# Digital Transformation in Energy Sector and Power Industry

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Digital transformation is a phenomenon introduced by the transformative power of digital technologies, and it has become a key driver for the energy sector, with advancements in technology leading to significant changes in the way energy is produced, transmitted, and consumed. The impact of digital transformation on the energy sector is profound, with benefits such as improved efficiency, cost reduction, and enhanced customer experience.

Keywords: digital transformation ; digitalization ; energy sector

## 1. Introduction

Digital transformation is rapidly changing the energy sector and the power industry, bringing significant benefits to companies and customers alike. The energy industry was a pioneer in adopting digital technology. Power utilities and oil and gas companies were digital pioneers in the 1970s, using new technology to simplify grid administration and operation or to model exploration and production assets [1][2][3].

It has been several years since the global digital revolution of the energy industry began. Decades ago, this sector was a pioneer in the use of emerging technology, such as IT. Industry 4.0, sometimes known as the fourth industrial revolution, has ushered in substantial developments in recent years. Companies in the energy industry have invested heavily in digital technology, and the pace of digitalization in this industry is growing [4][5][6]. Since 2014, according to the International Energy Agency (IEA), worldwide investments in digital power infrastructure and software have increased yearly by more than 20%, reaching USD 47 billion in 2016. In 2016, digital investments were almost 40% more than worldwide investments in the natural gas power industry (USD 34 billion) [7]. Deregulation of the power industry and the adoption of new policies for renewable energy formed the basis for these changes in several nations, mostly in European Union member states [6].

In recent years, the power industry has been experiencing a wave of digital transformation driven by the adoption of digital technologies such as the Internet of Things, AI, Big Data analytics, and blockchain. In the power industry, digital transformation is having a profound impact on the way electricity is generated, transmitted, and distributed.

The power industry has traditionally been characterized by large centralized power plants that generate electricity and transmit it to consumers through a network of high-voltage transmission lines. However, the emergence of digital technologies is changing the way electricity is generated, distributed, and consumed. The power industry is now moving towards a more decentralized model, where electricity is generated from renewable sources such as solar and wind, and distributed through microgrids and smart grids. Digital technologies are also being used to improve the efficiency of power generation, transmission, distribution systems, and customer experience resulting in lower costs, customer satisfaction and reduced carbon emissions [6][7].

- Impact on power generation: one of the most significant impacts of digital transformation on the power industry has been in the area of power generation. Power generation is the process of converting various sources of energy into electrical power that can be distributed to homes and businesses. Digital technologies have been used to improve the efficiency and reliability of power generation. Predictive maintenance using Big Data and machine learning algorithms is being used to identify potential equipment failures before they occur. This approach helps power companies to reduce downtime and improve the reliability of their power plants. Another impact of digital transformation on power generation is the use of renewable energy sources. Digital technologies are being used to integrate renewable energy sources such as solar and wind into the power grid. Although the unpredictable and intermittent nature of these variable energy sources can lead to challenges for maintaining the stability and reliability of the grid, digital technologies can support the integration process through enhancing grid visibility and providing tools for coordination and learning. In addition, digital technologies are being used to optimize the use of renewable energy sources. Machine learning algorithms are being used to predict when renewable energy sources will be available and when they will need to be stored for later use [3][6].

- Impact on power transmission: digital transformation has also had a significant impact on power transmission and distribution. Power transmission and distribution is the process of transmitting electrical power from power plants to homes and businesses. Digital technologies are being used to improve the efficiency and reliability of the power grid. Sensors and IoT devices are being used to monitor the health of power lines and transformers. This information is then used to identify potential issues and prevent power outages [3].

- Impact on power distribution: digital technologies are also being used to improve the distribution of power. Smart grids are being used to balance the supply and demand of power. This approach helps to reduce the cost of electricity and improve the reliability of the power grid. In addition, digital technologies are being used to optimize the use of power during peak demand periods. Machine learning algorithms are being used to predict when power demand will be high and when it will be low. This information is then used to adjust the distribution of power to meet the needs of customers [3].

- Digital transformation is also having a significant impact on customers. Digital technologies are being used to improve the customer experience. Mobile apps are being used to provide customers with real-time information about their energy consumption. This information helps customers to better manage their energy usage and reduce their energy bills. In addition, digital technologies are being used to improve the billing process. Digital billing and payment systems are being used to reduce the cost and time associated with the billing process. Another impact of digital transformation on customers is the emergence of new business models. For example, some power companies are now offering customers the ability to generate their own power using renewable energy sources such as solar panels. This approach allows customers to reduce their dependence on traditional power sources and save money on their energy bills [8][9].

Therefore, emerging technologies need particular consideration because they facilitate the development of other technologies and uses, are broadly adaptable, and contribute to the energy sector’s stability, efficiency, and environmental sustainability.

## 2. Drivers of Digital Transformation in the Energy Sector

Economic benefit and revenue growth through introducing new products, services, and customers are the primary goals of all businesses; digital technologies have the potential to provide economic benefits for all types of businesses. Energy companies have recognized the potential of digital technologies and taken steps to become digital [10].

Moreover, digital transformation in the power industry is being driven by a combination of factors. Increased demand for renewable energy, customer satisfaction and changed expectations, aging infrastructure, industry disruption, regulatory requirements, renewable energy, energy efficiency, cost reduction, increased competition, and the emergence of new technologies are some of the key drivers of digital transformation in the energy sector, and power industry. However, renewable energy is the most significant driver of digital transformation in the power industry. Digital technologies can enable power companies to optimize the placement and operation of wind turbines and solar panels which reduces costs and improves efficiency. The transition to renewable energy sources is also necessary to achieve environmental goals and lessen the carbon footprint of the power industry [11][12].

Customer satisfaction is another critical driver for going digital. Customers’ needs and expectations have changed through the years, and companies compete to provide better services and achieve higher satisfaction. For decades, customers have wanted cheaper and more accessible electricity, and consumers from highly developed countries have had even higher expectations. The importance of climate-friendly energy, its use, and cost transparency have increased. Smart meters and smart homes are digital applications that can assist in meeting the goals of decreased costs, increased transparency, and increased usage of renewable energy [13][14][15].

The smart home solution allows the daily measurement and invoicing of energy use, as well as the visualization and display of the energy consumption of particular household appliances [16]. This technology creates transparency and provides the opportunity to identify energy-saving potential. The utilization of artificial neural networks in such systems can help adapt to consumer preferences. As most interactions can be completed through online consumer portals, these solutions boost customer satisfaction while reducing costs [6][17].

## 3. Barriers to Digital Transformation of Energy Sector

The application of digital technologies that result in transformative change involves many challenges in the energy sector and in all other sectors. A qualified and skilled (mainly digital skills) workforce is the first and foremost need from a managerial perspective. All employees need digital knowledge and skills at different levels, regardless of their organizational roles (forecasting, designing, transmitting, producing, selling, and using energy). A clear managerial vision and a well-defined digital strategy are other vital requirements for an organization to take steps toward the digital [6][11]. Recent studies of success stories about different organizations' digital transformation have shown that a successful transition does not depend solely on the adopted technologies but, more importantly, builds on the digital strategies that its leaders deploy [18][19].

The capital to invest in purchasing, implementing, and using digital technologies is another vital requirement. The transformation of organizations, processes, and technologies is forced by digital transformation. Such reforms are often faced with resistance at various levels of management. Change management, which is mainly focused on overcoming employees' resistance, is a critical managerial skill for businesses that cannot expand without ongoing transformation [20].

Legacy systems, poor data quality, and cybersecurity are some of the technological barriers to digital transformation in the power industry. Many energy companies are still using legacy systems that are not compatible with new technologies, which can slow down the adoption of new systems. The quality and consistency of data are also critical for digital transformation, but most energy companies struggle with poor data quality and siloed data sources. The energy sector is one of the most critical infrastructures, which makes it a high-value target for cyberattacks, and digital technologies can increase the risk [19].

Even if organizations overcome internal barriers and meet the requirements, and the need to implement them is justified, prioritized, and feasible, difficulties in the application and use of digital technologies may arise from external conditions. Poor legal frameworks, a lack of national standards and policies, government limitation of investments in this area, the resistance of social groups, and a lack of industry-specific transformation guidelines are some examples of external barriers to the energy sector's digital transformation [6]. Although many national and regional governments have defined digitalization as a strategic priority and undertaken large-scale initiatives to support the digital transformation of science, industry, and society, the swift and effective digital transformation in the energy sector is impossible without support from the government and social groups that are associated with this sector. They must be aware of the vital changes that may occur due to sector transformation, especially the layoffs [6].

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

Macías [21] identifies three key factors that will transform work and employment in the digital age. The first factor is the *automation of work*, which involves the replacement of human labor with digitally enabled machines for certain tasks within production and distribution processes. While the concept of machine automation has been around for centuries, advancements in AI and other digital technologies have vastly expanded the possibilities for automation, meaning that a wider range of tasks can now potentially be automated.

The second factor that [21] identifies is the *digitalization of processes*. This involves using sensors and rendering devices to convert physical aspects of the production process into digital information (and vice versa), taking advantage of the enhanced processing, storage, and communication capabilities of digital information. Digitalization is the primary mechanism by which the characteristics of the digital economy are extended beyond the ICT sector to other industries and sectors.

The third factor is *coordination by platforms*, which refers to digital networks that algorithmically coordinate economic activities. Platforms are digital networks that facilitate transactions through algorithmic coordination. This definition encompasses two critical elements: the structured digital "space" where goods or services can be offered or demanded, and the set of algorithms that match and coordinate transactions in an automated way [21][22].

The vectors of change mentioned above of change can have a significant impact on the structure of employment, affecting both occupational and sectoral structures, as well as working conditions, industrial relations, and the social organization of production. As [12][21] notes, mid-skilled occupations in the energy sector that involve high levels of repetition, standardization, and limited social task content are at a high risk of being disrupted by automation as advanced robotics and AI-enabled machines, become more prevalent. However, digital transformation can also create new job opportunities based on high-value digital services and activities, as well as a new industrial value chain, which can mitigate job loss [12][21][23]

The digitalization of the grid through smart grids is a transformative development in the electricity sector. The World Economic Forum has highlighted that smart grids and grid-edge technologies, including smart meters, have resulted in cost reductions and enabled innovative business models that empower customers. Additionally, smart grids have led to a 60% improvement in the asset utilization of the electricity system. Digitalization has also facilitated increased data collection and analysis to optimize production processes, improve energy efficiency, and reduce waste, among other benefits that can be applied to all production processes [24][25].

Despite the advantages offered by smart grids and grid edge technologies, concerns related to privacy, safety, and loss of control have emerged in society. Therefore, the acceptance of consumers has become a critical factor in the digital transformation of the electricity sector [26]. To increase acceptance, it is important to raise awareness, educate consumers, and highlight the benefits of smart meters, such as providing precise billing, reducing energy consumption, and lowering costs by adjusting usage. A survey conducted by Smart Energy GB among individuals in the UK using smart meters found that 73% of respondents would recommend them, 82% believed that smart meters could help them better understand their energy expenses, 81% considered their energy bills accurate, and 82% had taken measures to reduce energy waste [27].

Engaging consumers and using microgrids (local energy communities) can enhance demand-side management (DSM), which is crucial for managing losses in transmission and distribution systems and improving energy efficiency for end-users. In addition, microgrids can contribute to the transition to future electricity systems by adding resilience and inclusiveness. As of 2014, over 3.5 billion euros had been earned annually by the local economy through demand response, increasing interest in DSM in the energy sector [23].

Digitalization, according to the International Energy Agency, has the potential to save approximately USD 80 billion per year, which is equivalent to 5% of the total annual power generation costs. This can be achieved through reduced operation and maintenance costs, improved efficiency of power plants and networks, minimized unplanned outages and downtime, and extended lifetimes of assets. For instance, using drones to monitor transmission lines over rough terrain can be a cost-effective way to monitor thousands of kilometers [28].

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