer appears to be constrained only by the costs associated with it (Røvik, 2016).

To profoundly understand the instrumental theory of technology, it is pivotal to comprehend what perceiving technology as 'neutral' means. According to Feenberg (2005), the concept of the 'neutrality' of technology implies four significant paradigms. The first concept is that technology, as a profoundly instrumental element, is indifferent to the various ends to which it could be employed. Therefore, the neutrality of technology is simply a unique circumstance of the neutrality of instrumental means, which could only be contingently associated with the substantive value it serves. Thus, the concept of neutrality is self-evident as well as familiar. The second notion of technology 'neutrality' is that technology seems indifferent to politics, especially in contemporary society. Based on this notion, technology significantly differs from conventional religious or legal institutions. It cannot be readily conveyed to novel social contexts because they are profoundly interconnected with other elements of the societies in which they emerge. On the other hand, transferring technology appears to be deterred only by its costs.

The third concept of technological 'neutrality' involves the socio-political paradigms where technology is perceived to be a 'rational' character and that it embodies the universality of truth. Thus, technology has its basis in a verifiable causal proposition. To the degree to which these suggestions are accurate, they are not politically or socially relative but similar to the scientific concepts; they uphold their cognitive status in every plausible social context (Feenberg, 2005). Therefore, what works in a particular society is expected to work in another.

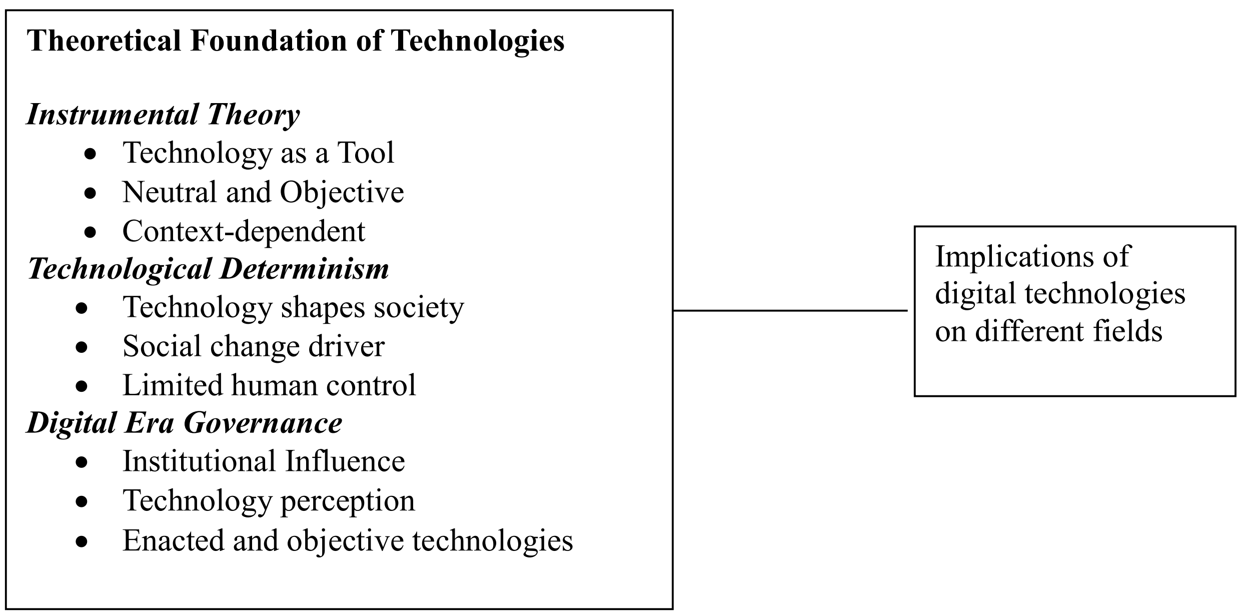
Many feel that the lack of bias on social and political issues is attributable to technology's "rational" nature and the very nature of universal truth it represents (Kynigos & Psycharis, 2013). In the simplest terms, technology depends on well-proven causal claims. If these claims are valid, these are trans-political and social boundaries and, like scientific concepts, have cognitive currency everywhere, no matter what social setting they find themselves in. If a strategy is successful in one culture, it should have the same effect in another (Kynigos & Psycharis, 2013). The other benefit of technology being universal is that it can use the same measuring standards, but in different contexts. By using technology, worker productivity increases in every nation, in every period, and every civilization. One says technology is neutral if it can work efficiently in any situation (Gunkel, 2020).

Subsequently, technology as a 'neutral' stem from its universality. This universality of the phenomenon means that similar measurement standards could be applied in varying settings. Therefore, technology is regularly perceived to increase labor productivity in different societies, civilizations, and eras (Feenberg, 2005). They are neutral because they affirm a similar concept of efficiency in each emerging context.

Digital Era Governance Approach: This principle attempts to establish the implications of technologies for the organization by taking the institutional perspective. According to this approach, there is a variation between objective and enacted technologies (Białożyt, 2017). Objective technologies integrate various innovations, including the Internet, while enacted technologies involve the utilization, design as well as perception of these technologies by individuals within a particular field (Białożyt, 2017). Institutional structures limit the perception and utilization of technologies; nevertheless, institutions influence technologies. Thus, the role of technology significantly varies and depends on the institution and what individuals within it make out of it (Białożyt, 2017).

1.3 Theoretical Model Formation

Digitalization is changing the energy market through the integration of novel technologies that elevate sustainability, efficiency, and effectiveness (Światowiec-Szczepańska & Stępień, 2022; Kohont & Gorensek, 2019; Xu et al., 2022). Systematic analysis of these changes requires integrating a structured theoretical model that illustrates the significant components, variables, and their interconnection. The theoretical model is depicted in Figure 1.



Source (Written by Author)

Figure 1: The Theoretical Foundation of Technologies

Key Components of the Theoretical Model. The first significant component involves technological enablers. These involve the individual technologies driving the digital transformation of the energy sector. The significant enablers include AI, big analytics, IoT, and blockchain (Xu et al., 2022). These technologies are often interconnected and facilitate automation, forecasting, analysis, and predictive maintenance within the energy market (Mhatre et al., 2021). Another key component involves renewable energy integration. One of the significant trends within the energy sector over the past five decades is the integration of renewable energy (Al-Shetwi, 2022). Digital tools are starting to play an essential role in enabling and accelerating the frontier of renewable energy. These are depicted through the realization of better grid management systems, real-time tracking and balancing of energy supply and demand, digital storage solutions, and optimization of renewable sources, including solar and wind energy (Pakulska & Poniatowska-Jaksch, 2022).

Another critical component involves demand response mechanisms. Digital energy systems such as smart grids and IoT devices have started to empower consumers to alter their energy consumption (Mahmood et al., 2024). These systems provide consumers with enhanced autonomy and control of their energy consumption, including the ability to respond to real-time pricing and be aware of grid conditions (Mahmood et al., 2024). Rathor and Saxena (2020) say these smart energy management practices and patterns improve efficiency and reduce peak loads. Data-driven decision-making is an essential aspect of digital transformation within the energy market. Digital transformation allows for a robust data collection, processing, and analysis capacity, thus enabling stakeholders to make informed decisions, policy decisions, and operational enhancements (Weigel & Fischedick, 2019). Market dynamics and regulation policies also play an essential role in the implications of digitalization in energy markets. Government policies such as carbon pricing and market incentives significantly shape digital adoption within the energy sector. These factors influence energy sectors, such as investments in smart grids, decentralization of power systems, and smart electrification (Alkkhayat et al., 2024).

Interrelationships in the Model. Technological enablers accelerate improvements in the energy sector, including novel practices such as renewable energy. Also, they impact demand response mechanisms within the industry. Factors such as data analytics, which are achieved by digital transformation technologies, assist in market forecasting, optimizing the grid, integrating smart energies, and achieving predictive maintenance. Subsequently, policy, regulations, and market forces impact the adoption and control of digital technologies within the energy sector. However, the use of technologies could be limited by institutions and individuals within these institutions. Thus, the degree of its implication could be only to the extent of the institutional patterns.

1.4 Conclusion

AI, IoT, and blockchain technology are the key concepts and enablers of digitalization within the energy sector. These factors have been crucial in renewable energy integration, demand response, and data-driven decision-making to address challenges and opportunities in modern energy markets. The instrumental theory of technology and technological determinism theory outline critical insights into digitalization's impact on the energy sector.

2. ANALYTICAL RESEARCH LEVEL ANALYZING THE IMPACT OF DIGITALIZATION ON THE ENERGY MARKET

2.1 Digitalization in the Energy System: Current Status and Challenges

Digitalization constitutes one of the emerging and critical trends in the energy economy globally (Singh et al., 2022). In particular, such technologies create new opportunities as well as mechanisms for undertaking different processes and thus establish the conditions for a shift in the traditional paradigms within energy (Maroufkhani et al., 2022). Digitalization constitutes a sequence of economic practices that utilize the Internet, smart technologies, information and communication technology (ICT), as well as knowledge of production factors, analysis, transmission, and generation factors in the energy sector (Xu et al., 2022). The 're-industrialization' approaches of nations around the globe, such as the 'German Industry 4.0' and 'Made in China 2025' have depicted the significant penetration of digitalization, which has profoundly altered operations of enterprises, modes of production, enhanced the efficiency of industrial resource allocation and elevated regional industrial structures (Xu et al., 2022). These factors have compelled individual countries to advocate for the deep incorporation of digitalization, especially in crucial sectors such as energy. In this sector, digitalization fosters the possibility of data paradigms and offers novel concepts for solving problems and seeking solutions for economic recovery (Fuerst et al., 2023). Digital technologies, such as smart grids and IoT-enabled devices, are crucial in efficiently managing these decentralized energy systems. Other technologies include energy storage optimization, digital twins for grid simulations, and AI-driven energy forecasting, which were all spurred by the crisis. These innovative solutions can alleviate vulnerabilities and guarantee stable operations during geopolitical tensions (Hoang et al., 2021).

The energy sector constitutes one of the most dynamic industries characterized by constantly changing dynamics and the integration of novel practices and parameters (Serban & Lytras, 2020). For instance, global warming is compelling nations within the EU and across the globe to adopt new forms of energy. The list of new practices within the energy sector is constantly growing as the pressure of global warming compounds. Also, the need to achieve efficiency when integrating these new energy sources and mechanisms is starting to emerge (Mhatre et al., 2021). Despite the efforts to integrate new alternative sources and approaches, the energy sector is still experiencing significant challenges (Serban & Lytras, 2020). According to Mhatre et al. (2021), limited capacity to forecast demand, increasing manufacturing costs, global politics, and regulatory limitations affect the energy markets effectively. Similarly, Al-Shetwi (2022) outlines environmental concerns, the effects of the rise in carbon dioxide emissions, and geopolitical and geo-economic challenges that are significant to the energy market.

To mitigate these challenges, Serban and Lytras (2020) argue that innovative sets of practices in the energy sector are emerging and evolving through multiple channels, including digitalization (Serban & Lytras, 2020). These ties are based on digital methods and media, founded on big data, AI, IoT, and blockchain technologies (Trzaska et al., 2021). Using these technologies, energy sector players have innovative and ambitious objectives, such as building a single data field that embeds a single conceptual model of the whole power system and a single metamodel that provides the means for communication (Trzaska et al., 2021). Another objective involves creating a new, digital, network-oriented, distributed data storage system proven to ensure the manageability and traceability of objects in the electric power industry (Xu et al., 2022).

Another significant change in the energy sector due to digital transformation involves creating an informative and reliable electronic system for the electric power industry to exchange technical information in real-time, but keep secret commercial and/or production information (Ren et al., 2021). Moreover, there is a new structure in electrical technology called the Internet of Energy. In the Internet of energy, the prosumers of energy cooperate in a complex system and share electricity, power, and energy (De Dutta & Prasad, 2020). These systems employ consumer-end devices with energy consumption management functions, distributed generation, and storage systems at the consumer end of the low or medium-voltage network or nearby areas (De Dutta & Prasad, 2020). Furthermore, the term ‘smart city’ has been associated with the extensive incorporation of ICTs in delivering comprehensive value-added services to citizens through integrating data from many disciplines, including the energy sector (Hossein et al., 2020).

Smart utilities in digital cities are helping to develop better and more sustainable living structures (Strielkowski et al., 2021). Multiple large economic countries are leading in integrating smart energy meters, home automation systems, and behavior-based power usage monitoring (De Dutta & Prasad, 2020). As more utility systems of electrification, decarbonization, and decentralization emerge, energy systems are being integrated within municipal or regional systems. In addition, innovative management of energy infrastructure may increase the quality of life in large cities worldwide (Hainoun et al., 2022; Ige et al., 2024).

The data consumption that translates into large-scale energy generation is fueling the smart grid, which, combined with information technology advancement, is driving the digitization of energy systems. Innovations and discoveries made from big data are altering the historic energy industry models (Ahmad et al., 2022). The nature of the inevitable technological evolution of the electrical power system to the next-generation smart grid (SG) method has placed smart grids high on the list of respected as well as significant areas of research and development. ICT integrates into power grid systems to employ SG, leveraging digital and information communication technologies that support both power flow and two-way communication, which can enhance the power systems' reliability, efficiency, and security (Rangel-Martinez et al., 2021).

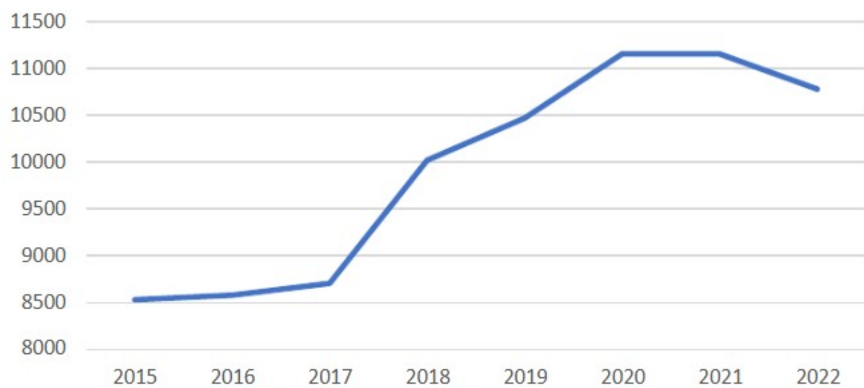
Thus, digitalization is an essential factor in the transformations experienced in the energy sector. It has enabled the management of large amounts of data and optimized sophisticated systems (Ahmad et al., 2022). In the energy sector, digitalization involves the facilitation of the conversion of data into value. The increasing significance of digitalization in this sector is an effect of advancements in two other innovation trends: electrification and decentralization. Decentralization is fronted by the rising deployment of small renewable sources like solar panels connected to the distribution grid. The electrification of transport, heating, and cooling in buildings entails large quantities of new loads like heat pumps, electric vehicles, and electric boilers (Ahmad et al., 2022). These new elements on the supply and demand sides are increasing the complexity in the energy sector. This implies monitoring, control, and management are essential for energy success.

Despite the increasing integration of digital transformation within the energy sector, various challenges still emerge. Ahmad et al. (2022) establish that digital transformation results in significant challenges, including infrastructure limitations, cybersecurity risks, regulatory barriers, constraints, and issues associated with data management. The existing energy systems depend on traditional components; therefore, modernization requires considerable investment. Cybersecurity risks and data management have also emerged as significant limitations of digital transformation (Ghelani, 2022). The increasing connection among the energy systems poses substantial risks, including heightened susceptibility to cyberattacks, breach of data, and system vulnerabilities.

As a result of the increasingly significant impact of digitalization on energy, researchers have developed a considerable interest in the energy economy field (Xu et al., 2022). The researchers have evaluated the link between digitalization and energy in a specific country or economy. However, existing studies on this association between digitalization and energy offer conflicting evidence. Some studies opine that the development of digitalization has significantly reduced the energy demand. Others suggest that digitalization has promoted economic demand, consequently increasing energy demand. Of note is that early researchers in this field highlighted some novel perspectives that digitalization and energy do not have a simple linear relationship (Xu et al., 2022). Therefore, looking into the reasons for this conflicting evidence is appropriate. It entails evaluating whether the existing measurement methods are not harmonized, whether the research studies have been focused on different energy aspects, or whether the impact is different for other countries or regions.

2.2 Technological Innovations in Digital Energy Systems

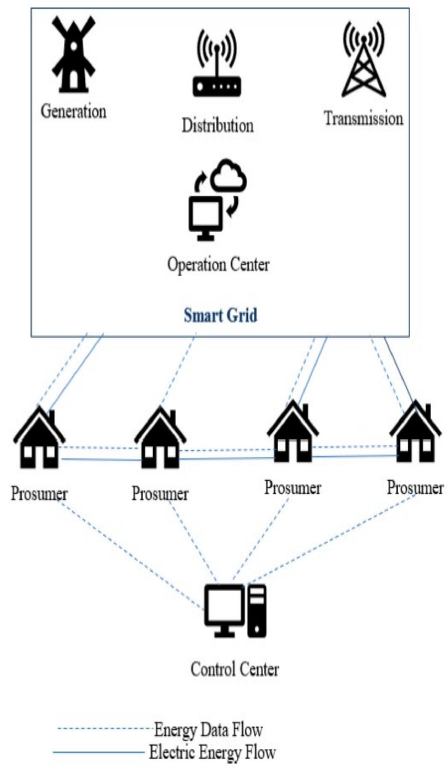
Despite the significant challenges brought by digitalization in the energy sector, expenditures on digital technologies have significantly increased in the past decade. Between 2015 and 2022, global spending on digital technologies increased from 8529 million USD to 10780 million USD as depicted in Figure 2 (Nazari & Musilek, 2023). This expansion was reflected in multiple components of the energy sector, including renewable energy, smart grids, big data analytics, and IoT.



Source (Nazari & Musilek, 2023).

Figure 2: Energy Sector Digital Technologies Spending Between 2015 and 2022

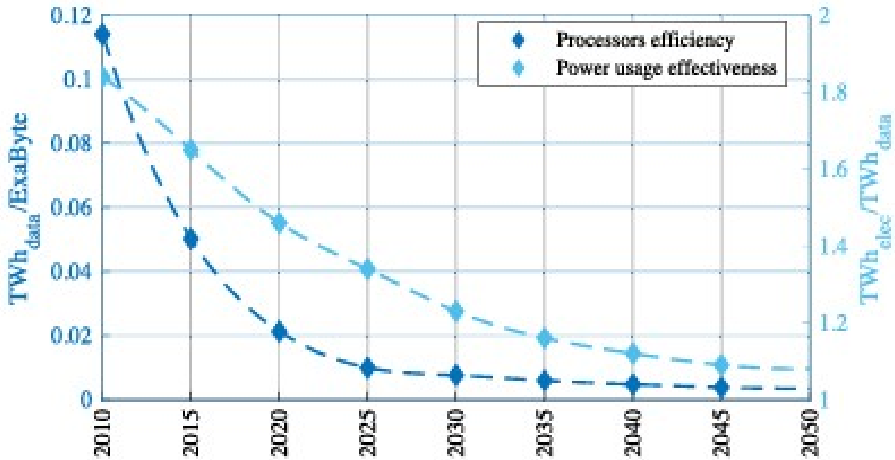
A smart grid means the data collected includes information on generation, transmission, distribution, and power consumption. The smart grid, as Figure 3 depicts, is an intellectual power storage system that has information storage attributes besides energy storage. Its electrical information data included currents from meters, data from distribution and switch stations, regions' economy, weather, and marketing (Rathor & Saxena, 2020). Identifying optimal solutions for addressing the requirements and challenges of power system infrastructure is the primary focus of a smart grid. It achieves this via cybersecurity, distributed energy resources, automated distribution, advanced metering infrastructure, and demand response (Kamran, 2022).



Source: Anthony et al. (2020).

Figure 3: Smart Grid Overview

A smart grid generates a wide range of benefits, including improved grid efficiency and reliability, reduced carbon footprint, and enhanced integration of renewable energy. Utility companies can achieve greater grid transparency and have more influence over the power system, which enhances control and planning. In general, smart grids are essential since they change and improve the power industry, thus making energy more sustainable and robust in the future (Dileep, 2020). In addition, Li et al. (2023) establish that applying digital tools to elements such as electricity and creating novel systems such as smart grids would result in a robust increase in energy and process efficiency, as depicted in Figure 4.



Source: (Li et al., 2023).

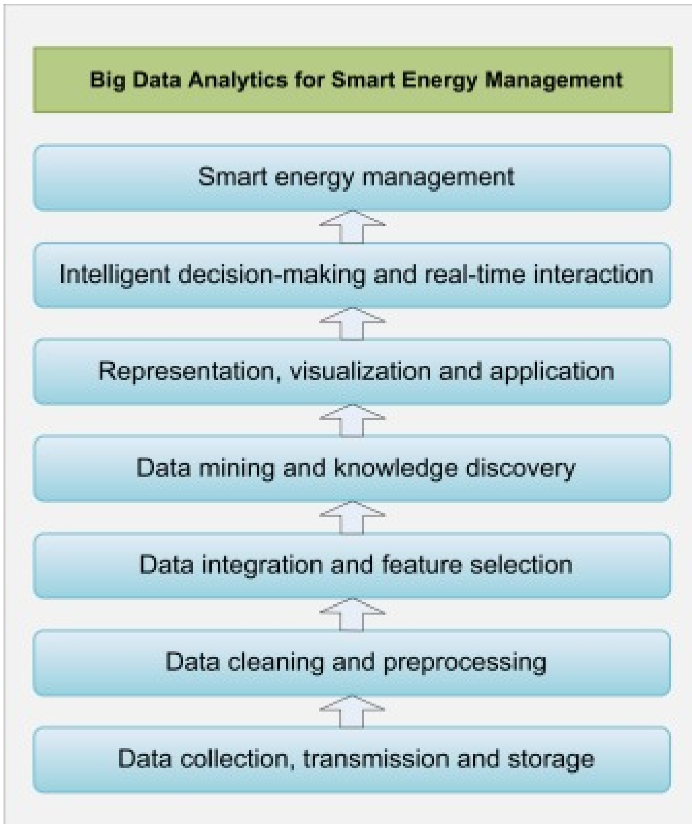
Figure 4: Increase in Energy and Process Efficiency due to Digital Technologies

The concept and modeling of big data involve extracting intelligence and making statistically informed decisions based on massive and inherently complex data. The word ‘modeling’ typically refers to creating and deploying mathematical and statistical models to analyze and predict various aspects of big data when applied in this setting. They tested it using traditional methods of data collection and analysis. As the authors found out, such methods could prove inadequate in handling big data due to the volumes, velocities, and varieties it possesses. Typically, three components are at the base of big data ideas: volume, velocity, and variety (Wu, 2021).

Businesses use data mining, statistics, machine learning, and other predictive modeling techniques to model large numbers. Since it allows them to gain insight into their competitors, these models can be used to identify patterns and correlations in business data. In modeling extensive data, several phases include data preparation, feature engineering, model selection, training, and assessment. One requires inevitable exposure to distributed computing frameworks like Apache Spark or Apache Hadoop, handling big data and top-notch analytics. It is crucial to optimize customers' actions, market tendencies, operational performance, risk management, and other needs to be enhanced by well-modeled big data. With this knowledge, it is possible to understand high-risk situations better and manage systems more efficiently (Yang et al., 2020).

Regarding managing energy systems, “smart energy management based on analytical big data” means using progressive data analysis tools to identify trends, increase usage amounts, and make decisions. In the innovative world, several types of big data, such as smart meters, weather sensors, energy grids, etc., are available that organizations can use to analyze energy utilization, identify issues, and optimize consumption (Marinakis et al., 2020).

Innovative energy management uses analytical tools to manage energy distribution networks, schedule maintenance, control, monitoring, and demand response control. Every stakeholder, be it the consumers, utilities, or businesses, is in a position to get that much-needed vantage point for their energy use habits to help them minimize costs and the environment. Big data for energy resources can help organizations attempt to save energy, produce energy, and control their energy loads by identifying patterns, trends, and anomalies in their energy usage. Figure 5 illustrates the seven strategic activities that comprise the intelligent energy management category related to big data. These innovative energy management approaches assist in improving the operation and overall efficiency, reducing further carbon emissions, and paving the way towards the transition to cleaner energy (Marinakis et al., 2020).



Source: Zhou (2016).

Figure 5: Big Data-Driven Smart Energy Management Process Model

An analysis of the research results carried out by other studies concerning the degree of implications of digitalization in the energy realm is provided in the table 2:

Table 2: Summary Research on Implications of Digitalization

Author(s)	**Aim of the Research**	**Research Methods**	**Sample Size**	**Research Results**
Serban & Lytras (2020).	Explore the role of AI in transforming energy	Review paper, literature analysis	40 articles reviewed	AI improves grid stability, lowers operational costs, and increases

	infrastructure, focusing on smart grids, predictive maintenance, and renewable integration.			energy efficiency. However, data access and cybersecurity are challenges.
Mhatre et al. (2021).	Analyze the implementation of Circular Economy (CE) practices in the EU, focusing on the framework of circular strategies.	Systematic literature review	108 papers reviewed	Recycling is the most used CE strategy; government policies and infrastructure are key to transitioning to CE.
Ali Q. Al-Shetwi (2021)	Discuss the integration of renewable energy (RE) into the power grid and its environmental,	Literature review,	177 papers analyzed	RE integration benefits sustainability but brings operational challenges; more focus on

	economic, and technical impacts.			mitigating harmful impacts is needed.
Trzaska, R. et al. (2021)	Propose a theoretical model combining digital strategies and business models for digital transformation in the energy sector.	Quantitative analysis, secondary data from Eurostat	All EU member states	Uncertainty in energy sector organizations is more related to employees' technical skills than ICT implementation.
Ren et al. (2021)	Study how internet development influences energy consumption in China and its associated transmission mechanisms.	Empirical analysis, evaluation system	18 articles reviewed	Internet development positively impacts energy consumption, but helps reduce energy consumption intensity through economic growth.

De Dutta, S., & Prasad, R. (2020)	Discuss the role of blockchain in managing energy data in smart grids and microgrids for sustainable urban energy solutions.	Conceptual framework, literature review	21	Blockchain secures microgrid data and allows prosumers to sell renewable energy back to the grid, enhancing smart city energy security.
Hossein Motlagh et al. (2020)	Review the role of IoT in energy systems, focusing on its application in smart grids, renewable energy integration, and optimization.	Literature review	14	IoT improves energy efficiency, increases renewable energy share, and optimizes energy systems, with blockchain helping address privacy issues.
Strielkowski et al. (2021)	Analyze the role of renewable	Literature review	71	Renewable energy aids

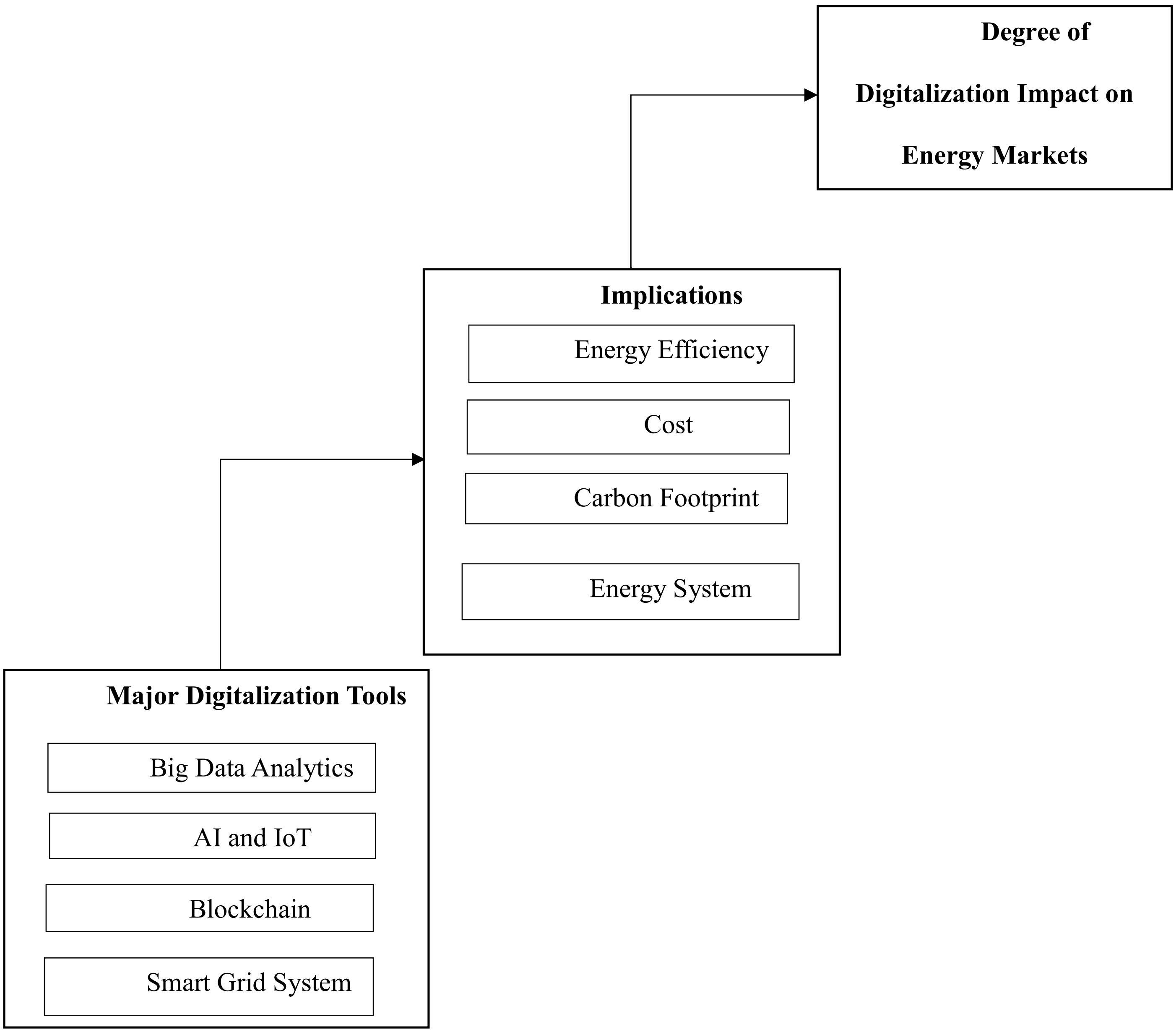
	energy in the sustainable development of the electrical power sector.			decarbonization, enhances grid stability, and promotes energy sustainability but requires careful management.
Ige et al. (2024)	Examine cybersecurity challenges in renewable energy, proposing solutions using AI and international cooperation.	Systematic literature review, content analysis	100 articles reviewed	Cybersecurity risks in renewable energy require tailored defense strategies, with AI and international cooperation as key solutions.
Ahmad et al. (2022)	Explore the use of machine learning (ML) in optimizing energy distribution and	Data-driven analysis, case studies	3 case studies reviewed	ML optimizes decision-making in energy distribution, with potential savings of up to $813

	its role in smart energy systems.			billion through automation and optimization.
Rangel-Martinez et al. (2021)	Investigate machine learning applications in renewable energy, smart grids, and energy management.	Literature review, algorithm analysis	12 articles reviewed	ML techniques, particularly artificial neural networks, play a central role in sustainable energy management, especially in data handling and safety.
Xu et al. (2022)	Study the impact of digitalization on energy consumption and intensity from an international perspective.	Empirical analysis, international comparison	60 countries studied	Digitalization significantly reduces energy consumption and intensity, more substantially impacting low-income countries.

Source (Written by Author)

2.3 Research Model on the Digitalization Impact on Energy Markets

Research Model Description. Based on the findings from other studies, the research model of this study is deduced and established in Figure 6:



Source: (Written by Author)

Figure 6: The Research Model

The first phase of the model constitutes the digitalization tools that have emerged and played an essential role, including big data analytics, IoT, AI, and smart grid systems. These systems affect the energy market system in terms of costs, efficiency, carbon footprint, system reliability, and risks. The degree of these impacts is then determined.

Digitalization impacts multiple segments of the energy market. These aspects include demand forecasting accuracy, energy trading efficiency, renewable energy integration, smart energy, and consumer engagement and integration. To profoundly analyze these implications, variables are categorized into independent, dependent, and moderating. This is critical in postulating the relationships between the digital enablers and primary energy sector outcomes. The independent variables included in the study entail grid implementation, big data analytics, blockchain technology, AI, and IoT. These are the key enablers that accelerate digital transformation within the energy market. On the other hand, the dependent variable involves energy efficiency, cost reduction, carbon footprint, and improved grid reliability. Subsequently, the significant moderating variables constitute regulatory policies, cybersecurity measures, data security risks, and market and government regulations. These factors are essential in seamlessly integrating and managing digitalization in energy systems. The hypotheses involved constitute:

H1: Digitalization enhances the accuracy of energy demand forecasting.

H2: Digitalization enhances energy trading.

H3: Digitalization enhances energy distribution and transmission.

H4: Digitalization enhances energy systems and infrastructure reliability.

H5: Digital tools simplify the integration of novel energy sources and practices, Including renewable energy.

H6: Digitalization reduces market entry barriers for new players within the market.

H7: Digitalization accelerates progress toward sustainability goals in the energy sector.

H8: Digitalization could result in various risks, including data security risks.

Survey Methodology. One hundred participants were selected and took part in the study. The participants chosen for the study included energy market analysts, digitalization and smart grid experts, policy-makers and regulators within the energy sector, and technology providers specializing in digital energy solutions. These participants were selected using the purposive sampling approach. Purposive sampling, also known as judgmental or selective sampling, is a non-probability sampling technique where participants are chosen intentionally based on their specific characteristics or knowledge relevant to the research question. This ensured the selection of different stakeholders in the energy sector, and thus, the study collected diversified perspectives on digitalization's impact on the energy sector. The survey involved multiple-choice questions and Likert-scale questions. This allowed for gathering opinions on digital tools, energy paradigms, renewable energy, and the relationship between cybersecurity and sustainability in the energy sector.

The survey was designed to capture quantitative insights to investigate the question under investigation comprehensively. This enabled a balanced representation of perspectives, enhancing the richness and accuracy of the data collected and, subsequently, the study results. In addition, incorporating diverse clusters of stakeholders and players enhanced the survey and ensured it offered valuable insights associated with the degree of impact of digitalization. The data collection tool focused on significant themes, including the efficiency of digital tools in the energy sector, including energy forecasting, challenges associated with advanced digital energy technologies such as smart grids, and the role and degree of influence of novel digital technologies such as AI on the energy market and practices such as predictive maintenance.

Combining the Likert-scale and multiple-choice questions enabled statistical analysis and trend interpretations. This allows the study to support a well-rounded evaluation of the role of digitalization in the energy sector.

2.4 Conclusion

The energy sector constitutes one of the most dynamic industries characterized by constantly changing dynamics and the integration of novel practices and parameters. This dynamic nature results in significant challenges. Understanding these challenges requires formulating a research model with three associated variables: independent, dependent, and moderating variables. One hundred participants were selected using a purposive sampling approach and participated in the study. The participants provided critical insights, which were analysed to draw conclusions.

3. EMPIRICAL RESEARCH ON THE IMPLICATIONS OF DIGITALIZATION ON ENERGY MARKETS

This chapter provides the research methods, data analysis, and discussion and evaluation of the findings.

3.1 Research Methods

Aim of the research – to analyze the influence of digitalization on the structural, economic, and operational dynamics of the energy market by examining its impact on efficiency, cost savings, transparency, and sustainability while considering the role of smart grids, big data, and digital tools.

Objectives of the thesis: The study had four objectives. The first objective involved examining the role of digitalization in enhancing energy demand forecasting accuracy and market efficiency. The second objective constituted assessing the impact of advanced digital technologies on transforming energy market paradigms. Also, the study aimed to evaluate the challenges and opportunities of digitalization in the energy sector transformation and analyze the contribution of digitalization to sustainability goals, including renewable energy integration.

Research methods and hypotheses. This study implemented a quantitative method. The quantitative method enables a researcher to focus on quantifying data collection and analysis (Mellinger et al., 2023). Therefore, it allows the researcher to utilize numerical and statistical methods over observations and opinions (Mellinger et al., 2023). A quantitative approach was selected to explore the statistical implications of digitalization on energy markets.

A questionnaire was administered to 100 respondents, who were selected using purposive sampling. Purposive sampling involved a non-probability sampling technique in which participants were chosen intentionally based on their specific characteristics or knowledge relevant to the research question. The selected participants included energy market analysts, digitalization and smart grid experts, policy-makers and regulators within the energy sector, and technology providers specializing in digital energy solutions. The purposive selection of this group was critical in ensuring that the data collected reflected informed perspectives and expert insights into the intersection of digitalization and the energy market. By targeting individuals with specialized knowledge and experience, the research aimed to obtain high-quality, relevant information that would contribute to a deeper understanding of how digital technologies shape the sector's structural, economic, and operational transformations. This approach also enhanced the credibility and applicability of the findings to real-world energy market challenges and opportunities.

The research data were collected using a questionnaire survey method provided in Appendix 1. This questionnaire was developed based on a comprehensive review of existing literature on the implications and role of digitalization in the energy market. The extensive review identified major themes: digital infrastructure, market efficiency, sustainability, AI, IoT, data analytics, and smart grid technologies. These central themes were then conveyed into measurable constructs, resulting in the formulation of the initial questions. Subsequently, the draft questionnaire was reviewed by a subject matter expert in energy policy and digital technologies. Feedback provided by the experts was then integrated, and the final questions were established. This ensured the questions were valid, relevant, credible, and transparent. However, various limitations could emerge. These include potential response bias, the possibility of limited generalizability due to purposive sampling, and the possibility of interpretation variance among respondents.

The collected data was analyzed using quantitative methods, consisting of closed-ended questions with predefined response options, enabling numerical data collection and statistical interpretation. The responses were quantified and analyzed using descriptive statistics, such as frequency distributions, percentages, and mean values, to identify trends and patterns in the impact of digitalization on the energy sector. The questionnaire was developed to test the eight hypotheses. These hypotheses and questionnaire statements assigned to their testing are presented in Table 3.

Table 3: Description of Hypotheses according to Questionnaire

Hypothesis	**Questionnaire Statement**
H1: Digitalization enhances the accuracy of energy demand forecasting.	1. How has digitalization affected the accuracy of energy demand forecasting?
H2: Digitalization enhances energy trading.	2. What digital tool has had the most significant impact on energy trading?
H3: Digitalization enhances energy distribution and transmission.	3. Which area of the energy sector has digitalization benefited the most?
H4: Digitalization enhances energy systems and infrastructure reliability.	7. What role does AI play in predictive maintenance for energy infrastructure? 8. How do digital twins affect the lifecycle management of energy assets? 12. What is the primary advantage of energy storage systems coupled with digitalization? 14. Which factor is most important for

	managing a digitalized energy system?
H5: Digital tools simplify the integration of novel energy sources and practices, including renewable energy.	5. How does digitalization influence renewable energy integration into the grid? 11. How critical is digitalization for advancing electric vehicle (EV) infrastructure? 12. What is the primary advantage of energy storage systems coupled with digitalization?
H6: Digitalization reduces market entry barriers for new players within the market.	17. How does digitalization impact energy market entry barriers for new companies?
H7: Digitalization accelerates progress toward sustainability goals in the energy sector.	20. What is the potential impact of digitalization on achieving sustainability goals in the energy sector?
H8: Digitalization could result in various risks, including data security risks.	4. What is the biggest challenge in implementing smart grids? 13. What risk does the digitalization of energy markets pose to data security? 18. What influence does digitalization have on energy market regulations?

3.2 Research Data Analysis

The survey findings were analysed using descriptive statistics. The SPSS tool was used for the quantitative analysis. The results were presented visually in tables, as demonstrated in the next section.

3.3 Analysis of Survey Findings

This section presents data analysis based on 100 responses from a survey examining the impact of digitalization on the energy market. Data collection, sorting, cleaning, and subsequent analysis were performed using two software programs: Microsoft Excel and IBM SPSS. Table 4 presents the descriptive analysis, which depicts the mode outcome obtained from each survey question.

Table 4: Descriptive Statistics

Descriptive Statistics: Mode

	N		
	Valid	Missing	Mode
Q1	100	0	Greatly improved accuracy
Q2	100	0	Blockchain
Q3	100	0	Generation
Q4	100	0	Technological complexity
Q5	100	0	Simplifies it
Q6	100	0	More volatile
Q7	100	0	Crucial role
Q8	100	0	Substantially reduced consumption
Q9	100	0	Significantly improves engagement
Q10	100	0	Greatly extend the lifecycle
Q11	100	0	Cost reduction
Q12	100	0	Advanced analytics
Q13	100	0	Lowers barriers significantly
Q14	100	0	Greatly accelerates progress towards goals
Q15	100	0	Highly critical for system optimization
Q16	100	0	Requires new regulatory frameworks

Q17	100	0	Cost reduction
Q18	100	0	Increase employment opportunities
Q19	100	0	High risk
Q20	100	0	Absolutely critical

The descriptive analysis of the survey responses highlights the significant trends in how digitalization impacts the energy markets. The mode represents the response selected most frequently for each survey question. Therefore, portraying the most profound perspectives. According to the analysis, the respondents identified "greatly improved accuracy" as the primary effect of digitalization on energy demand forecasting. Also, the respondents established that “blockchain” is the most impactful tool in energy trading. The biggest challenge in integrating smart grids was “technological complexity.” Furthermore, “more volatile” connoted a prevailing response regarding market stability. Thus, these findings highlight the critical role of digitalization in transforming energy infrastructure, regulatory frameworks, and employment opportunities. Further descriptive analysis of the outcome is provided in Appendix 2.

Since the data was not normally distributed, non-parametric tests that made minimal assumptions about the underlying distribution were first utilized to analyze the results. Under the first objective, the study aimed to understand the implications of digitalization on energy markets, including accuracy and efficiency. This analysis included a one-sample Wilcoxon test on the question, “How has digitalization affected the accuracy of demand forecasting?” The null hypothesis was established at a median of 3 with a value label of “No significant change.” The hypothesis test summary is shown in Table 5.

Table 5: Summary of Hypothesis

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The median of How has digitalization affected the accuracy of energy demand forecasting? equals 3.	One-Sample Wilcoxon Signed Rank Test	<.001	Reject the null hypothesis.
a. The significance level is .050.				
b. Asymptotic significance is displayed.				

The test statistic (W) was = 227.5, and the Standardized Test Statistic (Z) was = -6.454. Subsequently, the p-value was < 0.01, deducing that the null hypothesis should be rejected ($p < .05$). The negative Z-score portrays that the observed median was less than 3, therefore indicating that the respondents overwhelmingly rated digitalization's impact on accuracy as better than 'no significant change,' as portrayed in Figures 7 and 8.

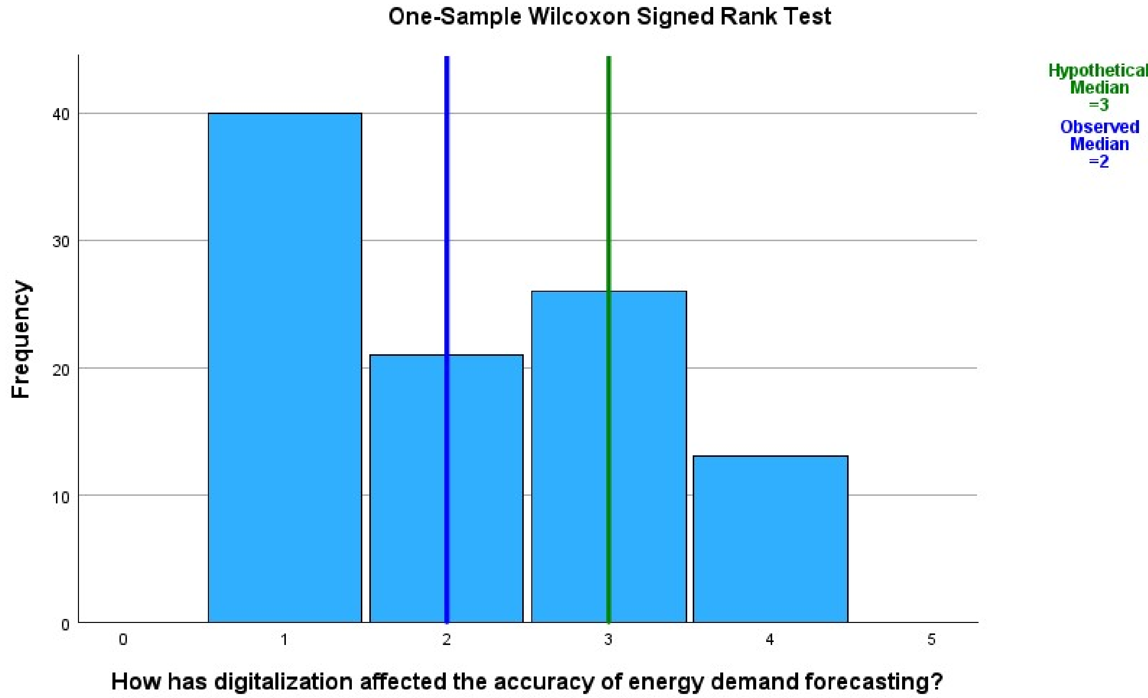


Figure 7: The hypothetical and observed median of the one-sample Wilcoxon

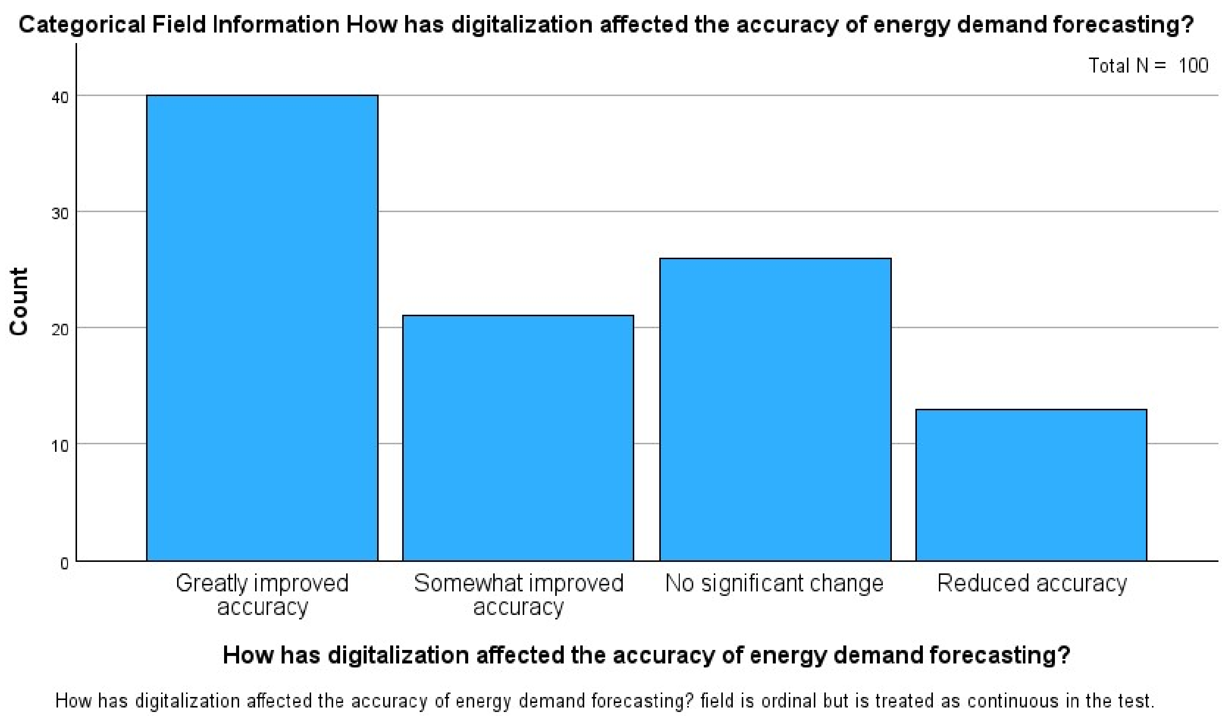


Figure 8: Categorical Field Information on the Implication of Digitalization on Energy

To describe the relationship between two categorical variables, a special form of analysis known as cross-tabulation was employed. In this analysis, the categories of one variable, the digital tool, determined the row of the table, while the categories of the other variable, implications of digital tools in terms of volatility, determined the columns. The cross-tabulation between the two variables is depicted in Table 6.

Table 6: Cross-tabulation of Digital Tools and Market Volatility

What digital tool has had the most significant impact on energy trading? * Has digitalization made energy markets more or less volatile? Crosstabulation							
			Has digitalization made energy markets more or less volatile?				Total
			More volatile	Less volatile	No significant change	Volatility is influenced by other factors	
What digital tool has had the most significant impact on energy trading?	Blockchain	Count	8	3	9	13	33
		Expected Count	10.2	2.0	7.3	13.5	33.0
		% within What digital tool has had the most significant impact on energy trading?	24.2%	9.1%	27.3%	39.4%	100.0%
		% within Has digitalization made energy markets more or less volatile?	25.8%	50.0%	40.9%	31.7%	33.0%
	Artificial Intelligence (AI)	Count	3	0	2	5	10
		Expected Count	3.1	.6	2.2	4.1	10.0

		% within What digital tool has had the most significant impact on energy trading?	30.0%	0.0%	20.0%	50.0%	100.0%
		% within Has digitalization made energy markets more or less volatile?	9.7%	0.0%	9.1%	12.2%	10.0%
	Internet of Things (IoT)	Count	9	2	5	10	26
		Expected Count	8.1	1.6	5.7	10.7	26.0
		% within What digital tool has had the most significant impact on energy trading?	34.6%	7.7%	19.2%	38.5%	100.0%
		% within Has digitalization made energy markets more or less volatile?	29.0%	33.3%	22.7%	24.4%	26.0%
	Big Data Analytics	Count	11	1	6	13	31
		Expected Count	9.6	1.9	6.8	12.7	31.0
		% within What digital tool has had	35.5%	3.2%	19.4%	41.9%	100.0%

		the most significant impact on energy trading?					
		% within Has digitalization made energy markets more or less volatile?	35.5%	16.7%	27.3%	31.7%	31.0%
Total		Count	31	6	22	41	100
		Expected Count	31.0	6.0	22.0	41.0	100.0
		% within What digital tool has had the most significant impact on energy trading?	31.0%	6.0%	22.0%	41.0%	100.0%
		% within Has digitalization made energy markets more or less volatile?	100.0%	100.0%	100.0%	100.0%	100.0%

From the cross-tabulation table, a Chi-Square test of independence was then performed, with the independent variable being digital tools and the dependent variable being the market volatility outcome. The Chi-square analysis outcome is provided in Table 7.

Table 7: Chi-square Analysis Digital Tools and Market Volatility

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3.337[a]	9	.949
Likelihood Ratio	3.930	9	.916
Linear-by-Linear Association	.331	1	.565
N of Valid Cases	100		
a. 7 cells (43.8%) have expected countless than 5. The minimum expected count is .60.			

The Chi-square analysis found no significant relationship between digital tools and market volatility (p = .949). Nevertheless, this analysis shows significant limitations due to the small expected counts. Cramer's V (Effect Size) showed a weak association (V = 0.105), indicating a negligible effect, as depicted in Table 8 (0.1 = Small effect, 0.3 = Medium effect, >0.5 = Large effect). However, the initial descriptive trends depict that Big Data users report more volatility, while Blockchain users attribute volatility to external factors, as portrayed in Figure 9.

Table 8: Cramer's V Analysis of Digital Tools and Market Volatility

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	.183	.949
	Cramer's V	.105	.949
N of Valid Cases		100	

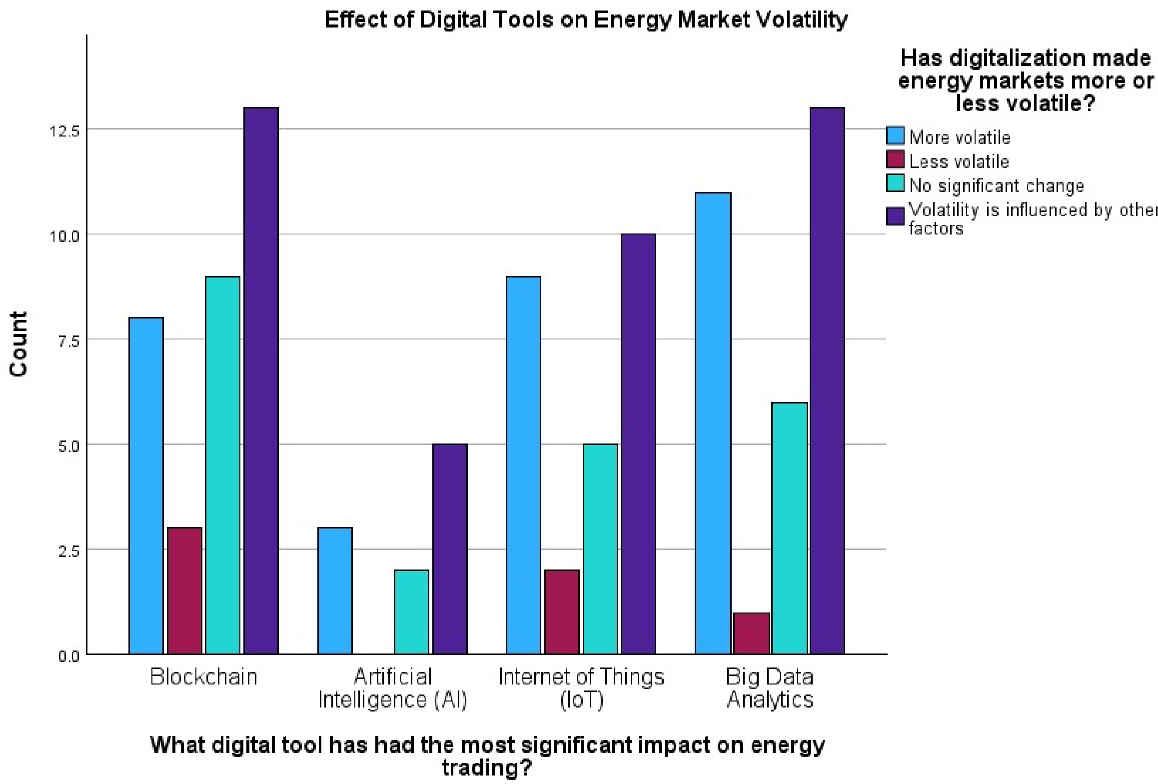


Figure 9: Descriptive Relationship between Digital Tools and Market Volatility

Furthermore, the Chi-square analysis revealed no significant relationship between energy sectors (Q3) and perceived market entry barriers (Q17), $p = 0.804$, Cramer's $V = 0.13$. The weak effect size confirms the minimal practical significance. On the other hand, a significant association was found between risk perception (Q13) and (Q14), $p < 0.001$, with a moderate to strong effect ($V = 0.41$), as depicted in Table 9. The respondents who perceived a "high risk" prioritized "cybersecurity measures," while those who reported "no risk" undervalued cybersecurity, as depicted in Figure 10.

Table 9: Digitalization and Market Entry

Hypothesis	Variables	χ^2	df	p-value	Cramer's V	Key Finding Summary
H6	Q17 × Q3	5.334	9	0.804	0.133	No significant sector differences in barriers
H8	Q13 × Q14	50.550	9	<0.001	0.410	Strong link: high risk perception → Cybersecurity priority

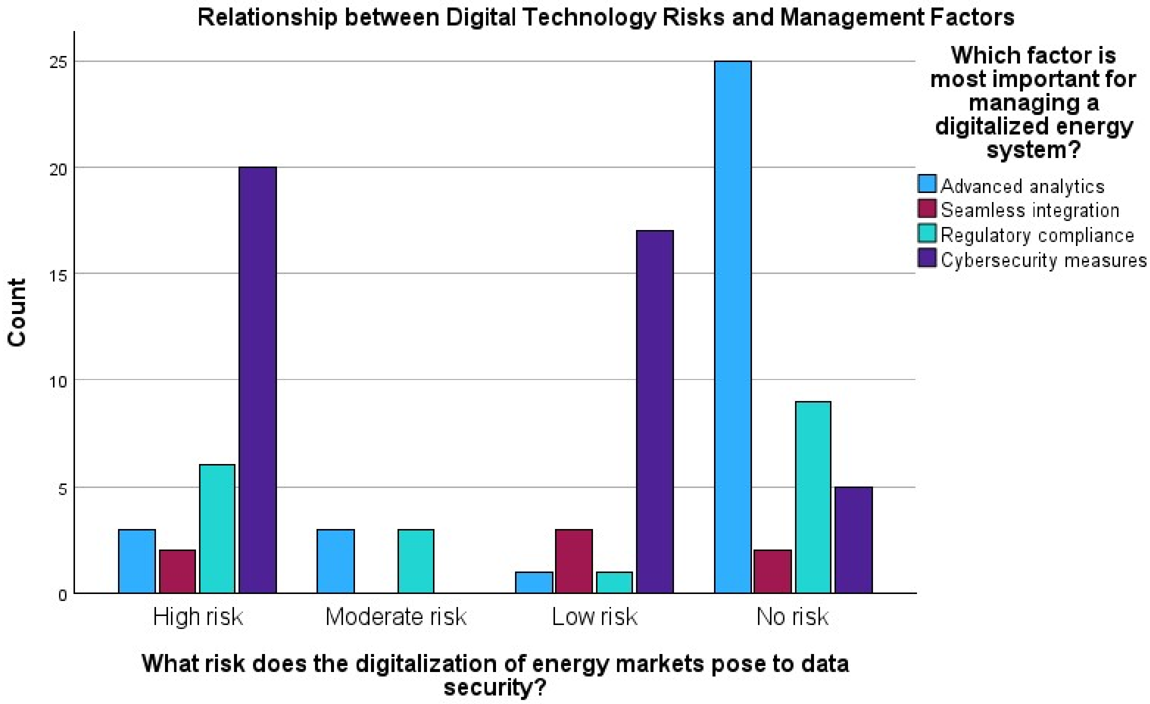


Figure 10: Relationship between Digital Technology Risks and Management Factors

Spearman's correlation was performed to test whether digitalization enhances energy systems and infrastructure reliability. The variables that were used constituted the role of AI in predictive maintenance and the implications of digital twins on lifecycle management. The outcome of Spearman's correlation is portrayed in Table 10.

Table 10: Implications of digitalization on energy systems and infrastructure reliability

Correlations		
	What role does "AI" play in predictive maintenance	How do digital twins affect the lifecycle management

			for energy infrastructure ?	of energy assets?
Spearman's rho	What role does “AI” play in predictive maintenance for energy infrastructure?	Correlation Coefficient	1.000	-.336**
		Sig. (2-tailed)	.	<.001
		N	100	100
	How do digital twins affect the lifecycle management of energy assets?	Correlation Coefficient	-.336**	1.000
		Sig. (2-tailed)	<.001	.
		N	100	100
**. Correlation is significant at the 0.01 level (2-tailed).				

According to the analysis, the p-value of -0.336 indicates a negative correlation. This means that AI’s perceived importance increased. The effect size was also moderate, portraying the reliability of the data. The respondents who perceived AI as critical in maintaining energy systems also reported that digital twins significantly enhanced asset lifecycles.

Additionally, Spearman’s correlation analysis revealed that digitalization accelerates sustainability goals, such as adopting renewable energy. There was a positive correlation between digitalization and renewable energy, which improved sustainability. As depicted in Table 11, p = 0.367 ($p < 0.001$), indicating a positive correlation.

Table 11: Digitalization and Sustainability Goals

Correlations					
			What is the potential impact of digitalization on achieving sustainability goals in the energy sector?	How does digitalization influence renewable energy integration into the grid?	What is the primary advantage of energy storage systems coupled with digitalization?
Spearman's rho	What is the potential impact of digitalization on achieving sustainability goals in the energy sector?	Correlation Coefficient	1.000	.367**	.050
		Sig. (2-tailed)	.	<.001	.624
		N	100	100	100
	How does digitalization influence renewable energy integration into the grid?	Correlation Coefficient	.367**	1.000	.181
		Sig. (2-tailed)	<.001	.	.071
		N	100	100	100

	What is the primary advantage of energy storage systems coupled with digitalization?	Correlation Coefficient	.050	.181	1.000
		Sig. (2-tailed)	.624	.071	.
		N	100	100	100
**. Correlation is significant at the 0.01 level (2-tailed).					

Hypothesis 1: Digitalization enhances the accuracy of energy demand forecasting. According to the research analysis, digitalization significantly improves the accuracy of the energy markets, including in demand forecasting. As depicted in Table 4 and Figures 7 and 8, using the one-sample Wilcoxon analysis approach, digitalization is shown to have a significant impact on energy paradigms. These findings align with various literature, including the study by Weigel and Fischedick (2019), which establishes that digitalization tools such as AI and ML are critical in enhancing energy forecasting, including energy demand and price, and energy security paradigms. To maximize efficiency and minimize waste, artificial neural networks (ANNs) learn by analyzing historical data and alter power production based on those analyses (Mahmood et al., 2024). Additionally, Galperova and Mazurova (2019) establish that the advancements in Information and communication technologies further elevate this capability. These benefits and utility have prompted different countries, including the US, the UK, the European Union, and China, to focus on integrating digital tools such as AI into their energy markets and systems.

Hypothesis 2: Digitalization enhances energy trading. From the analysis, this hypothesis was accepted. This hypothesis was tested by examining whether the choice of digital tool affected market volatility. Even though the Chi-square analysis found no significant relationship between digital tools and market volatility, the descriptive trend from the cross-tabulation depicted that tools such as Blockchain had a significant impact on energy trading. Also, Big Data users reported more volatility (35.5%). Blockchain-based peer-to-peer (P2P) energy trading platforms are profoundly impacting energy systems. These systems, through the use of distributed ledger technology of blockchain, allow for safe and transparent energy trades directly between generators and consumers (Kumar, 2024). P2P trading networks are decentralized, so everyone is on equal footing and does not need a central authority to conduct energy transactions with each other. The blockchain technology records all transactions, from production to consumption, in an immutable ledger, ensuring they remain open. With the integration of smart contracts into the P2P systems, it will be possible to perform real-time settlements and eliminate central authorities (Kumar, 2024) due to the automation of agreements.

Hypothesis 3: Digitalization enhances energy distribution and transmission. This hypothesis was supported. According to descriptive analysis, 44% of the respondents established that digitalization assisted in energy consumption. However, 22% established that digitalization assisted energy distribution, while 13% outlined that it was critical in energy transmission. According to Aghahadi et al. (2024), digitalization radically alters grid design, operations, energy transmission, as well as distribution and interaction with the market. Supervisory control and data acquisition (SCADA) systems and intelligent electronic devices (IEDs) are technologies that provide a strong foundation for the adoption of more advanced digital solutions in medium voltage (MV) networks by distribution system operators (DSOs) (Aghahadi et al., 2024). Furthermore, the literature by Olson (2024) further supports these assertions by outlining that the influx of digital technologies, including IoT, ML, and AI, is revolutionizing modern energy systems. With this digital transition, electricity is produced, transmitted, and consumed more efficiently, sustainably, and resiliently. A major priority is improving smart grids that rely on intelligent algorithms and data in real-time to optimize grid operations. The energy industry is improving cybersecurity using deep learning and reinforcement learning methods. Deep learning is a master at sifting through massive datasets and looking for patterns and signs of danger. For now, lessons about reinforcement learning can help develop defensive actions that mimic assault situations adaptively (Olson, 2024).

Hypothesis 4: Digitalization enhances energy systems and infrastructure reliability. The analysis supported this hypothesis. According to Spearman's analysis in Table 10, a significant negative correlation was found between the role of AI in predictive maintenance (Q7) and the lifecycle benefits of digital twins (Q8) ($\rho = -0.34$, $p < .001$). This indicated that greater reliance on AI aligns with more substantial perceived benefits from digital twins. This supports H4: Digitalization improves infrastructure reliability. Predictive maintenance is an essential subfield of management that AI technologies are currently revamping (Alqasi et al., 2024). Innovative structures use artificial intelligence to employ intelligent sensors to identify emerging problems and monitor structure health. In contrast, the use of analytics prescribes anticipatory action to avoid the transformation of minor issues into major structural failures. It is possible to reduce the maintenance costs by half, preventing almost 92% of unplanned breakdowns and increasing response times using the proposed predictive maintenance model (Tang et al., 2021). The effectiveness raises the hope that AI methods could optimize the safety and sustainability of urban transport concerning the frequency of unexpected disruptions, resource allocation, and the lifespan of transport structures (Alqasi et al., 2024).

Hypothesis 5: Digital tools simplify the integration of novel energy sources and practices, including renewable energy. This hypothesis was accepted by Spearman's analysis, which showed a positive correlation between renewable energy integration and digital technologies, as depicted in Table 10 and the descriptive analysis, where the mode outcome involved digital energy "simplifies" the integration of energy sources. This aligns with the technological determinism theory, which establishes that technologies constantly result in shifts of existing structures and their replacement of novel approaches and mechanisms (Hallström, 2022). According to the technological determinism perspective, technological developments are primarily responsible for large-scale shifts in social structure (Azman et al., 2020).

Hypothesis 6: Digitalization reduces market entry barriers for new players within the market. The analysis does not support this hypothesis; therefore, it was rejected. As depicted in Table 8, digitalization had no significant impact on market entry, and this finding was consistent across all energy sectors. Nevertheless, literature such as that of Gkrimpizi et al. (2023) and Sivaram (2024) outlines that digitalization in the energy markets increases barriers for new companies, and these barriers are attributable to the immense upfront investment required in advanced technologies for digitization. Consequently, the high costs of obtaining, integrating, and maintaining digital systems can hinder small entrants with limited resources. The nature of digital technologies themselves can explain this outcome. Digital technologies frequently require substantial capital investment, specialized technical expertise, and compliance with complex cybersecurity and data management standards. Currently, established players often possess the resources to absorb these costs and manage regulatory complexities. Nevertheless, new entrants could struggle to compete at similar levels (Sivaram, 2024). In addition, energy markets are highly regulated, and the integration of digital technologies often requires alignment with national grid standards and interoperability protocols. This further raises the entry threshold for new firms. As such, while offering operational improvements, digitalization inadvertently favors existing players over the new parties.

Hypothesis 7: Digitalization accelerates progress toward sustainability goals in the energy sector. Statistical analysis supported this hypothesis, as portrayed in Table 11. Digitalization's impact on sustainability (Q20) significantly correlated with renewable energy integration (Q5) ($\rho = 0.37$, $p < .001$). Nevertheless, this was not the case with energy storage advantages (Q12) ($\rho = 0.05$, $p = .62$). Sustainability is a critical parameter within the energy sector (Światowiec-Szczepańska & Stępień, 2022). According to Światowiec-Szczepańska and Stępień (2022), digital technologies have broad applicability and offer comprehensiveness in efficiency, stability, and sustainability when applied in the energy market.

Hypothesis 8: Digitalization could result in various risks, including data security risks. This hypothesis was accepted since there was a significant association between risk levels and cybersecurity, as depicted in Table 8 and Figure 10. Ahmad et al. (2022) outline that despite the increasing integration of digital transformation within the energy sector, various challenges still emerge, including cybersecurity risks as well as issues associated with data management. The existing energy systems depend on traditional components; therefore, modernization requires considerable investment. Cybersecurity risks and data management have also emerged as significant limitations of digital transformation (Ghelani, 2022). According to Ghelani (2022), the increasing connection among the energy systems poses substantial risks, including heightened susceptibility to cyberattacks, breach of data, and system vulnerabilities.

Interpretation of Findings through Theoretical Lenses: The results of this study profoundly support the instrumentalist perspective of technology. The study's findings consistently established that technological tools, including AI, blockchain, and big data, elevated practices within the energy sector, including improving forecasting, transmission, distribution, and integration of renewable energy sources. Participants outlined that digital tools were integrated to assist in harnessing clear objectives, including efficiency, sustainability, and cost reduction. Therefore, aligning with the instrumentalist perspective that outlines technology connotes components that serve specific ends.

The study's findings also support the technological determinism perspective. Technological determinism focuses on how technology transforms alterations in behaviors, structures as well as policies that are beyond the control of individuals. Technological determinism posits that technology has an enduring effect on human thought processes, behavior, and attitude. The respondents postulated that digitalization has rendered the energy market 'more volatile' and outlined the emergence of significant regulatory challenges and risks associated with data security. These unintended consequences show that digital technologies can trigger autonomous influence on market behaviors. Also, the emergence of elements such as regulations depicts the implications of digital technologies on systematic and institutional changes.

CONCLUSIONS

1. Analysis of the implications of digitalization on the energy markets reveals Critical insights and patterns. As technology advances, digitalization is becoming an important segment of the energy sector. Therefore, it is essential to have a profound understanding of digitalization's role in this sector. Therefore, the major objectives of this study involved:

- To examine the role of digitalization in enhancing energy demand forecasting accuracy and market efficiency.
- To assess the impact of advanced digital technologies on the transformation of energy market paradigms.
- To evaluate the challenges and opportunities of digitalization in the energy sector transformation.
- To analyze the contribution of digitalization to sustainability goals, including renewable energy integration.

2. Analysis of 100 participants who were purposively selected from a pool of Experts in the energy markets and digitalization revealed critical insights into the relationship between energy markets and digitalization. From the analysis, digitalization is essential to enhancing the accuracy of energy demands and practices such as energy trading, distribution, transmission, and sustainability. Digitalization components such as artificial neural networks can maximize efficacy and minimize waste. In addition, blockchain-based peer-to-peer (P2P) energy trading platforms profoundly impact energy systems. Furthermore, systems such as SCADA systems and intelligent electronic devices (IEDs) are technologies that provide a strong

foundation for the adoption of more advanced digital solutions in medium voltage (MV) networks by distribution system operators (DSOs).

Furthermore, the study found that digital tools simplify the integration of novel energy sources and practices, including renewable energy. These findings align with the technological determinism theory, which establishes that technologies constantly result in shifts of existing structures and the replacement of novel approaches and mechanisms. Also, the analysis found that digitalization does not reduce market entry barriers for new players. This is attributed to the high costs of obtaining, integrating, and maintaining digital systems. The study also identified significant risks associated with digitalization integration into the energy markets. The significant dangers included cybersecurity risks, breaches of data, and system vulnerabilities.

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APPENDIX

Appendices 1: Survey Questionnaire

1-How has digitalization affected the accuracy of energy demand forecasting?

a) Greatly improved accuracy

b) Somewhat improved accuracy

c) No significant change

d) Reduced accuracy

2-What digital tool has had the most significant impact on energy trading?

a) Blockchain

b) Artificial Intelligence (AI)

c) Internet of Things (IoT)

d) Big Data analytics

3-Which area of the energy sector has digitalization benefited the most?

a) Generation

b) Transmission

c) Distribution

d) Consumption

4- What is the biggest challenge in implementing smart grids?

a) Technological complexity

b) Cybersecurity threats

c) Regulatory barriers

d) High implementation costs

5-How does digitalization influence renewable energy integration into the grid?

a) Simplifies it

b) Complicates it

c) No significant impact

d) Only beneficial in the long term

6-Has digitalization made energy markets more or less volatile?

a) More volatile

b) Less volatile

c) No significant change

d) Volatility is influenced by other factors

7-What role does "AI" play in predictive maintenance for energy infrastructure?

a) Crucial role

b) Important, but not indispensable

c) Marginal role

d) Unnecessary for maintenance

8-How do digital twins affect the lifecycle management of energy assets?

a) Greatly extend lifecycle

b) Slightly extend lifecycle

c) No impact

d) Shorten lifecycle due to complexity

9-What impact does digitalization have on consumer engagement in energy management?

a) Significantly improves engagement

b) Somewhat improves engagement

c) Negligible effect on engagement

d) Reduces engagement due to complexity

10- How has the emergence of smart homes changed energy consumption patterns?

a) Substantially reduced consumption

b) Slightly reduced consumption

c) No significant change in consumption

d) Increased consumption due to additional devices

11- How critical is digitalization for advancing electric vehicle (EV) infrastructure?

a) Absolutely critical

b) Important but not mandatory

c) Somewhat useful

d) Not critical at all

12- What is the primary advantage of energy storage systems coupled with digitalization?

a) Cost reduction

b) Stability in renewable energy supply

c) Increased energy security

d) All of the above

13- What risk does the digitalization of energy markets pose to data security?

a) High risk

b) Moderate risk

c) Low risk

d) No risk

14- Which factor is most important for managing a digitalized energy system?

a) Advanced analytics

b) Seamless integration

c) Regulatory compliance

d) Cybersecurity measures

15 -How does the use of digital technologies in energy systems impact employment in the sector?

a) Increases employment opportunities

b) Shifts the types of available jobs

c) Reduces total employment

d) No impact on employment

16-In your view, what is the biggest opportunity of digitalization for utility companies?

a) Cost reduction

b) Improved customer satisfaction

c) new business models

d) Enhanced operational efficiency

17-How does digitalization impact energy market entry barriers for new companies?

a) Lowers barriers significantly

b) Lowers barriers slightly

c) Does not affect barriers

d) Raises barriers due to technology costs

18-What influence does digitalization have on energy market regulations?

a) Requires new regulatory frameworks

b) Minor adjustments to existing regulations

c) No influence; regulations remain unchanged

d) Leads to deregulation

19-How critical is interconnectivity among various energy systems (e.g., gas, electricity, heating) in the context of digitalization?

a) Highly critical for system optimization

b) Somewhat important for efficiency

c) Not very important

d) Unnecessary and potentially risky

20-What is the potential impact of digitalization on achieving sustainability goals in the energy sector?

a) Greatly accelerates progress towards goals

b) Some positive impact but not decisive

c) Marginal impact with other factors being more significant

d) No impact or potential to hinder sustainability efforts

Appendices 2: Descriptive Analysis

How has digitalization affected the accuracy of energy demand forecasting?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Greatly improved accuracy	40	40.0	40.0	40.0
	Somewhat improved accuracy	21	21.0	21.0	61.0
	No significant change	26	26.0	26.0	87.0
	Reduced accuracy	13	13.0	13.0	100.0
	Total	100	100.0	100.0	

What digital tool has had the most significant impact on energy trading?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Blockchain	33	33.0	33.0	33.0
	Artificial Intelligence (AI)	10	10.0	10.0	43.0
	Internet of Things (IoT)	26	26.0	26.0	69.0
	Big Data Analytics	31	31.0	31.0	100.0
	Total	100	100.0	100.0	

Which area of the energy sector has digitalization benefited the most?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Generation	21	21.0	21.0	21.0
	Transmission	13	13.0	13.0	34.0
	Distribution	22	22.0	22.0	56.0
	Consumption	44	44.0	44.0	100.0
	Total	100	100.0	100.0	

What is the biggest challenge in implementing smart grids?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Technological complexity	27	27.0	27.0	27.0
	Cybersecurity threats	17	17.0	17.0	44.0
	Regulatory barriers	27	27.0	27.0	71.0
	High implementation costs	29	29.0	29.0	100.0

	Total	100	100.0	100.0	

How does digitalization influence renewable energy integration into the grid?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Simplifies it	23	23.0	23.0	23.0
	Complicates it	14	14.0	14.0	37.0
	No significant impact	24	24.0	24.0	61.0
	Only beneficial in the long term	39	39.0	39.0	100.0
	Total	100	100.0	100.0	

Has digitalization made energy markets more or less volatile?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	More volatile	31	31.0	31.0	31.0
	Less volatile	6	6.0	6.0	37.0
	No significant change	22	22.0	22.0	59.0
	Volatility is influenced by other factors	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

What role does "AI" play in predictive maintenance for energy infrastructure?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Crucial role	32	32.0	32.0	32.0
	Important, but not indispensable	7	7.0	7.0	39.0
	Marginal role	19	19.0	19.0	58.0
	Uncessary for maintenance	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

How has the emergence of smart homes changed energy consumption patterns?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Substantially reduced consumption	29	29.0	29.0	29.0
	Slightly reduced consumption	8	8.0	8.0	37.0
	No signficant change in consumption	24	24.0	24.0	61.0
	Increased consumption due to additional devices	39	39.0	39.0	100.0
	Total	100	100.0	100.0	

What impact does digitalization have on consumer engagement in energy management?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Significantly improves engagement	28	28.0	28.0	28.0
	Somewhat improve engagement	16	16.0	16.0	44.0
	Negligible effect on engagement	23	23.0	23.0	67.0
	Reduces engagement due to complexity	33	33.0	33.0	100.0
	Total	100	100.0	100.0	

How do digital twins affect the lifecycle management of energy assets?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Greatly extend lifecycle	23	23.0	23.0	23.0
	Slightly extend lifecycle	9	9.0	9.0	32.0
	No impact	26	26.0	26.0	58.0
	Shorten lifecycle due to complexity	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

What is the primary advantage of energy storage systems coupled with digitalization?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cost reduction	24	24.0	24.0	24.0
	Stability in renewable energy supply	12	12.0	12.0	36.0
	Increased energy security	23	23.0	23.0	59.0
	All of the above	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

Which factor is most important for managing a digitalized energy system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Advanced analytics	32	32.0	32.0	32.0
	Seamless integration	7	7.0	7.0	39.0
	Regulatory compliance	19	19.0	19.0	58.0
	Cybersecurity measures	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

How does digitalization impact energy market entry barriers for new companies?

		Frequency	Percent	Valid Percent	Cumulative Percent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Lowers barriers significantly	28	28.0	28.0	28.0
	Lowers barriers slightly	14	14.0	14.0	42.0
	Does not affect barriers	26	26.0	26.0	68.0
	Raises barriers due to technology costs	32	32.0	32.0	100.0
	Total	100	100.0	100.0	

What is the potential impact of digitalization on achieving sustainability goals in the energy sector?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Greatly accelerates progress towards goals	32	32.0	32.0	32.0
	Some positive impact but not decisive	7	7.0	7.0	39.0
	Marginal impact with other factors being significant	19	19.0	19.0	58.0
	No impact on potential to hinder sustainability efforts	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

How critical is interconnectivity among various energy systems (e.g., gas, electricity, heating) in the context of digitalization?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly critical for system optimization	31	31.0	31.0	31.0
	Somewhat important for efficiency	6	6.0	6.0	37.0
	Not very important	22	22.0	22.0	59.0
	Unnecessary and potentially risky	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

What influence does digitalization have on energy market regulations?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Requires new regulatory frameworks	24	24.0	24.0	24.0
	Minor adjustments to existing regulations	12	12.0	12.0	36.0
	No influence, regulations remain unchanged	23	23.0	23.0	59.0
	Leads to deregulation	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

In your view, what is the biggest opportunity of digitalization for utility companies?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cost reduction	28	28.0	28.0	28.0
	Improved customer satisfaction	16	16.0	16.0	44.0
	New business models	23	23.0	23.0	67.0
	Enhanced operational efficiency	33	33.0	33.0	100.0
	Total	100	100.0	100.0	

How does the use of digital technologies in energy systems impact employment in the sector?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Increases employment opportunities	23	23.0	23.0	23.0
	Shifts the types of available jobs	9	9.0	9.0	32.0
	Reduces total employment	26	26.0	26.0	58.0
	No impact on employment	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

What risk does the digitalization of energy markets pose to data security?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High risk	31	31.0	31.0	31.0
	Moderate risk	6	6.0	6.0	37.0
	Low risk	22	22.0	22.0	59.0
	No risk	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

How critical is digitalization for advancing electric vehicle (EV) infrastructure?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absolutely critical	28	28.0	28.0	28.0
	Important but not mandatory	14	14.0	14.0	42.0
	Somewhat useful	26	26.0	26.0	68.0
	Not critical at all	32	32.0	32.0	100.0
	Total	100	100.0	100.0	