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Review

The Impact of COVID-19 on the Energy Sector and the Role of AI: An Analytical Review on Pre- to Post-Pandemic Perspectives

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Abstract: The COVID-19 pandemic has disrupted global energy markets and caused significant socio-economic impacts worldwide, including the energy sector due to lockdowns and restricted economic activity. This paper presents a comprehensive and analytical review of the impact of COVID-19 on the energy sector and explores the potential role of artificial intelligence (AI) in mitigating its effects. This review examines the changes in energy demand patterns during the pre-, mid-, and post-pandemic periods, analyzing their implications for the energy industries, including policymaking, communication, digital technology, energy conversion, the environment, energy markets, and power systems. Additionally, we explore how AI can enhance energy efficiency, optimize energy use, and reduce energy wastage. The potential of AI in developing sustainable energy systems is discussed, along with the challenges it poses in the energy sector's response to the pandemic. The recommendations for AI applications in the energy sector for the transition to a more sustainable energy future, with examples drawn from previous successful studies, are outlined. Information corroborated in this review is expected to provide important guidelines for crafting future research areas and directions in preparing the energy sector for any unforeseen circumstances or pandemic-like situations.

Keywords: COVID-19; pandemic; energy; artificial intelligence; digital technology; power system

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1. Introduction

The world was surprised with a global scale COVID-19 pandemic in early 2020, which caused countless lockdowns to be implemented with the hope of slowing down the infectious rate. The initial affected location is originally detected in a specific region of China called Wuhan and later emerged over hundreds of countries across the globe [1,2]. The effect of national restrictions on public gathering has shaped a new norm of living. A sharp decline in energy demand due to lockdown implementation, including travel restrictions and business closures, significantly impacted various economic sectors. According to the reports by International Energy Agency (IEA), the dramatic impact of COVID-19 lockdowns on global electricity use caused a slump in demand, where the usage typically fell by up to 20% for each month a nation's lockdown persisted [3]. Generally, the fall in energy demand was due to the reduced level of economic activity. However, with more people working from home, there was a rise in residential load demand [4].

Before the COVID-19 pandemic, there was a steady increase in energy demand globally as a result of population growth, economic development, and urbanization. In fact, the energy demand growth was relatively stable in developed countries, such as the United States of America. Moreover, the efforts to reduce energy intensity and increase energy efficiency by developing renewable energy had some level of success in reducing the rising energy demand. Pre-pandemic also marked the energy demand trends by adopting clean and green technology, and policies targeted to decrease carbon emissions, which align with environmental targets set by countries and international organizations such as United Nations Environment Programme (UNEP). The worldwide spread of COVID-19 has affected the entire global energy system in good and bad ways. For instance, the COVID-19 crisis has negatively affected economic growth due to the decreased electricity demand and industrial production. In addition, it also badly impacts the oil price fluctuations, supply chain disruptions, and changes in job markets within the energy industry. However, a significant reduction in pollutants due to factory closures and decreased transportation demand has shown a positive impact, especially for carbon mitigation pathways envisioned under the Paris Agreement.

On the other side of the perspective, the lesser consumption of power during the pandemic has opened more doors for renewable energy (RE) penetration into the existing power system, as the dependency on coal and gas power production has weakened. The effort to fight monopolism of conventional energy generation sources was definitely a challenge before the pandemic. Some regions, such as India, China and Europe, have grabbed the opportunity of this gap to shift from the traditional way of producing energy to a cleaner way of power production [5]. The importance of practicing green energy sentiments has grown among human society and the number of studied cases on smart RE has escalated two times greater since COVID-19 was officially reported. The focus of the energy sector on long-term sustainability and cleaner energy sources has also presented the opportunity for the integration of Artificial Intelligence (AI) in the sector. As countries begin to recover from the pandemic, the use of AI in the energy sector can play a crucial role in improving efficiency and reducing costs. By adapting to fast-moving energy development, allowing a power system to be monitored remotely or virtually is a charming area to be explored and closely followed. The changes in the energy industry during COVID-19 has been reviewed to properly discuss the impact and revolutionary advancements [6]. In addition to disruptions in energy demand patterns, energy production and consumption, and energy market dynamics, the pandemic has prompted changes in policymaking, necessitating adaptive measures to ensure energy security and sustainability [7,8]. AI technologies offer innovative solutions to address the complexities arising from the pandemic's effects. By harnessing AI's predictive capabilities, energy providers can optimize their operations, anticipate demand fluctuations, and devise robust contingency plans [9]. Additionally, AI's role in enhancing energy efficiency and sustainability cannot be overlooked. The integration of AI in power systems facilitates real-time monitoring and control, enabling smarter utilization of resources and minimizing environmental impact. Indeed, numerous studies have extensively explored the effectiveness of AI in enhancing the efficiency of energy-related research and applications [10–14]. Furthermore, AI is proving to be applicable in other engineering fields, such as its use in predicting the life cycle of machinery, as investigated by Li et al. [15]

Table 1 shows the collective of review papers published in Scopus based on the search using the keyword "artificial intelligence" AND "energy sector". The search was refined where only "review" documents were selected from 2015 to 2023. Only "full access" documents in the "English" language are presented. Based on the refined search, 18 review papers were found that related to the utilization of AI in the energy sector. Reviews on AI in the energy sector started to be published in 2019, where three papers were found. Then, it increased to seven papers in 2021, followed by six papers in 2022. We believe that the number of review papers on AI in the energy sector will keep increasing since the growing interest in using AI to enhance energy efficiency, reduce energy costs, and optimize energy management across various industries is prevalent. Moreover, the development of new AI technologies and the increasing ease of implementing AI applications have led to more industries adopting these systems, further increasing interest in this area, finally leading to more publications. To obtain an insight into the new revolution of AI in the energy sector, especially after the pandemic crisis, we have presented this review that aims to analyze and compare the change in energy demand in three timeframes: pre-pandemic, mid-pandemic, and post-pandemic crisis. A detailed analysis of the COVID-19 impact in the energy-related sector is discussed, including policy making, communication, digital technology, energy conversion, environmental, energy market, and power system operation. This review stands as a pioneering effort in analyzing the impacts of COVID-19 on various energy sectors within distinct timeframes of the pandemic crisis, while also exploring the revolutionary role of AI in the energy recovery process post-pandemic. The comprehensive temporal analysis yields valuable insights into the dynamic nature of energy demand patterns during different phases of the pandemic. Furthermore, the focus on AI integration highlights its significant novelty, as it emerges as a promising and increasingly intriguing area of interest in shaping the future of the energy industry. This review includes the methodology and scope of the research that was discussed in Section 2. Then, Section 3 discusses the impact of COVID-19 on the energy sector, including policy-making, communications, power systems, and others. A summary of AI applications in the energy sectors is discussed in Section 3 too, followed by recommendations in Section 4, and finally the conclusion in Section 5.

Table 1. Review papers on AI in energy sectors.

No.	Authors	Title	Year	Source Title	Cited by	Ref.
1	Zhao N. et al.	Emerging information and communication technologies for smart energy systems and renewable transition	2023	Advances in Applied Energy	2	[16]
2	Li J. et al.	Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management	2023	Energy and AI	4	[17]
3	Bojanovský J. et al.	Rotary Kiln, a Unit on the Border of the Process and Energy Industry—Current State and Perspectives	2022	Sustainability (Switzerland)	1	[18]
4	Liu Z. et al.	Artificial intelligence powered large-scale renewable integrations in multi-energy systems for carbon neutrality transition: Challenges and future perspectives	2022	Energy and AI	4	[19]
5	Singh R. et al.	Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability	2022	Sensors	9	[20]
6	Amir M. and Khan S.Z.	Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa	2022	Energy and Built Environment	25	[21]
7	Mitchell D. et al.	A review: Challenges and opportunities for artificial intelligence and robotics in the offshore wind sector	2022	Energy and AI	10	[22]
8	Chawla Y. et al.	Artificial intelligence and information management in the energy transition of India: lessons from the global IT heart	2022	Digital Policy, Regulation and Governance	7	[23]
9	Kumbhar A. et al.	A comprehensive review: Machine learning and its application in integrated power system	2021	Energy Reports	22	[24]
10	Adekanbi M.L.	Optimization and digitization of wind farms using internet of things: A review	2021	International Journal of Energy Research	10	[25]

Table 1. *Cont.*

No.	Authors	Title	Year	Source Title	Cited by	Ref.
11	Mabina P. et al.	Sustainability matchmaking: Linking renewable sources to electric water heating through machine learning	2021	Energy and Buildings	5	[26]
12	Baashar Y. et al.	Toward blockchain technology in the energy environment	2021	Sustainability (Switzerland)	8	[27]
13	Chatterjee J. and Dethlefs N.	Scientometric review of artificial intelligence for operations & maintenance of wind turbines: The past, present and future	2021	Renewable and Sustainable Energy Reviews	25	[28]
14	Halhoul Merabet G. et al.	Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques	2021	Renewable and Sustainable Energy Reviews	68	[29]
15	Ahmad T. et al.	Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities	2021	Journal of Cleaner Production	111	[14]
16	O'Dwyer E. et al.	Smart energy systems for sustainable smart cities: Current developments, trends and future directions	2019	Applied Energy	187	[30]
17	Shafiee M. et al.	Decision support methods and applications in the upstream oil and gas sector	2019	Journal of Petroleum Science and Engineering	37	[31]
18	Fallah S.N. et al.	Computational intelligence on short-term load forecasting: A methodological overview	2019	Energies	72	[13]

2. Review Methodology and Scope

This review paper focuses on the effect of COVID-19 on the energy sector. To clearly compare pre-, mid-, and post-pandemic, we have limited the search from 2015 to 2022. By limiting the search results from 2015–2022, we can achieve our aim to compare the impact of the pandemic on the energy sector by focusing on the most up-to-date and relevant materials. In addition, the publications and data analyzed within the limited years are current and reflect the most current status of the energy sector, besides helping to narrow the search focus. The referenced articles and the data presented in this review are collected from reputable journal search engines such as Scopus, Google Scholar, and others. A few keywords used to find the related articles and data were: 'policy on energy sector', 'digital technology', 'energy conversion', 'environmental effect', 'economy', and 'power system operation'.

Figure 1 shows the number of published articles related to the energy sector from 2015 to 2022. The graph shows increasing trends in articles published from the pre-pandemic until the post-pandemic period. The results proved that research on the energy sector is still actively performed despite the world having faced a pandemic crisis. No doubt, the priority on finding alternative and renewable sources of energy, such as wind, solar, and hydro power, has resulted in a growth in research and development in the energy sector, leading to more publications. Additionally, government policies and regulations have played a role in the increase in publications in the energy sector. A large investment has been made for innovation and improvements in technology related to energy production, transmission, and storage, which encourages more research and publications in the industry.

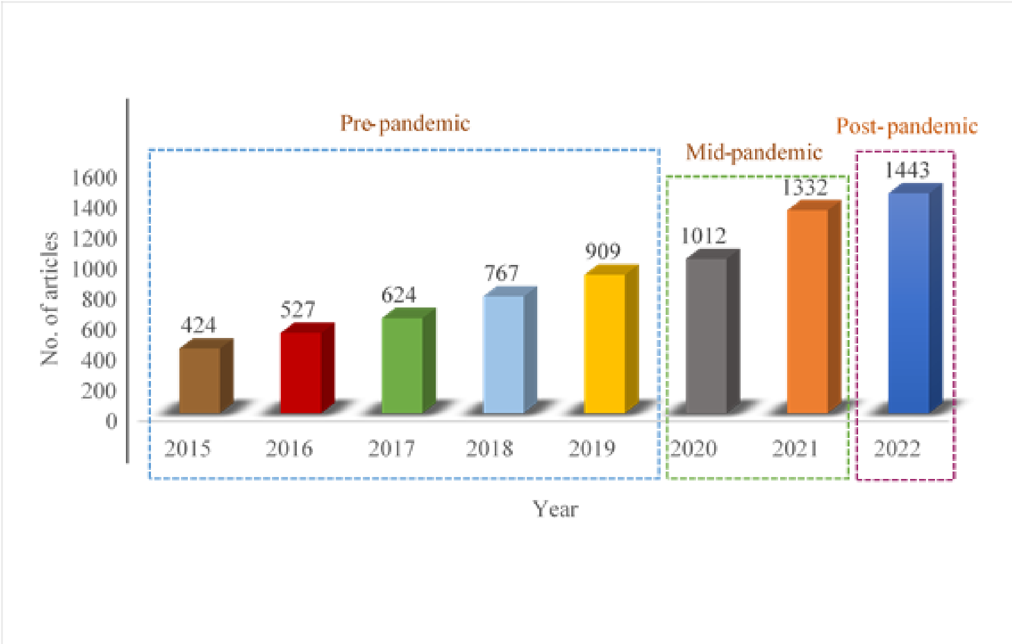


Figure 1. The number of articles published in energy sector from 2015–2022.

Among the published articles presented in Figure 1, we have analyzed the articles in different timeframes, pre-pandemic, mid-pandemic, and post-pandemic. For the purpose of the discussion in this paper; we define the timeframe as follows:

Pre-pandemic: Refers to the time before the WHO declared COVID-19 a global pandemic on 11 March 2020. This could range from before 2020 to March 2020, depending on the country and region.
Mid-pandemic: Refers to the period during the pandemic, which began in March 2020 and continued until the end of 2021. Some people may consider the period from the beginning of widespread vaccine distribution in late 2020 to mid-2021 as the mid-pandemic period. This period is characterized by a global health crisis, economic slowdowns, travel restrictions, and various public health measures to slow the spread of the virus.
Post-pandemic: Refers to the current period after the pandemic, where most countries have declared they are over or have successfully controlled the pandemic's effects. The exact timeframe for the post-pandemic period is difficult to predict and may vary by countries, but some experts predict that it begins when the majority of the population is vaccinated, the easing of restrictions, the recovery of global economies, and daily COVID-19 cases and deaths are consistently low. In this review, we consider 2022 as a post-pandemic period.

Analyzing and comparing the effects of COVID-19 to the energy sectors between pre-, mid-, and post-pandemic can provide an essential foundation for developing policies and strategies to navigate a similar public health crisis, as well as continue to develop and shape the energy industry to meet the needs of the future better. However, several limitations and challenges to analyzing and comparing the results between the timeframe need to be noted. Since the COVID-19 pandemic is still a new phenomenon, there is limited research to reference on this topic. Therefore, there may be a lack of available data to conclude the true impact of the pandemic on the energy sector. Additionally, it is challenging to have a comprehensive perspective in this review due to constantly emerging information and changing government policies and market trends.

3. Analysis of COVID-19 Impact towards Energy Sector: Pre–Mid–Post Pandemic

This section is divided into seven sub-sections that detail the analysis of COVID-19's impact on the various energy sectors. This analysis includes the obvious changes experienced by the energy industry, which bring positive and negative effects to society.

3.1. Policy Making in Energy Sector

Policy making in the energy sector plays a crucial role for achieving various objectives, including energy security, economic growth, technological innovation, and global cooperation. The specific policies and approaches adopted by governments can vary depending on national priorities, available resources, technological advancements, and political contexts. Table 2 shows the general policy adopted by different countries prior to different timeframes. Effective energy policies provide a roadmap for a sustainable and resilient energy future, benefiting both current and future generations.

Table 2. Policy implementation on energy sector by US, France, and Switzerland from 2019 to 2021.

	2019	2020	2021
USA	1. Introduction of the Clean Energy Standard 2. Expansion of tax credits for wind and solar energy. 3. Implementation of efficiency standards for appliances and buildings	1. Increase in funding for energy efficiency and RE research and development. 2. Expansion of tax credits for EV and charging infrastructure.	1. Rejoining the Paris Agreement 2. Plan to decarbonize the power sector by 2035. 3. Increase in funding for energy efficiency and RE research and development.
France	1. Energy Transition for Green Growth Act 2. Increase in the share of RES in the national energy mix. 3. Implementation of a carbon tax 4. Rollout of EV charging infrastructure.	1. Introduction of a nationwide ban on fossil fuel vehicles by 2040. 2. Increase in funding for RE research and development. 3. Expansion of EV charging infrastructure.	1. Introduction of a plan to make France carbon neutral by 2050. 2. Increase in funding for RE research and development. 3. Expansion of EV charging infrastructure.
Switzerland	1. Increase in investment in RES. 2. Implementation of a CO_2 tax on fuel and heating products. 3. Support for research and development in energy efficiency and RE technologies.	1. Carbon tax increased renewable targets for 2030. 2. Nationwide ban on single-use plastic products	1. Carbon neutral by 2050 2. Increase in funding for RE projects. 3. Regulations to increase energy efficiency in buildings and industry.

Prior to the pandemic, efforts were already in progress to address the impact of energy production and consumption on the environment, and to transition towards RE sources. These efforts of transitioning were driven by variety of factors, including concern about climate change [32], air pollution [33,34], and energy security [35]. Policy approaches on these issues have varied across different countries and regions, but typically involve a mix of regulatory measures, financial incentives, and educational campaigns. One example of policy efforts towards the energy sector is the Paris Agreement [36]: an international deal that was signed in 2015 that aims to limit global warming to well below 2 °C by 2030. Under the agreement, countries commit to reducing their greenhouse gas emissions, particularly in the energy sector that is responsible for a significant portion of global emissions. To achieve the goal, France applied an Act on Energy Transition for Green Growth in 2019 to reduce greenhouse gas emissions and improve energy efficiency [37]. In addition, the US federal law enforced the Clean Air Act in the 70s, which establishes air quality standards and regulates the emission of air pollutants, including those from the energy sector [38]. Other policy approaches towards the energy sector have included financial incentives such as subsidies and tax credits, and regulatory measures such as energy efficiency standards and renewable portfolio standards. These measures have been adopted by countries around the world, including the United States, China, India, Germany, France, the United Kingdom, and Japan. Furthermore, the operation of the energy sector is working on normal operating conditions of power systems and usual business activity is conducted by executing previous or existing strategy plans [39,40]. In addition, normal budget allocation is implemented by respective governments in the world for the energy sector, with no preparation of a global pandemic [41,42]. Experts in the power and energy sector have already predicted that the existing business model would transform in the future due to SDGs regulation by the UN, which has been promoted since 2015 [43]. However, most signatories had failed to meet the agreed targets of the SDGs. This is due to the high cost to deploy RE and digital energy systems, and the mechanism for recycling and reusing retired units of conventional plants was not yet established [44].

During the mid-pandemic phase, policy makers faced the challenge of responding to the rapid and unprecedented changes in energy demand and supply. On the demand side, lockdowns and other measures to contain the spread of the virus have led to a sharp drop in energy consumption around the world in 2020, particularly in the transportation and industrial sectors. The energy consumption in the US shows an example of the sharp drop, as can be observed in Figure 2.

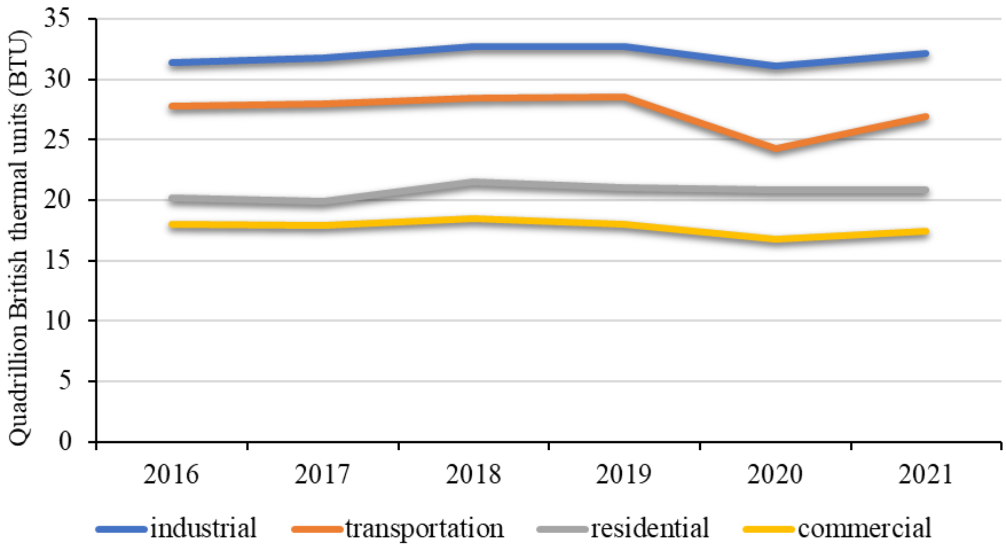


Figure 2. Energy consumption by different sectors in the US.

In response to the drop in demand, many governments have implemented policies to support the energy sector, including measures to stabilize prices and provide financial assistance to affected companies [42,45]. Some governments have also used the pandemic as an opportunity to accelerate the transition to renewable energy sources, recognizing the potential long-term benefits of this shift in terms of both economic and environmental sustainability. One example of a policy measure implemented in response to the pandemic is the extension of tax credits and other incentives for renewable energy projects. US and France have expanded the tax credits for EV and charging infrastructure to escalate the usage of EV in the community. Additionally, the pandemic saw an increase in the cost of maintaining normal operations of power systems, with the IEA estimating an increase of 5% in 2020 compared to the previous year [46]. This has led to many state-investigated energy projects and plans for new facilities and infrastructure being delayed or shelved, as well as a significant reduction in investment in the energy sector, with an estimated drop of 18% in 2020.

In the wake of the COVID-19 pandemic, policy-making related to energy security has been revised and improved to better prepare for a potential global infectious virus outbreak in the future. This involves a heightened awareness of energy security and the need to be able to adapt to changing circumstances quickly. Policymakers also had to scramble to create laws and regulations that can ensure a gradual transition to renewable energy sources, rather than a revolutionary change. Such a transition requires careful consideration of the various factors involved, including the potential for job losses, social stability, economic growth, and the energy market. According to a report by IEA, the deployment of renewable energy sources has been boosted by high motivation from governments, businesses, and individuals to transition to cleaner energy sources faster [47]. This is due to a combination of factors, including the declining cost of renewable energy technologies, the need to meet climate targets, and the need for energy security. In response to the economic downturn caused by the COVID-19 pandemic, many countries have implemented policies to encourage investment in renewable energy and digital energy systems [48]. In the United States, the federal government provided more than $90 billion in investment and tax incentives for renewable energy projects from 2009 to 2019. This has led to significant growth in the sector, with renewable energy sources accounting for more than 20% of the country's total energy production in 2020. It is also important to develop new cost-effective strategies that reflect the current domestic and international realities. Such strategies can help various audiences be more innovative and proactive by rethinking and reshaping global energy strategies based on trend-based insights and big data. Additionally, data from the United Nations Environment Programme shows that the share of renewable energy in global energy consumption grew from 16.1% in 2010 to 18.4% in 2021 [49]. This suggests that renewable energy is becoming increasingly cost-effective and viable in many countries.

Policy-making on the energy sector post-pandemic has been driven by a more vigorous push to promote sustainability and achieve the SDGs. This is reflected in increased funding for research and development in the renewable energy sector, as well as a focus on investing in sustainable energy technologies and infrastructure, the progress, impact analysis, challenges and new perceptions for electric power and energy sectors in the light of the COVID-19 pandemic [45]. This has also enabled the quick growth of renewable energy sources in order to maintain air quality during the COVID-19 pandemic. However, the impact of the pandemic on the energy sector was initially viewed as temporary, and it remains to be seen whether the progress towards SDG 7 (affordable and clean energy) by nations will be significantly affected in the long term. There is also the potential for serious employment issues to arise if the transition to renewable energy happens too quickly, as many workers in the fossil fuel industry may be displaced. According to a report by the International Labour Organization (ILO), the global transition to renewable energy could result in the displacement of up to 6.5 million workers in the fossil fuel industry. This number could be even higher if the transition happens too quickly, and the ILO estimates that up to 17 million jobs could be at risk. Additionally, the report argues that the transition to renewable energy could also create up to 24 million new jobs but warns that these jobs may not be accessible to all workers, as they may require specific skills or qualifications.

However, not all countries are able to implement such policies. Countries with large financial funds are often able to execute proposed policies more quickly and effectively than those with limited resources. Therefore, while countries with strong financial resources are in the best position to take advantage of policy incentives for renewable energy and digital energy systems, those with limited resources are still able to make progress in this area. By implementing policies that are tailored to their specific needs and resources, such as providing tax exemptions and incentives to local businesses, they can still make progress towards a more sustainable energy future. Additionally, international collaboration between countries can help to ensure that all countries are able to benefit from the advances in renewable energy technologies and digital energy systems.

At the same time, it is important to note that these initiatives and strategies provide only a general insight into the global energy market. A detailed analysis is needed to test and refine these strategies based on local circumstances in order to obtain a more accurate and realistic insight. As an example, the International Energy Agency has conducted research which suggests that the cost of renewable energy varies significantly between countries and regions. While some countries, such as Germany and Denmark, were able to achieve a significant share of renewable energy in their energy mix, other countries have struggled to keep up. Additionally, the cost of energy storage was identified as a major obstacle to the global adoption of renewable energy. To address these issues, governments can look to implement policies and regulations that incentivize investment in renewable energy and energy storage technologies. Additionally, countries can look to collaborate with businesses and organizations to develop innovative solutions that reduce the cost and increase the efficiency of renewable energy sources.

The introduction of RE and distributed energy resources (DER) into retired units of conventional power plants has become increasingly popular in the aftermath of the pandemic [50]. By introducing RE and DER into retired units of conventional power plants, it can avoid serious resource waste while also creating a more sustainable future. Additionally, this approach provides an opportunity for innovative businesses models, such as leasing out space within a plant site or providing services related to maintenance of equipment associated with RE/DER installations at sites where they have been installed previously. By retrofitting these units, it is possible to improve their efficiency and reduce their carbon emissions. It is important, however, that when considering installing RE/DER systems at any site, careful consideration must be taken regarding safety issues, especially if there are hazardous materials present such as those found in nuclear power plants, which may affect how suitable a particular location may be for installation purposes. Furthermore, since many retired systems will already have aged components, it can make them less attractive from both cost and efficiency standpoints, this making it difficult for their saleability or recyclability even after retrofitting with newer technologies is completed successfully.

The US has implemented various policy initiatives and incentives in favor of production of bio-ethanol from corn [51], which has helped to increase corn prices and farmers' income, enhance rural employment, and encourage value-added businesses. In addition to these benefits, the production of bio-ethanol has also helped to increase energy security and reduce pollutants and greenhouse gases. To further improve energy efficiency, the US government should develop and implement policies and incentives that encourage energy efficiency in buildings, industry, and transportation. This could include incentives for energy-efficient appliances, investments in public transportation, and regulations that require buildings to meet certain energy efficiency standards. Additionally, the US should invest in research and development to develop new technologies that can further improve energy efficiency. A shift to renewable energy sources will reduce the amount of pollution emitted into the atmosphere and help to combat climate change. This shift will also create jobs and stimulate economic growth in many countries. Therefore, it is important for government and lawmakers to consider the potential implications of their decisions, and to ensure that they create policies that are designed to promote economic growth, energy security, and sustainability.

3.2. Communication

Figure 3 shows different timeframes and the use of communication mediums. Before the pandemic happened, face-to-face communication was the normal or usual way for humans to communicate. Face-to-face communication requires the physical presence of an individual and may involve the use of transportation and buildings, which contribute to low electricity usage but high energy usage on transportation and traveling. In contrast, electronic communications medium such as telephone calls, emails, and online meetings can be conducted remotely and may have a lower energy footprint [52]. During the COVID-19 pandemic, the medium through which human communication occurred has had an impact on energy consumption. One key trend during the pandemic was the shift towards electronic communication mediums, such as telephone calls, emails, and online meetings, which can be conducted remotely and may contribute to lower energy footprint compared to face-to-face communication. Zoom reported that it had surpassed 300 million daily meeting participants in April 2020, which was up from 10 million daily meeting participants in December 2019 [53]. In addition, more than 91% of registered students worldwide were affected by the closure of academic institutes, according to the United Nations Education, Scientific and Cultural Organization (UNESCO). Thus, they shifted to online/virtual meeting due to the need for social distancing and the widespread adoption of remote work and online education. In addition, the way in which different communication mediums are used can also impact energy usage. The use of energy-intensive devices such as laptops and smartphones can contribute to energy consumption [54]. For example, using a laptop or desktop computer with a high-performance processor can result in a higher energy usage than a smartphone or tablet with a lower-powered processor. This is also proven by the increase in electricity in the residential area as people were required to stay at home.

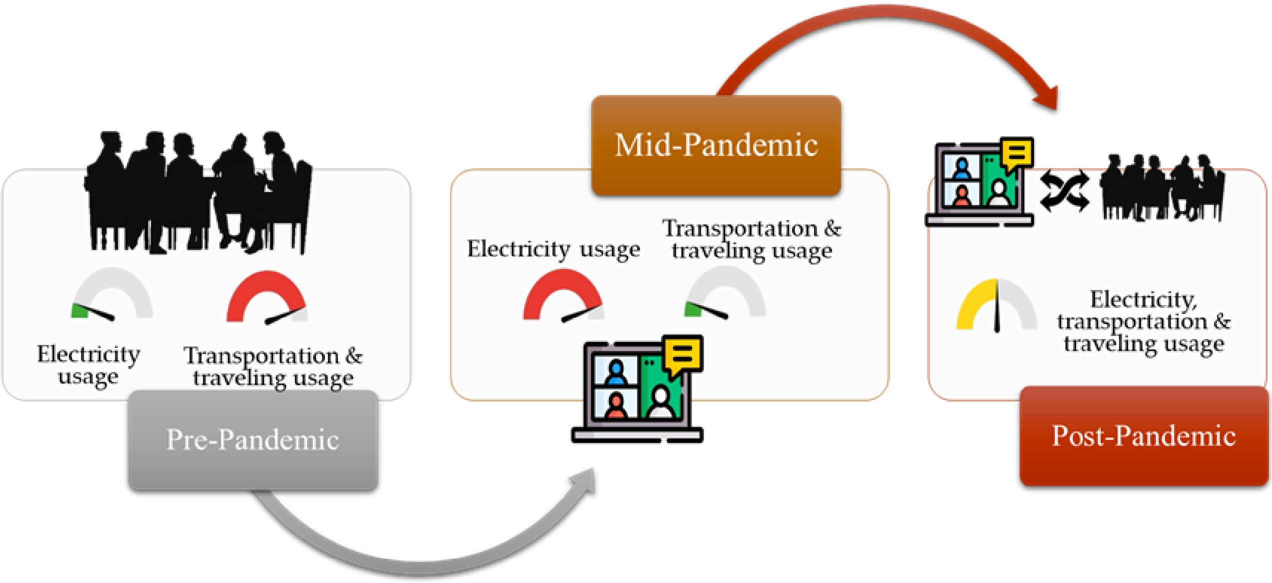


Figure 3. The use of different communication mediums and their effect on energy usage for different timeframes.

Nonetheless, the shift to virtual communications has a higher impact on mankind, as it can reduce travelling cost and time. In addition, people were forced to acquire computational knowledge/skill in order to resume daily activities, such as virtual communication for work purposes, etc. However, some people have struggled to adapt to the online environment and have found it difficult to absorb knowledge and complete assignments effectively. This has led to a decrease in the quality of work in some sectors, as people who may not be fully proficient in using online platforms may be producing lower quality outputs. Additionally, online experience is not the same as in-person interactions, and some people may feel disconnected or isolated due to the lack of physical presence. Therefore, in certain sectors, the quality of work dropped due to generating low quality staff/students through online training/studies.

The rise of digital technologies has had a significant impact on the development of virtual power plants (VPPs). A VPP is a system that allows for the integration and control of DERs, such as solar panels, wind turbines, and energy storage systems. This integration allows for the optimization of DERs and the efficient management of the power grid. Advancements in digital technologies, such as smart grids, blockchain, and the internet of things (IoT), have enabled the concept of VPPs. Smart grids are intelligent power grids that use advanced communication and control technologies to optimize the efficiency and reliability of the power grid. Blockchain technologies provide a secure and decentralized platform for energy trading and management. IoT solutions enable the integration and control of connected devices in the energy sector, allowing for the optimization of energy usage and the management of power grids. However, there are also concerns surrounding the use of digital technologies in the energy sector, particularly with regard to data breach and cybersecurity, as highlighted in [55]. Furthermore, many studies stated that hackers have targeted energy companies and utilities in the past, leading to disruptions in the power grid and potentially posing a risk to public safety [56,57]. It is important for energy companies to prioritize cybersecurity and implement robust measures to protect against potential attacks. Overall, the adoption of digital technologies in the energy sector has brought about significant innovations and improvements in the efficiency and reliability of the power grid.

3.3. Digital Technology

Before the COVID-19 pandemic, the normal operating condition of power systems was heavily reliant on the constant and fixed-load-consumption behavior of energy consumers [58–60]. For power utilities to correctly plan and manage their generation capacity, as well as to optimize the operation of their transmission and distribution networks, it is important that they have a thorough understanding of the constant and fixed-load-consumption behavior of energy customers. Power utilities can maintain the power system's normal operational state and deliver a reliable and steady supply of electricity to customers by precisely forecasting the load demand and effectively managing the generation and distribution of electricity. However, one major challenge was the neglect of electrical energy wastages, which were often overlooked in traditional energy systems [61,62].

Next, digital technology was already having a major effect on how energy companies operated their businesses by allowing them access real time information related to market trends, customer demand forecasts or even supply chain management issues from anywhere in the world at any given time. By using advanced analytics tools, such as predictive modelling or machine learning algorithms, they could also identify potential problems before they arose so that corrective action could be taken swiftly if necessary. Moreover, with the increasing adoption of renewable sources like solar power, smart grids were being implemented, which allowed utility providers better control over electricity distribution networks, while also enabling customers more flexibility when it came to choosing their preferred supplier. Furthermore, the reliance on manual logbooks and traditional meters to track energy consumption is one of the challenges [63]. These methods were prone to errors and inconsistencies, thus making it difficult to accurately measure and monitor energy use. Jiang et al. (2021) reported that the exact effectiveness of digitization and its energy consumption have remained uncertain due to complex assessments of the datasets and the underdeveloped methods to define its benefits [54].

Other than that, the energy sector faced a challenge that is related to the integration of renewable energy sources (RES) into the power grid. One major challenge was the instability and inconsistency of RES production, which made it difficult to rely on these sources as a primary source of power [41,64]. This was often due to the variability of RES, such as solar and wind power, which can be affected by weather conditions. To address this challenge, many energy companies implemented grid modernization plans to handle bidirectional power flow from distributed generators based on renewable energy sources. By enabling real-time monitoring and control of power flow, digital technologies helped to improve the integration of RES into the grid and reduce the reliance on fossil fuels.

Another challenge faced by the energy sector in the pre-pandemic period was the dependence of energy consumers on the grid [45,64,65]. Many energy consumers were grid-dependent, meaning that they relied on the grid for their energy needs and had limited options for generating their own power. This made them vulnerable to disruptions in the grid and to fluctuations in energy prices. In addition, the ineffective communication between the electric energy providers and the end customers presented another difficulty. It was frequently impossible for end users to acquire the data they needed in order to control their energy consumption, because communication was typically restricted to a one-way flow of information from the power energy provider to the end user.

In particular, a few studies claimed that data analytics played a major role in helping energy companies to make better decisions by providing them with real-time insights into their operations. This helps the energy companies to identify areas where they can optimize processes or develop new strategies that are more cost effective or efficient than traditional methods. Additionally, predictive analytics can help companies anticipate future trends, which in turn allows them to plan ahead accordingly. Furthermore, cloud computing provides access to massive amounts of data, which then enables further analysis and decision making on this information at scale.

Next, AI is being used as well in the energy sector, from automated systems, monitoring production levels across various sites remotely through sensors, to robots performing tasks such as drilling wells safely under hazardous conditions; AI offers improved accuracy over manual labor while reducing human errors associated with it [66,67]. All these advances demonstrate how important digital technologies have become during mid-pandemic times when physical contact needs to be minimized. As we move forward, it will only become even more crucial for organizations within this sector to leverage these tools effectively if they want to remain competitive going forward.

The energy sector has seen significant changes In the post-COVID period as a result of the rise of digital technologies, which help in reshaping the load curves and increasing the demand for load forecast technology to collect and record real-time data [68]. This shift has enabled the energy sector to better anticipate and prepare for changes in energy demand. The access to real-time data on energy consumption helps energy companies and policy makers to plan and respond to changes in energy demand, leading to more efficient and reliable energy systems and a reduced risk of disruptions in energy supply.

Additionally, a lot of energy companies have set up systems for two-way communication between power providers and end users [61,62,65]. This brings benefits for the energy sector, including the ability to use the grid, renewable energy sources, and power systems more efficiently. Energy companies are able to optimize the performance of their systems and recognize potential for waste reduction due to accessing real-time data on energy consumption. This also enabled real-time data exchange and enables end users to access information about their energy consumption. Two-way communication between power providers and end users also enables shorter response times and better customer service, which boosts the effectiveness of energy systems.

To increase the precision and dependability of data on energy usage, smart meters with digital technology have also been widely adopted [17,30,64]. In 2020, the International Energy Agency reported that as of the end of 2019, over 27% of all power users worldwide have smart meters installed in their homes. By the end of 2025, this figure is anticipated to reach over 50%. Figure 4 shows the percentage of electricity customers in different regions with a smart meter installed [69]. The deployment rate of smart meters is projected to be highest in North America and Europe, reaching approximately 80% and 60%, respectively. However, installations in East Asia and the Pacific, as well as in Latin America, are also expected to steadily increase. These variations in the percentage of installed smart meters can be due to differences in government policies, economic conditions, technological infrastructure, consumer awareness and demand, and energy usage patterns [30,64,65]. Smajla et al. (2021) reported that if more than 10,000 smart meters were installed, deviation between average estimated natural gas consumption and the real data would be less than 2.96% [70]. However, the adoption of smart meters has also highlighted the lack of availability of past load data and corresponding prediction models pre-pandemic. Many energy companies were unable to access data on historical trends of energy consumption or create precise forecasting models for future demand. This made it challenging to evaluate whether adding renewable energy sources to the energy mix was feasible or to improve the efficiency of energy systems.

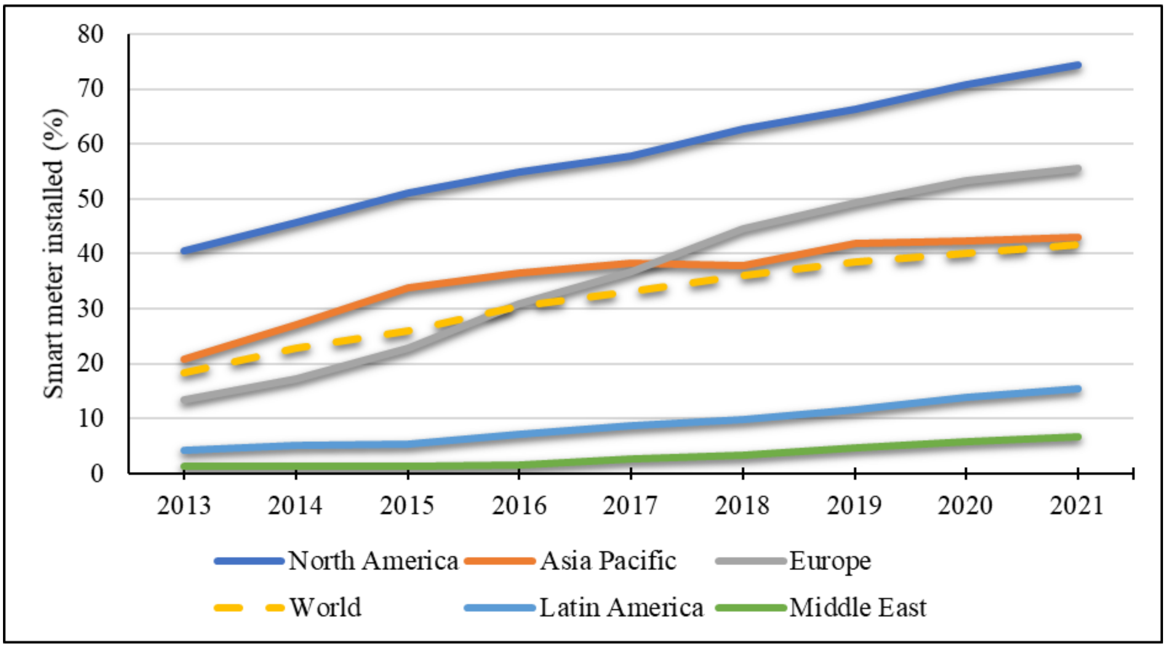


Figure 4. Percentage of customers with smart meters in different regions [69,71].

In addition, digital technologies have enabled utility providers to create smarter grids, which enables them to monitor usage patterns more accurately [72]. This helps them respond faster when there is an outage. Furthermore, smart grids help consumers track their electricity consumption, thus leading towards conservation efforts due to increased awareness about individual contributions regarding environment protection initiatives. In conclusion, the use of modern-day computing capabilities, combined with advanced analytics tools, have allowed organizations within this domain to achieve unprecedented levels of success, apart from providing tangible benefits both economically and environmentally speaking.

Digital technology has had a major impact on the energy sector in recent years, especially in terms of stabilized RES production, improved energy efficiency and cost savings, and greater environmental considerations [64,65]. This has allowed more people to invest in and deploy RES, as the stable output and smart management technology has provided investors with greater confidence in the technology. Many energy consumers have become self-sustaining "prosumers," generating their own power and reducing their dependence on the grid [45,64,65]. This has allowed consumers to drastically reduce their electricity bills, as they no longer need to rely on the grid for their energy needs. However, some developing countries have had to pause or hold back on some RE plant investments, due to financial constraints caused by the pandemic, with a focus on the health sector to survive. On the other hand, this has resulted in a massive loss of revenue for power utilities, as more consumers are turning to self-generated energy sources.

In addition, to address the challenges of energy pricing, many energy companies have adopted digital technology and introduced electricity price forecasting (EPF) systems [73]. These systems use data analytics and machine learning to predict future energy prices and enable more effective management of energy resources. This has allowed for easier study and analysis of energy market data from providers and lawmakers, as well as for owners of RE sources to make a profit through energy trading. This has weakened grid dependence but has had a negative effect on the power providers' business.

Furthermore, during the transition to the endemic phase, there has been an increased awareness of the need to efficiently use energy and to practice smart energy systems [30,65]. Coordinating the use of energy can reduce the load on the national grid, thereby decreasing the need for load shedding. Additionally, Smart Energy Systems can be operated remotely with the presence of the internet, thus eliminating some traditional job positions. This shift towards digital technology in the energy sector is not only beneficial for the environment, but also for businesses and consumers, as it helps to reduce costs and increase efficiency. However, the implementation of these systems has been challenging due to the financial impact of the pandemic.

Despite these challenges, the data recorded by AI in the coal, oil, and gas upstream industry can be studied and analyzed for future reference and to improve operations [74]. This has allowed for the removal of human errors and for operations to be conducted in a more time and cost-efficient manner, thus allowing for the maximization of cumulative production. Additionally, the use of AI-enabled solutions has motivated oil and gas production, as the traditional skills of the past have become less relevant. Digital technology has also been used to quantify the development of renewable energy sources before and during the pandemic, enabling energy companies to better understand the performance and reliability of these sources under different conditions. This has allowed policy makers to easily analyze data and make better decisions regarding the energy sector. This data has also allowed for an obvious distinction between the financial states of developed countries and developing countries, based on the results of their renewable energy development. With the use of digital technology, policy makers can have access to more accurate and up-to-date information that can help them make informed decisions about the energy sector.

Finally, digital technology in the energy sector is also used for increasing operational efficiency [75]. Companies are using big data analysis techniques to identify areas where they can save money or increase production levels with minimal investment costs. For example, predictive maintenance algorithms allow companies to detect problems before they occur so that corrective action can be taken quickly and efficiently, without having an adverse effect on operations or customers' experience with services being provided by those companies. Additionally, automation solutions are also becoming increasingly popular as a way of reducing labor costs, while still maintaining high standards of quality assurance across all processes involved in energy production activities, such as drilling sites or power plants operating at peak capacity throughout their lifecycle period.

3.4. Energy Conversion

Energy conversion is a critical process in the energy sector, as it involves the transformation of one form of energy into another. There are various sources of energy that are commonly used in the energy sector, including fossil fuels such as coal and oil, as well as renewable energy sources such as solar, wind, and hydroelectric power [68,74]. The use of fossil fuels, particularly coal, has long been a dominant source of energy for many countries around the world. However, in recent years, there has been a growing recognition of the negative environmental and health impacts of fossil fuel use, leading to a shift towards renewable energy sources. This transition was driven by a number of factors, including concerns about energy security, environmental sustainability, and economic competitiveness operations [67,68]. Despite the many challenges associated with energy conversion, the use of renewable energy sources is increasingly being seen as a viable and necessary alternative to fossil fuels.

It can be observed in Figure 5 that coal has been a major energy production resource in many countries around the world, particularly in developing countries (India and China), where it is often the primary source of electricity. According to data from the World Bank, coal accounted for approximately 38% of global electricity generation in 2019, making it the most widely used fossil fuel for power generation [76]. In developed regions (US, Japan and Europe), the reliance on coal is often even higher, with many countries relying on coal for more than 50% of their electricity generation [77]. The use of coal for electricity generation has significant environmental impacts, including the release of greenhouse gases and other pollutants, which contribute to climate change and air pollution. Despite these impacts, the use of coal has continued to grow in many parts of the world, particularly in developing countries where economic growth and increasing energy demand have driven the expansion of coal-fired power plants. However, the U.S Energy Information Administration reported that the coal demand for electricity generation dropped to 10.7 quadrillion BTU from 14.26 quadrillion BTU in the previous year [78].

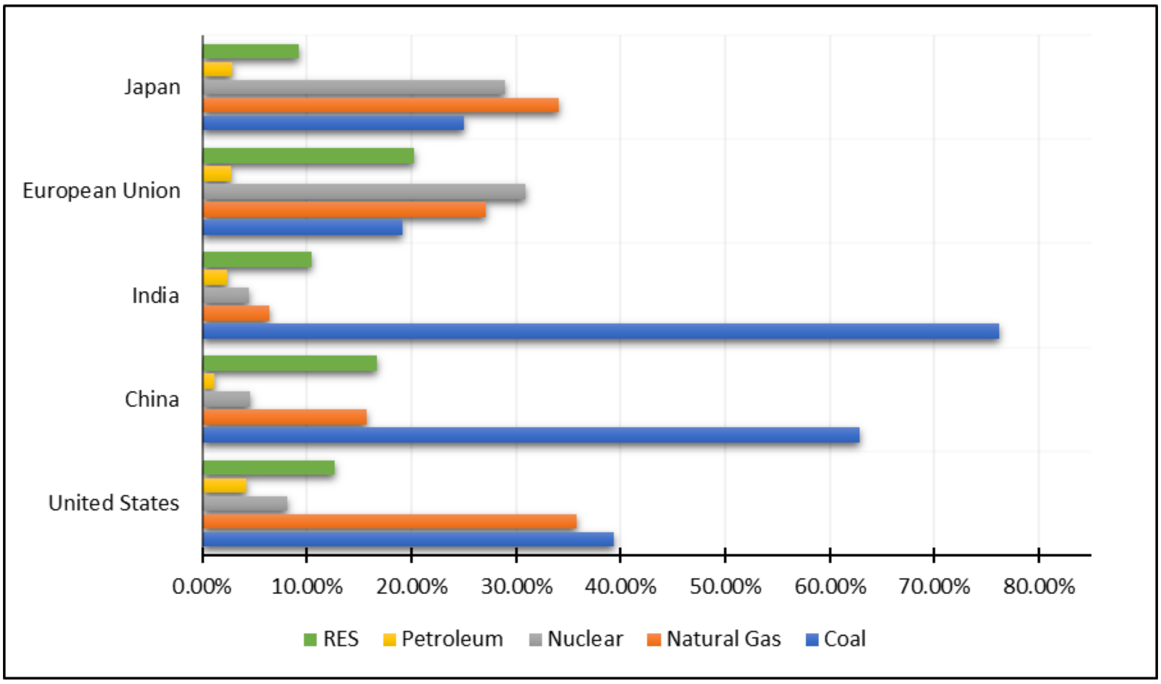


Figure 5. Energy usage for different countries in 2020 [77].

Other than coal, oil also has been one of the major energy production resources for many countries. During the early stages of the COVID-19 pandemic, major oil-producing countries, including Russia and Saudi Arabia, refused to reduce their production levels, leading to a surplus of oil on the global market [6,39,74]. This surplus, combined with a significant drop in global demand for oil due to the economic downturn caused by the pandemic, resulted in a sharp decrease in international oil prices. According to data from the International Energy Agency, the price of crude oil fell by more than 50% in the first quarter of 2020, reaching its lowest level in the market for more than two decades [39,74]. The drop in oil prices had a major impact on the global energy sector, leading to financial losses for many oil-producing countries and companies, as well as job losses and economic downturns in regions heavily reliant on the oil industry.

In response to these challenges, there has been a renewed focus on investing in building a more resilient power system that is based on RES. RES, such as solar and wind power, have the potential to provide a reliable source of energy that is cleaner and more sustainable than fossil fuels. According to data from the International Energy Agency (IEA), global investment in renewable energy reached a record high of $318.4 billion in 2015 and continued to increase in the following years. In 2017, the IEA reported that renewable energy capacity had reached a new record with around 161 GW of renewable capacity added globally, representing an increase of almost 9% over the previous year. These investments in RE were driven by a variety of factors, including concerns about climate change, the increasing cost competitiveness of RE compared to fossil fuels, and the potential for economic and job growth in the RE sector. Overall, the trend towards increased investment in RE and the building of a more resilient power system with RE sources was already well underway in the pre-pandemic period.

Other than that, one area of the energy sector that has seen significant growth in recent years is the adoption of electric vehicles (Evs). Evs are powered by electricity rather than fossil fuels, and they offer a number of benefits over traditional gasoline-powered vehicles. However, the widespread adoption of Evs has been slow, and many people continue to rely on gasoline-powered vehicles. This is due to a variety of factors, including the higher upfront cost of Evs compared to traditional gasoline-powered vehicles, limited availability of charging infrastructure, and concerns about the range and performance of Evs. Figure 6 shows the number of EV sales in different countries. China has the highest number of EV sales of over 3 million in 2021, followed by the US with over 600 thousand. Based on the figure, it can be observed that, in 2021, the EV sales from most of the countries increased significantly except of South Africa. According to data from the International Energy Agency (IEA), the global market share of electric cars was just 2.2% in 2019, and the majority of electric car sales were concentrated in a few regions, such as China, the United States, and Europe [79]. There were also significant differences in the adoption of Evs between developed and developing countries. In developed countries, the uptake of Evs was generally higher due to the presence of supportive policies and incentives, as well as the availability of charging infrastructure.

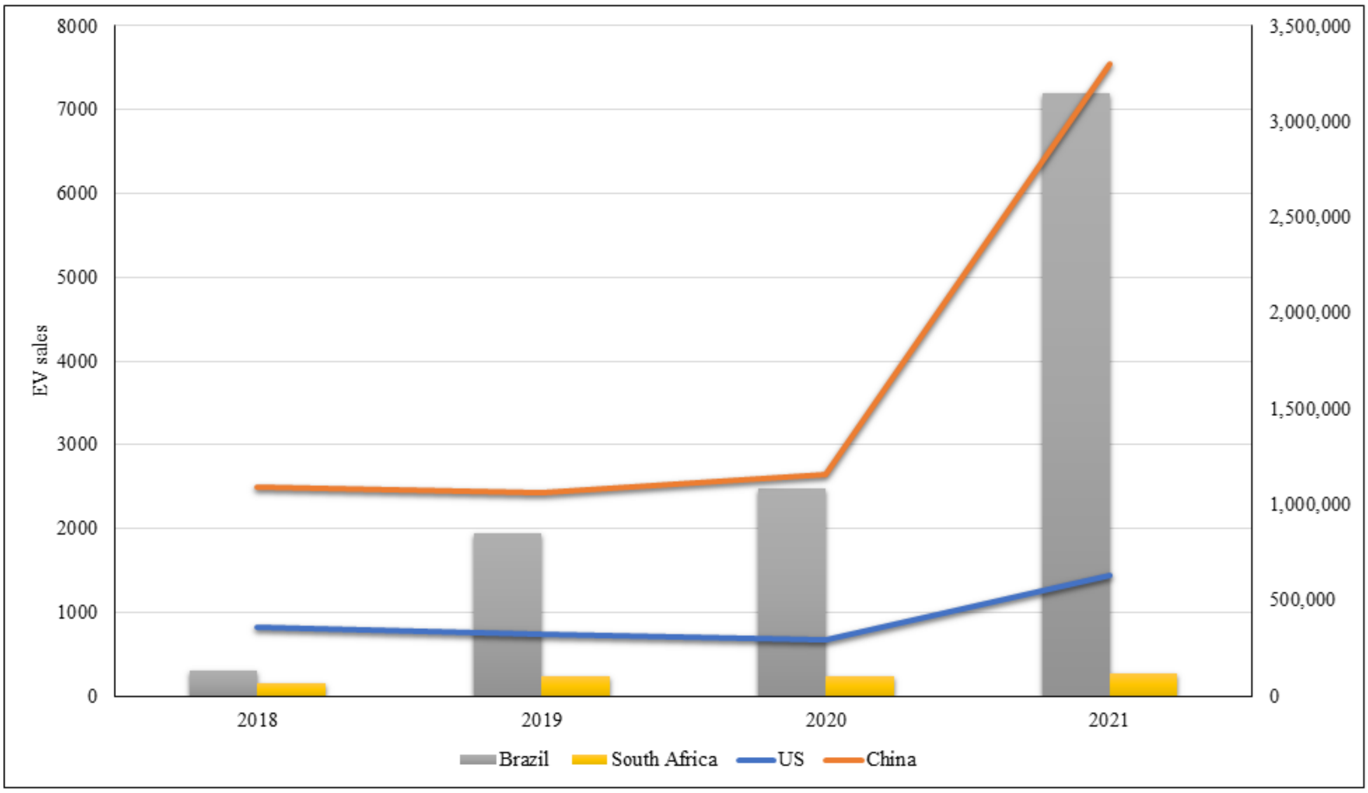


Figure 6. EV sales for developed countries (US) and developing countries (Brazil, South Africa, and China) from 2018 to 2021 [79].

In contrast, the adoption of Evs in developing countries such as South Africa was often limited by the lack of supportive policies, infrastructure, and consumer awareness. In many parts of the world, there were limited options for charging Evs, and gasoline-powered vehicles were more convenient and practical for most consumers. As a result, petrol stations were the dominant fuel source for transportation during this time, with most people relying on gasoline or diesel to power their vehicles. Petrol stations were a common feature of the energy sector, serving as the primary means of supplying fuel to vehicles. According to data from the International Energy Agency, global consumption of petroleum products reached 95 million barrels per day in 2019, with much of this consumption taking place at petrol stations [46]. In many countries, petrol stations are an integral part of the transportation infrastructure, providing a convenient and accessible source of fuel for cars, trucks, and other vehicles.

The energy sector saw a sharp decline in oil and gas demand in 2020 as a result of the pandemic, with global oil demand declining by 8.5% and natural gas demand declining by 2.5% [79] In response to the decline in oil demand and prices, there were efforts to transform the oil and gas market from a seller's market to a buyer's market and to re-boost the economy through the use of renewable energy alternatives [39,61,68]. Throughout 2020, there were numerous initiatives undertaken by governments around the world that aimed at reducing emissions from burning fossil fuels through increasing investments in renewable energies such as solar and wind power generation technologies. However, the pandemic also led to delays and stoppages of renewable energy initiatives, causing stress on national budgets, and affecting project developers, investors, and renewable energy industries.

As part of the effort towards achieving climate goals set by United Nations Framework Convention Climate Change (UNFCCC), energy storage systems must also be improved so that intermittent renewables can become viable options when it comes to providing baseload electricity demand. In terms of practical solutions, there are several approaches currently being explored, including advanced battery storage systems combined with smart grid management techniques. These strategies allow utilities companies to manage their load according to customers' needs, while maintaining reliable service even during high-peak demand periods or unexpected weather events. Additionally, thermal storage units using materials like molten salts provide large scale opportunities for storing excess solar thermal energy that is generated throughout the day for later release, such as at night, when it is needed the most. Finally, emerging hydrogen fuel cell technology provides a potential future solution, allowing the conversion of electrical currents directly into hydrogen gas, then storing until needed again and converted back into usable electric form via an electrolysis reaction.

One notable change has been the transformation of the oil and gas market from a seller's market to a buyer's market, as the pandemic has led to a significant drop in international oil prices. On the other hand, the transformation of the oil and gas market into a buyer's market has provided advantages to buyers, as it has weakened the political and monopolistic attributes of oil and gas, opening more opportunities for new energy sources, such as renewables. This shift has also led some countries to take steps to re-boost their economies by investing in renewable energy alternatives, in an effort to reduce their reliance on oil and gas. However, it is important to note that the reduction in carbon emissions and pollution, which occurred during the pandemic, will likely be temporary, and the adverse factors associated with fossil fuel use will likely rebound quickly after the complete end of the pandemic if no policies are put in place to support a transition to cleaner, more sustainable energy sources.

Many RE projects were delayed or stopped due to the pandemic, which has had a range of consequences. One effect has been the emergence of new research areas in emergency medical management, disaster management, and power system management as a result of the pandemic. This has led to a greater focus on resilience and sustainability in the energy sector and has highlighted the importance of developing systems that are better equipped to cope with crisis situations. The delay or stoppage of RE initiatives has also had a significant financial impact, particularly on project developers, investors, and RE industries. Many of these parties have been deeply affected by the pandemic and have faced significant challenges as a result of the economic downturn and reduced demand for energy. This has had a knock-on effect on the national budget, and has put stress on lawmakers, governments, and the politics of different countries to decide how to allocate resources and support the energy sector. According to International Renewable Energy Agency (IRENA), the pandemic has had a particularly negative impact on the solar and wind energy sectors, with many projects experiencing delays or cancellations as a result of the pandemic. The organization estimates that the total investment in renewable energy fell by almost 20% in 2020, with the solar and wind sectors being the most heavily impacted.

3.5. Environmental

Sustainable energy development is critically important to reduce climate change, which is one of the greatest challenges nowadays. Additionally, sustainable energy development is important to ensure access to energy for quality-of-life reasons and for economic development. Governments and organizations worldwide were implementing policies and initiatives to reduce carbon emissions, increase the use of renewable energy and shift towards a low-carbon economy, before the outbreak of COVID-19. This led to an increased focus on developing and using renewable energy sources, such as solar, wind, and hydropower, as well as efforts to improve energy efficiency. Furthermore, there was also a growing awareness and concern among consumers and investors about the impact of energy production and consumption on the environment, which led to increased demand for sustainable energy options. Based on the data from The World Bank Group regarding the carbon dioxide (CO_2) emissions, China, USA, India, Russia, and India are the world's largest CO_2 emitters [80]. The trend of CO_2 emissions from these countries keeps increasing every year as shown in Figure 7. China is the largest emitter of CO_2 in the world where the primary source of CO_2 emissions is come from fossil fuels, most notably those that burn coal in power and industrial plants, whereas the USA is the second largest emitter of CO_2 that came from transportation, power generation, and industry. Coal is the main energy source for India that contributes to CO_2 emissions, meanwhile natural gas is the primary source of energy and power generation in Russia that make it the fourth-largest contributor to CO_2 emissions in the world. In contrast, the primary source of CO_2 emissions in Japan came from oil and nuclear gas [81].

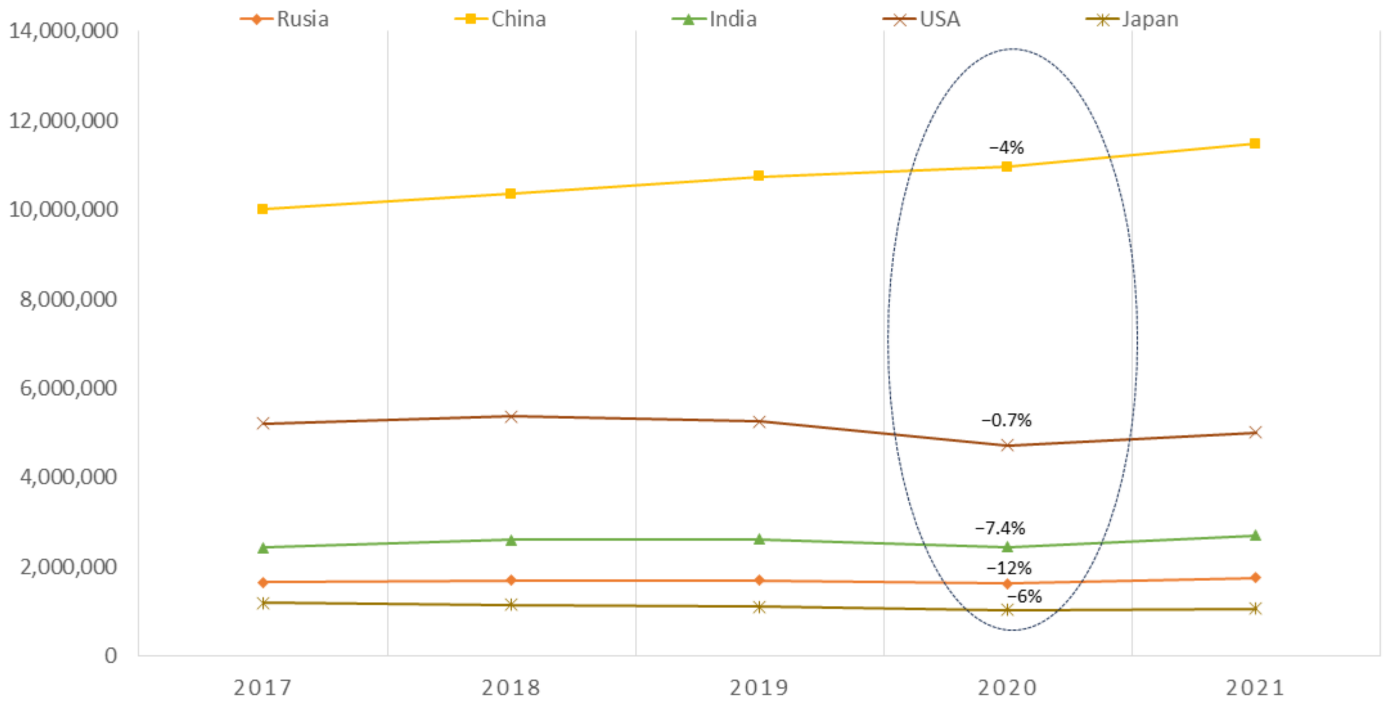


Figure 7. CO_2 emission from five largest emitter's countries from 2017–2021.

The outbreak of the COVID-19 pandemic in December 2019 in the Chinese city of Wuhan has had a significant impact on the environment, which globally decreased CO_2 emissions. As can be seen in Figure 7, all five major CO_2 emitters have reduced in comparison to 2019. Russia significantly reduced CO_2 emissions by 12% during the pandemic, followed by a 7.4% reduction from India, 6% from Japan, 4% from China, and USA reduced by only 0.7%, respectively. One of the most notable impacts has been a decrease in energy demand and a corresponding reduction in greenhouse gas emissions, which is the primary reason for a sustainability environment. This decrease in energy demand and emissions can be attributed to the lockdowns, travel restrictions and economic downturn since they have decreased the use of fossil fuels for transportation and industry. During the early stages of the pandemic, many countries implemented lockdowns to reduce the crowding of people, which increased the possibility of massive virus transmission to the community. Lockdown involves restricting movements, shutdown of economic activities and restriction of social engagements, including airports for international and local air travel, schools, markets, and industries, and limiting social activities such as weddings and sports. Only essential activities such as medicals, food business, banks, communication, and utilities were allowed to operate during the pandemic. However, they were required to strictly follow the Standard Operating Procedure (SOP) implemented by the government.

The lockdown implementation of the work-from-home policy apparently affected transportation energy consumption. For example, in the United States, transportation energy consumption fell by 27% in April 2020, compared to the same month in 2019 [82]. In fact, the decreasing number is the lowest monthly transportation energy consumption in the United States since May 1983. Other countries such as Japan, Brazil, and Italy also experienced the lowest energy consumption during the pandemic due to the implementation of the work-from-home policy. This decrease in transportation energy consumption, especially for highly populated countries, led to a reduction in overall energy demand and the vehicles combustion by-products particularly carbon dioxide and nitrogen dioxide dropped accordingly.

The positive impacts of lockdown implementation during a pandemic are not only towards air quality, but also other aspects of the environment, such as water, noise pollution and waste management. Many studies have discussed the impact of lockdown on the environment of highly populated countries such as China, India, Spain, and the USA [83]. While CO_2 emissions were most discussed, greenhouse gases, which play a major role in global warming, there are also studies about the emission of nitrogen oxide, which plays a role in atmospheric reactions that produce ozone and fine particulates, harming health. Generally, the reduction in concentrations of carbon dioxide and nitrogen dioxide across the major cities of the world positively impacts the environment where the air quality is highly improved. Wang et al. [84] reported the sudden drop of nitrogen dioxide over China in early 2020 during the COVID-19 outbreak and the lockdown period. This was similar to other countries, such as Spain and the USA, where the nitrogen dioxide levels reduced compared to the same month (January–May 2020) of the previous year. Another study by Zambrano–Monserrate et al. discussed the other aspect of the environment, where they reported on the reduction of noise pollution due to a reduction in commercial activities and public transportation [85]. The study also reported on the reduction of beach and coastal water contamination, which is seen globally, where quarantine measures exist due to fewer commercial activities, industrial contamination, and agricultural wastewater. Obviously, the sudden shut off of all types of industrial, economic, and social activity due to the COVID-19 outbreak has provided advantages to nature, with an improvement in air quality, cleaner water and less noise pollution.

Besides the positive impact, the lockdown implementation due to COVID-19 transmission also has negative impacts. During the pandemic, the government enforced a new policy where wearing a mask was necessary to prevent COVID-19 transmission. On the other hand, it was also encouraged to put on gloves to avoid virus transmission. The frequent use of masks and gloves has become an additional source of plastic usage, which led to plastic contamination during the pandemic [86]. Additionally, plastic contamination increases with poor disposal management during the lockdown. Patricio Silva et al. discussed the impact of plastic pollution due to COVID-19 in their review paper [87]. Even though plastic pollution was highlighted as an environmental problem a few years ago, the COVID-19 incidence has made it worse because of the increase in the use of personal protective equipment (PPE) such as face masks and gloves by medical staffs and healthcare workers, and later by ordinary citizens.

Apart from that, the negative impacts of the COVID-19 can be seen when there is an increase in the water consumption and energy consumption. A study by Rouleau and Gosselin showed that energy consumption changed drastically for the first two months of the lockdown when the most intensive movement restrictions were applied [88]. It was observed that the increased energy expenditures are 46% higher throughout the day than before lockdown, resulting in higher energy bills for consumers. Therefore, the stay-at-home policy during the lockdown comes with a cost, especially for those living in large suburban houses. These homes are not as energy efficient on average as schools and offices. Indeed, the COVID-19 outbreak has significantly impacted environmental conditions, indoors or outdoors.

The study on the positive and negative environmental impact can be a useful guideline to governments in planning and developing new policies to control global environmental pollution and carbon emissions with strategies for sustainability in the pandemic period, which may continue for long periods in the future. Different from during the pandemic, the post-COVID-19 period is more significant to highlight, as worldwide struggles to live in a new normal contrast towards a new future as a result of the pandemic. The focus on economic recovery has disadvantages towards environmental conditions when industries are allowed to continue with their normal practices that are harmful to the environment. These positive environmental effects, as discussed in the previous paragraph, have started to vanish as various activities resume to normal levels [89]. The energy demand increases, and highly polluted atmosphere gas emits again. For example, as shown in Figure 7, the five largest CO_2 emitter's countries have increased their CO_2 emissions in 2021, with Russia and India having the largest increases in relative terms (10.5% and 8.1%, respectively) [90]. However, because of COVID-19, many countries have announced ambitious plans to invest more in renewable energy and sustainable infrastructure. Even though the effects of the pandemic towards the environment are hard to determine, as the pandemic is still ongoing in many countries, it is clear that the pandemic has highlighted the importance of environmental protection and the urgent need to address climate change.

3.6. Energy Market

A number of trends have characterized the global energy market since before COVID-19 hit the world, where the major trend was the increasing use of renewable energy sources. Many countries have set the targets for increasing their use of renewable energy, including wind and solar electricity, as they offer several benefits compared to fossil-fueled electricity generation. As shown in Figure 8, the largest sources of CO_2 came from the energy sector, which includes electricity, heat, and transport. Therefore, the government put more effort into decarbonizing the energy sector, such as supporting the growth of renewable energy to reach net-zero emissions in the near future. According to the forecast from International Energy Agency (IEA) in the Renewables 2018 reports, the energy market based on renewable energy will have the fastest growth in the electricity sector, providing almost 30% of power demand in 2023, up from 24% in 2017 [91]. During this period, renewables are forecast to meet more than 70% of global electricity generation growth, led by solar PV and followed by wind, hydropower, and bioenergy. Hydropower remains the largest renewable source, meeting 16% of global electricity demand by 2023, followed by wind (6%), solar PV (4%), and bioenergy (3%). In our opinion, single solutions, such as replacing fossil fuels with renewable energy, are insufficient to reach net-zero emissions because other sectors, as shown in Figure 8, also need solutions to reduce CO_2 emissions.

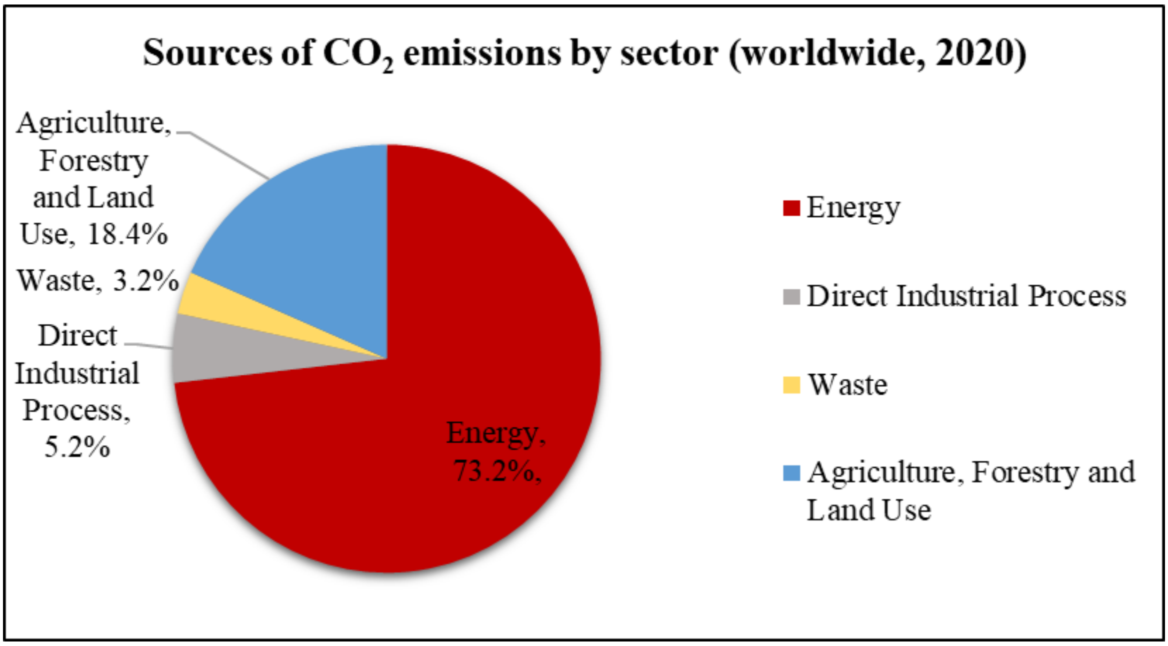


Figure 8. Sources of CO_2 emissions by sector [92].

The unexpected outbreak of COVID-19 has witnessed changes in the energy market when the energy demand has decreased significantly. This resulted in lower prices for oil, natural gas, and other energy sources, leading to financial loss in energy businesses. The reason is due to the new policy implemented to control the spread of the virus, such as lockdowns, travel and social restrictions, and economic recession. The reduced electricity demand during the lockdown tends to lift the share of renewables in the electricity supply, such as the rise in the direct contribution of electric heating and heat pumps to renewable heat consumption. However, the effect overall is insignificant. In fact, renewable energy production and consumption have been severely influenced by the COVID-19 pandemic. More specifically, the unexpected decline in energy production caused a serious disruption in worldwide renewable energy production. Since before the pandemic, governments worldwide recognized the importance of transitioning to renewable energy sources to address the environmental problems caused by carbon dioxide emissions. The government has implemented many policies and programs to encourage the use of renewable energy sources, such as solar, wind, hydroelectric power, and biomass. For this purpose, governments offer incentives, such as tax credits, subsidies, or grants, to encourage the adoption of renewable energy technologies. However, the unexpected pandemic of COVID-19 has slowed down the progress of renewable energy development. For example, the pandemic has interrupted renewable energy projects, especially in actively involved regions, such as USA, China, India, and EU, because of the lack of funding allocation due to lockdown measures [93]. Moreover, the supply chain of renewable energy is also seriously disrupted due to the large-scale closure of economic activities. Lack of support from the government also seemed to be a factor that has distracted the developers of this energy [94].

From the environmental perspective, as discussed in Section 3.5, COVID-19 has mainly helped to achieve what the global efforts over the years have failed to achieve with the environment, where carbon emission is greatly reduced. Still, the spread of the pandemic had a more negative impact towards the economic sector, which caused the energy market to collapse, the stock market to crash and the global economy to slow [95]. One of the factors that triggered panic in the global market economy was the decline in crude oil and coal prices. On 20 April 2020, where the highest number of COVID-19 cases were recorded, crude oil fell to a negative value, which was the first time in history [96]. The price of coal also fell on 27 April 2020, which caused the market to enter a depression. Since then, many papers have been published to analyze the impact of COVID-19 on the energy market. For example, a study by Szczygielski et al. found that COVID-19 has added uncertainty to the energy markets of all countries [97]. Narayan analyzed the impact of COVID-19 and fluctuations in oil prices on future oil prices [98]. In addition, Huang and Zheng focused on the relationship between investor sentiment and crude oil futures prices during the COVID-19 [99].

Furthermore, studies by [100] observed the negative impacts of the pandemic, such as inflation, unemployment, and bankruptcy. Also, unstable politics and war might happen if the COVID-19 pandemic is not controlled. Due to the economic recession during the pandemic, industries could stop manual operations. Hence, it will affect the finances of ordinary citizens who work in the industrial sector. Moreover, the pandemic era has witnessed a heavy dependency on internet connectivity. For example, before the pandemic, payment transactions were based on physical payment; however, due to COVID-19, most transactions are preferred via online payment. Undoubtedly, online transactions are easier, faster, and improve customer service experience. Additionally, contactless payment is an excellent way to prevent COVID-19 transmission. Nevertheless, the dependency on internet connectivity makes people from isolated or not congested areas experience fewer difficulties, such as lag in online payments due to lower internet speeds.

Overall, the COVID-19 pandemic has significantly impacted the energy market, leading to a decrease in energy demand and a corresponding reduction in prices for many energy supplies. Renewable energy sources, such as wind and solar, also decreased in investment and construction activity as the pandemic caused supply chain disruptions and made it difficult for workers to safely continue building projects [101]. It is important to note, however, that these impacts are likely to be temporary, and it will be important for the energy sector to adapt to the challenges posed by the pandemic in order to continue to meet the energy needs of societies around the world. As the world economy recovers, energy demand also recovers, but at a different rate among different countries and energy forms. For example, China has recovered much quicker than other countries, which may lead to different recovery rates for the oil, coal, and the natural gas market. The analysis of the energy market from time to time is necessary, in order to obtain updates for reference and guidelines to benefit the future energy market, helping to shift towards more sustainable and secure energy systems.

3.7. Power System Operation

Power system operation is the process of controlling and coordinating the generation, transmission, and distribution of electricity in a power system, which is a vital function that helps to ensure the reliable, stable, and efficient delivery of electricity to consumers. Before the pandemic, power prices were relatively stable, as reported by EIA from 2016 to 2018 [82]. Power generators were also able to earn consistent profits. In addition, power companies were able to plan and predict future demand and supply with a certain level of accuracy. Conventional power plants are currently the predominant source of system flexibility in modern power systems [102]. To maintain a power system's reliability, stability, and efficiency of a power system, it is necessary to conduct periodic maintenance for the power system, usually performed by physical or on-site work.

The lockdown Implementation during the COVID-19 pandemic had big consequences for power system operation, where the physical maintenance work for power plants were suspended to prevent the threat of COVID-19 for employees. It was a challenging phase for the power system industry, as flexibility resources are not fully developed enough to replace conventional power plants.

Many strategies are available to further develop power plants' flexibility resources, including wind and solar photovoltaic power plants. However, as COVID-19 spreads further, power consumption continues to drop and has also caused many companies to dump more investment into solar photovoltaic generation [103]. Since then, by nurturing

VPP technologies, a plan for sustainable energy has been pushed forward to adapt to the pandemic era. VPPs used advanced algorithms and control technologies, such as a decentralized network of distributed energy resources, to provide the same services as a traditional power plant, such as generation, transmission, and electricity distribution. As a relatively new concept, developing and operating VPPs, especially during the pandemic, is quite challenging in overcoming regulatory and technical issues. Some potential impacts of the COVID-19 pandemic on VPPs implementation include cost increases due to supply chain disruptions, changes in labor costs, or other economic impacts. In addition, the VPP projects may have experienced delays due to difficulties coordinating remote teams. Regardless of the challenges in developing VPPs, it is worth continuing with the plan, as VPPs can transform the way electricity is generated and distributed and could play a significant role in the future energy system. Virtual working practices take advantage of the COVID-19 incidence and highlight novel practices in the operation and management of power systems, such as non-operator substations. However, regular operation maintenance costs of the system are higher than normal practices before the pandemic.

Power system operation can also play a role in promoting sustainable energy practices. For example, power system operators can prioritize using renewable energy sources and implement demand-side management strategies to reduce energy consumption and greenhouse gas emissions. The challenge to stabilize the power system with renewable energy existed and was discussed even before the pandemic. One major challenge is the intermittent nature of renewable energy sources [104]. Solar panels and wind turbines do not produce electricity constantly, as they rely on the availability of sunlight and wind, respectively. This means that the power output from these sources can vary significantly over short periods of time. To address this issue, grid operators must find ways to store excess energy when it is available and quickly ramp up conventional power sources when renewable energy production drops.

Another challenge is the integration of RES into the power grid. A study conducted by Swain et al. [105] addressed this issue and looked for a solution, particularly the stability of voltage, through controlling reactive and active power. The power grid was designed to transmit electricity from a central generation source to consumers, but renewable energy sources are often distributed and located closer to the end users. This can create issues with the transmission and distribution of power, as well as the overall stability of the grid. A study by Madurai Elavarasan et al. [106] reported that a sudden load demand reduction during lockdown caused an overvoltage in transmission and distribution networks in India. Due to this reason, the voltage must be controlled by raising the grid stability and retaining a constant voltage at the power stations. To overcome this and similar problems, the Indian power sector took a few precautionary measures, such as ensuring full-service of all reactors for overvoltage control, in order to maintain grid stability. Additionally, they used capacitor banks, which were equipped with wind generators, and utilized reactive power.

Meanwhile, Japan has increased the renewable energy power generation, such as photovoltaic (PV), in the public grid to overcome the total-load demand reduction [107]. However, the increased use of PV power generation has reduced electricity prices. Considering the economic constraints, it is necessary to maintain PV power generation with lower marginal costs by adjusting the generation structure, for example, increasing the energy storage capacity of non-schedulable continuous generation units. Strengthening power grid stability also has caught the attention of ASEAN's countries to tackle the demand for power that has increased in 2021, during the post-COVID-19 period. Several approaches were taken, including the digitalization of the power sector to ensure a stable and resilient power system. Malaysia has announced that it uses Capgemini and Google Cloud software to implement an Application Programming Interface (API) infrastructure for the nation's largest power provider: Tenaga Nasional Berhad [108]. In addition, Vietnam's National Power Development Plan 8 (PDP8) revision includes allocating $32.9 billion over 2021–2030 to improve grid infrastructure [109]. Furthermore, the Philippines plans to scale up its battery storage capacity to secure power stability [110].

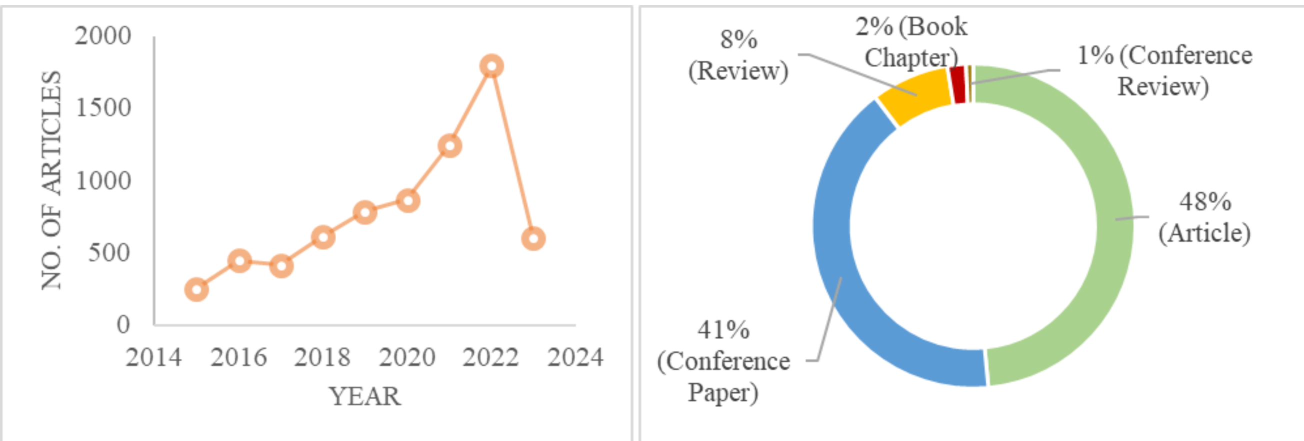
Finally, the pandemic has taught that power operation systems have had to adapt to changes in the supply and demand of electricity. Some systems have had to reduce their electricity generation or find alternative sources of energy in order to meet the reduced demand. In some cases, power operation systems have had to implement measures to manage the excess capacity that has resulted from the decrease in demand. After the critical period of the pandemic, energy demand is slowly recovering, which may not be a serious challenge. However, the huge amount of power changes after the pandemic is important to note. In this regard, load profile changes must be monitored carefully. In conclusion, power operation systems must continue to be flexible and adaptable to meet the changing energy needs of societies worldwide, especially to adapt to the new, post-world pandemic.

3.8. Application of Artificial Intelligence in Energy Sector

Energy systems with various energy sectors are undergoing a paradigm shift toward clean and sustainable energy sources that involve technological upgrades, such as energy generation, transmission, and distribution. The application of AI-based techniques is becoming popular in solving the planning and operation of the energy system, as AI has the potential to overcome the limitations of conventional modeling techniques. Additionally, the study shows that AI has numerous applications and potential benefits in the energy sector, which could bring significant benefits in terms of efficiency, cost-effectiveness, and sustainability. In a study conducted by [12], artificial neural networks were utilized to assess overvoltage in power systems. The findings revealed that employing artificial neural networks enabled accurate discrimination between switching and fast-front overvoltage, achieving an impressive accuracy rate of 95.5%. Moreover, the efficacy of the AI model in predicting electricity demand is shown in a study by Ghimire et al. [111]. Utilizing a hybrid deep learning model, comprising Convolutional Neural Networks and Echo State Networks algorithm, the study demonstrates that prediction accuracy can reach an impressive 95%. AI's versatility extends to developing smart energy management systems that optimize energy usage and reduce wastage. Advanced algorithms and machine learning techniques can discern patterns in energy consumption, enabling accurate predictions of future energy demands. This empowers energy providers to optimize their supply chain and grid management, fostering a more efficient and sustainable energy landscape [112]. In addition, robotics systems and automation can be utilized in predictive maintenance, where robots can be used to monitor equipment and predict potential failures or maintenance needs, ensuring that equipment is maintained before a failure occurs. This can reduce downtime, extend equipment lifespan, and improve safety [113]. Collecting and analyzing large volumes of data can also assist energy providers in optimizing operations, improving energy efficiency, and enhancing customer satisfaction. Handling big data analysis in a short time is only possible with AI-based technology. Furthermore, enabling technologies of IoT in the energy sector, including cloud computing and different platforms for data analysis, can improve energy efficiency, increase the share of renewable energy, and reduce the environmental impacts of energy use [61,64].

Today, AI technologies play a key role in every aspect of the COVID-19 crisis, including the energy sector. A SEIS model incorporating artificial intelligence has been developed to forecast energy demand, as a time series, based on hours, days and weeks [13,62]. The Artificial Neural Network (ANN) technique is a common structure to formulate the mathematical algorithm of AI [114]. In addition, automation and virtual operation became more popular during COVID-19 because the government restricted social movement to minimize virus infection through physical interaction. When human activity is halted, they begin to consume their needs from online platforms, which led to logistic limitations because the demand requested could not be satisfied. Robotic system technology has eased the concern and helped resume usual business operations. Autonomous robots are the executors of intelligent digital technology [22]. This is one of the motivations for maintaining the supply chain survivability in the O&G industry mentioned by the paper [115]. During COVID-19, the oil and gas industry can be mobilized, though these robotic systems are programmed with AI algorithms. ExxonMobil and MIT are robots powered by AI to detect oil seeps located at the seabed and their coverage area has been widened by allowing deeper exploration, able to reach extreme sport without risking any life [116]. The lesser human intervention also reduces human error: another justification of its efficiency point.

The advent of the IoT allows a system to be managed and automated remotely. A study paper applied the IoT in the lighting system as a response to COVID-19 pandemic to address the issue of rising electricity bills that were affected by the stay-at-home orders implementation [65]. They experimented on ESKOM's billing system, a power provider company located in South Africa, to investigate energy wastage by observing two factors: light intensity and powered-on duration. Less carbon gas was emitted into the air due to low power generation and is seen as a solution to one of the many environmental problems. Plus, it is understood that the majority of South Africa's energy mix are from non-sustainable products [117]. Aside from lighting system, this technology was also typically found in buildings integrated with an RE system for a similar objective [29,118]. It aids in securing human interactions during the COVID-19 pandemic, when most communication happened digitally. Big data efficiency has been proven to facilitate the speed of processing an image/data, the capacity to process data at a time and data arrays are taken into consideration to help supervise social harmony in the heat of COVID-19 [40]. To conclude this section, AI application in the energy sector has been established since IR 4.0 was practiced in the industry. The COVID-19 incident only strengthened the practice and forced more nations into integrated green energy systems. Figure 9a shows the number of publications in AI-related to the energy sector from 2015 to 2023. It shows the increasing trends in the number of publications from 2015 to 2022, which proved that AI research and development is gaining more attention in parallel with the rapidly increased energy demand. Due to the importance of managing this demand without compromising on the environment, the utilization of AI in the energy sector is essential to help optimize and reduce energy consumption with minimal environmental impact on energy production. This will lead to numerous research works and a high number of future publications. Therefore, it is predicted that the number of publications will be increased towards the end of 2023. Figure 9b also proved that AI research and development in technologies is actively performed; the number of articles published is 48%, followed by 41% from conference papers.



(**a**) (**b**)

Figure 9. (**a**) Number of articles published on AI within the energy sector from 2015 to 2023. (**b**) Type of documents published based on the number in (**a**).

4. Recommendation

The energy sector is one industry that stands to gain significantly from implementing AI technologies after the pandemic crisis. Analyzing everything from energy production to delivery, customer engagement, and strategic planning is the most significant to ensure the energy system management's efficiency. Developing AI strategies can improve operational efficiency, safety, and regulatory compliance, while balancing the potential implementation costs. It is also important for policy makers and energy companies to work together to develop strategies for building a more resilient and sustainable energy system, in order to withstand the challenges posed by future crises. Additionally, energy companies and policy makers must invest in data collection, data analytics (to provide knowledge/profiling) and analysis technologies to improve their understanding of past and present energy consumption patterns and prepare themselves for future changes. They must ensure that the data they collect is accurate, complete, and reliable to obtain accurate insights. Furthermore, it is highly recommended that customer privacy regulations be considered when implementing new technologies within the energy sector to ensure compliance with relevant laws and guidelines. Addressing these concerns early in the AI implementation process is crucial to ensuring a smooth and effective implementation. Additionally, energy companies should focus on energy security for developing countries by improving access to energy and increasing the actions toward moving towards RE. Like many other energy sectors, the RE industry also has been severely impacted by the COVID-19 pandemic. It is highly recommended that the RE sector focus on investing in digital technologies to facilitate remote operations, such as implementing cloud technology, AI, and automation, which can assist the industry in streamlining their process and improve their capabilities to manage RE assets. In addition, there should be more innovation in the RE sector as a key role in driving the success of the RE sector during and after the pandemic. More investment in research and development is required to achieve this goal. Additionally, more collaboration and public-private partnerships should be created to help generate investment in the sector, promote large-scale adoption of RE sources, and achieve RE policies. Furthermore, governments and/or private organizations should continue to invest in AI talent to deliver the necessary expertise needed to implement AI into the energy sector.

5. Conclusions

In conclusion, the COVID-19 pandemic has significantly impacted the energy sector by disrupting supply chains, causing a decrease in demand, and affecting oil prices. The pandemic crisis also has created new challenges for the energy sector, where there is a need for greater resilience and adaptability in the sector during a global health and economic crisis. However, the pandemic has also presented an opportunity for the integration of AI-based technology in the energy sector. Research shows that AI has the potential to help utilities and energy companies optimize their operations, reduce costs, and increase efficiency. Through the use of digital technologies like cloud computing, automation, and machine learning, AI systems can improve the efficiency of energy production and distribution, reducing costs and carbon footprints. In conjunction with the global policies to achieve a sustainable and cleaner energy source, implementation of AI in the energy sector can play a vital role in achieving these goals. With the right applications of AI in the energy sector, sustainability issues can be addressed while simultaneously meeting energy demands. While AI adoption in the energy sector is still in its early stages, the potential benefits are vast, and the adoption trend is rising. Renewable energy and sustainability have become more prominent than ever, and AI can help achieve these goals. The review of the impact of the pandemic in the energy sector and the implementation of AI in energy has shown that there is a need for the industry to be more adaptive, innovative, and flexible in the face of the emerging challenges. In the future, it is crucial that the industry continues to invest in digital transformation and leverages the power of AI to drive innovation and sustainability. Only through such strategic measures can the industry overcome the challenges posed by the pandemic and successfully transition to a more sustainable future.

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References

1. The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The Epidemiological Characteristics of an Outbreak of 2019 Novel Coronavirus Diseases (COVID-19)-China, 2020. *China CDC Wkly.* **2020**, *2*, 113–122. [CrossRef]
2. Mohan, B.; Vinod, N. COVID-19: An Insight into SARS-CoV2 Pandemic Originated at Wuhan City in Hubei Province of China. *J. Infect. Dis. Epidemiol.* **2020**, *6*, 146. [CrossRef]
3. International Energy Agency (IEA). Global Energy Review 2020. 2020. Available online: https://www.iea.org/reports/global-energy-review-2020/electricity (accessed on 31 July 2023).
4. Bielecki, S.; Dukat, P.; Skoczkowski, T.; Sobczak, L.; Buchoski, J.; Maciag, Ł. Impact of the Lockdown during the COVID-19 Pandemic on Electricity Use by Residential Users. *Energies* **2021**, *14*, 980. [CrossRef]
5. Çelik, D.; Meral, M.E.; Waseem, M. The progress, impact analysis, challenges and new perceptions for electric power and energy sectors in the light of the COVID-19 pandemic. *Sustain. Energy Grids Netw.* **2022**, *31*, 100728. [CrossRef]
6. Wang, B.; Yang, Z.; Xuan, J.; Jiao, K. Crises and opportunities in terms of energy and AI technologies during the COVID-19 pandemic. *Energy AI* **2020**, *1*, 100013. [CrossRef]
7. Madurai Elavarasan, R.; Pugazhendhi, R.; Jamal, T.; Dyduch, J.; Arif, M.T.; Manoj Kumar, N.; Nadarajah, M. Envisioning the UN Sustainable Development Goals (SDGs) through the lens of energy sustainability (SDG 7) in the post-COVID-19 world. *Appl. Energy* **2021**, *292*, 116665. [CrossRef]
8. Belaïd, F. Implications of poorly designed climate policy on energy poverty: Global reflections on the current surge in energy prices. *Energy Res. Soc. Sci.* **2022**, *92*, 102790. [CrossRef]
9. Stanelyte, D.; Radziukyniene, N.; Radziukynas, V. Overview of Demand-Response Services: A Review. *Energies* **2022**, *15*, 1659. [CrossRef]
10. Tao, H.; Salih, S.Q.; Saggi, M.K.; Dodangeh, E.; Voyant, C.; Al-Ansari, N.; Yaseen, Z.M.; Shahid, S. A Newly Developed Integrative Bio-Inspired Artificial Intelligence Model for Wind Speed Prediction. *IEEE Access* **2020**, *8*, 83347–83358. [CrossRef]
11. Waraga, O.A.; Talib, M.A.; Bettayeb, M.; Ghenai, C.; Nasir, Q.-S. A framework application for improving energy demand forecasting using digital twining. In Proceedings of the 2nd International Conference on Distributed Sensing and Intelligent Systems (ICDSIS 2021), Online, 30–31 July 2021; Institution of Engineering and Technology: Stevenage, UK, 2021; pp. 95–105.
12. Mehinović, A.; Grebović, S.; Fejzić, A.; Oprašić, N.; Konjicija, S.; Akšamović, A. Application of artificial intelligence methods for determination of transients in the power system. *Electr. Power Syst. Res.* **2023**, *223*, 109634. [CrossRef]
13. Fallah, S.; Ganjkhani, M.; Shamshirband, S.; Chau, K. Computational Intelligence on Short-Term Load Forecasting: A Methodological Overview. *Energies* **2019**, *12*, 393. [CrossRef]
14. Ahmad, T.; Zhang, D.; Huang, C.; Zhang, H.; Dai, N.; Song, Y.; Chen, H. Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities. *J. Clean. Prod.* **2021**, *289*, 125834. [CrossRef]
15. Li, X.; Zhang, W.; Ma, H.; Luo, Z.; Li, X. Degradation Alignment in Remaining Useful Life Prediction Using Deep Cycle-Consistent Learning. *IEEE Trans. Neural Netw. Learn. Syst.* **2022**, *33*, 5480–5491. [CrossRef]
16. Zhao, N.; Zhang, H.; Yang, X.; Yan, J.; You, F. Emerging information and communication technologies for smart energy systems and renewable transition. *Adv. Appl. Energy* **2023**, *9*, 100125. [CrossRef]
17. Li, J.; Herdem, M.S.; Nathwani, J.; Wen, J.Z. Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management. *Energy AI* **2023**, *11*, 100208. [CrossRef]
18. Bojanovský, J.; Máša, V.; Hudák, I.; Skryja, P.; Hopjan, J. Rotary Kiln, a Unit on the Border of the Process and Energy Industry—Current State and Perspectives. *Sustainability* **2022**, *14*, 13903. [CrossRef]
19. Liu, Z.; Sun, Y.; Xing, C.; Liu, J.; He, Y.; Zhou, Y.; Zhang, G. Artificial intelligence powered large-scale renewable integrations in multi-energy systems for carbon neutrality transition: Challenges and future perspectives. *Energy AI* **2022**, *10*, 100195. [CrossRef]
20. Singh, R.; Akram, S.V.; Gehlot, A.; Buddhi, D.; Priyadarshi, N.; Twala, B. Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability. *Sensors* **2022**, *22*, 6619.
21. Amir, M.; Khan, S.Z. Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa. *Energy Built Environ.* **2022**, *3*, 348–362. [CrossRef]

22. Mitchell, D.; Blanche, J.; Harper, S.; Lim, T.; Gupta, R.; Zaki, O.; Tang, W.; Robu, V.; Watson, S.; Flynn, D. A review: Challenges and opportunities for artificial intelligence and robotics in the offshore wind sector. *Energy AI* **2022**, *8*, 100146. [CrossRef]
23. Chawla, Y.; Shimpo, F.; Sokołowski, M.M. Artificial intelligence and information management in the energy transition of India: Lessons from the global IT heart. *Digit. Policy Regul. Gov.* **2022**, *24*, 17–29. [CrossRef]
24. Kumbhar, A.; Dhawale, P.G.; Kumbhar, S.; Patil, U.; Magdum, P. A comprehensive review: Machine learning and its application in integrated power system. *Energy Rep.* **2021**, *7*, 5467–5474. [CrossRef]
25. Adekanbi, M.L. Optimization and digitization of wind farms using internet of things: A review. *Int. J. Energy Res.* **2021**, *45*, 15832–15838. [CrossRef]
26. Mabina, P.; Mukoma, P.; Booysen, M.J. Sustainability matchmaking: Linking renewable sources to electric water heating through machine learning. *Energy Build.* **2021**, *246*, 111085. [CrossRef]
27. Baashar, Y.; Alkawsi, G.; Alkahtani, A.A.; Hashim, W.; Razali, R.A.; Tiong, S.K. Toward Blockchain Technology in the Energy Environment. *Sustainability* **2021**, *13*, 9008.
28. Chatterjee, J.; Dethlefs, N. Scientometric review of artificial intelligence for operations & maintenance of wind turbines: The past, present and future. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111051.
29. Halhoul Merabet, G.; Essaaidi, M.; Ben Haddou, M.; Qolomany, B.; Qadir, J.; Anan, M.; Al-Fuqaha, A.; Abid, M.R.; Benhaddou, D. Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques. *Renew. Sustain. Energy Rev.* **2021**, *144*, 110969. [CrossRef]
30. O'Dwyer, E.; Pan, I.; Acha, S.; Shah, N. Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Appl. Energy* **2019**, *237*, 581–597.
31. Shafiee, M.; Animah, I.; Alkali, B.; Baglee, D. Decision support methods and applications in the upstream oil and gas sector. *J. Pet. Sci. Eng.* **2019**, *173*, 1173–1186. [CrossRef]
32. Iqbal, S.; Bilal, A.R.; Nurunnabi, M.; Iqbal, W.; Alfakhri, Y.; Iqbal, N. It is time to control the worst: Testing COVID-19 outbreak, energy consumption and CO_2 emission. *Environ. Sci. Pollut. Res.* **2021**, *28*, 19008–19020. [CrossRef]
33. Bhatti, U.A.; Zeeshan, Z.; Nizamani, M.M.; Bazai, S.; Yu, Z.; Yuan, L. Assessing the change of ambient air quality patterns in Jiangsu Province of China pre-to post-COVID-19. *Chemosphere* **2022**, *288*, 132569. [CrossRef] [PubMed]
34. Zhang, Y.; Li, W.; Wu, F. Does energy transition improve air quality? Evidence derived from China's Winter Clean Heating Pilot (WCHP) project. *Energy* **2020**, *206*, 118130. [CrossRef]
35. Memmott, T.; Carley, S.; Graff, M.; Konisky, D.M. Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic. *Nat. Energy* **2021**, *6*, 186–193. [CrossRef]
36. Meinshausen, M.; Lewis, J.; McGlade, C.; Gütschow, J.; Nicholls, Z.; Burdon, R.; Cozzi, L.; Hackmann, B. Realization of Paris Agreement pledges may limit warming just below 2 °C. *Nature* **2022**, *604*, 304–309. [CrossRef] [PubMed]
37. Dialga, I. Evaluating Normandy's sustainable development and energy transition policies. *J. Clean. Prod.* **2021**, *305*, 127096. [CrossRef]
38. Hand, J.L.; Prenni, A.J.; Copeland, S.; Schichtel, B.A.; Malm, W.C. Thirty years of the Clean Air Act Amendments: Impacts on haze in remote regions of the United States (1990–2018). *Atmos. Environ.* **2020**, *243*, 117865. [CrossRef]
39. Wu, B.; Wang, L.; Wang, S.; Zeng, Y.-R. Forecasting the U.S. oil markets based on social media information during the COVID-19 pandemic. *Energy* **2021**, *226*, 120403. [CrossRef]
40. Sharifi, A.; Ahmadi, M.; Ala, A. The impact of artificial intelligence and digital style on industry and energy post-COVID-19 pandemic. *Environ. Sci. Pollut. Res.* **2021**, *28*, 46964–46984. [CrossRef]
41. Zhang, D.; Li, H.; Zhu, H.; Zhang, H.; Goh, H.H.; Wong, M.C.; Wu, T. Impact of COVID-19 on Urban Energy Consumption of Commercial Tourism City. *Sustain. Cities Soc.* **2021**, *73*, 103133. [CrossRef]
42. Rita, E.; Chizoo, E.; Cyril, U.S. Sustaining COVID-19 pandemic lockdown era air pollution impact through utilization of more renewable energy resources. *Heliyon* **2021**, *7*, e07455. [CrossRef]
43. Robert, K.W.; Parris, T.M.; Leiserowitz, A.A. What is Sustainable Development? Goals, Indicators, Values, and Practice. *Environ. Sci. Policy Sustain. Dev.* **2005**, *47*, 8–21. [CrossRef]
44. Arent, D.J.; Green, P.; Abdullah, Z.; Barnes, T.; Bauer, S.; Bernstein, A.; Berry, D.; Berry, J.; Burrell, T.; Carpenter, B.; et al. Challenges and opportunities in decarbonizing the U.S. energy system. *Renew. Sustain. Energy Rev.* **2022**, *169*, 112939. [CrossRef]
45. Ahmad, T.; Zhu, H.; Zhang, D.; Tariq, R.; Bassam, A.; Ullah, F.; AlGhamdi, A.S.; Alshamrani, S.S. Energetics Systems and artificial intelligence: Applications of industry 4.0. *Energy Rep.* **2022**, *8*, 334–361. [CrossRef]
46. IEA. Global Energy Review 2021. 2021. Available online: https://www.iea.org/reports/global-energy-review-2021 (accessed on 2 August 2023).
47. IEA. Renewables 2020. 2020. Available online: https://www.iea.org/reports/renewables-2020?mode=overview (accessed on 2 August 2023).
48. Madurai Elavarasan, R.; Pugazhendhi, R.; Shafiullah, G.; Manoj Kumar, N.; Arif, M.T.; Jamal, T.; Chopra, S.S.; Dyduch, J. Impact of COVID-19 on Sustainable Development Goals and effective approaches to maneuver them in the post-pandemic environment. *Environ. Sci. Pollut. Res.* **2022**, *29*, 33957–33987. [CrossRef] [PubMed]
49. REN 21. Global Status Report 2021: Renewables 2021-Analysis and Key Findings. 2021. Available online: https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf (accessed on 25 November 2022).
50. Li, Y.; Zhao, K.; Zhang, F. Identification of key influencing factors to Chinese coal power enterprises transition in the context of carbon neutrality: A modified fuzzy DEMATEL approach. *Energy* **2023**, *263*, 125427. [CrossRef]

51. Chu, D.; Xin, Y.; Zhao, C. Production of bio-ethanol by consecutive hydrogenolysis of corn-stalk cellulose. *Chin. J. Catal.* **2021**, *42*, 844–854. [CrossRef]
52. D'Agostino, D.; Merelli, I.; Aldinucci, M.; Cesini, D. Hardware and Software Solutions for Energy-Efficient Computing in Scientific Programming. *Sci. Program.* **2021**, *2021*, 5514284. [CrossRef]
53. Zoom Video Communications. 90-Day Security Plan Progress Report: April 22. 2020. Available online: https://blog.zoom.us/90-day-security-plan-progress-report-april-22/ (accessed on 25 November 2022).
54. Jiang, P.; Van Fan, Y.; Klemeš, J.J. Impacts of COVID-19 on energy demand and consumption: Challenges, lessons and emerging opportunities. *Appl. Energy* **2021**, *285*, 116441. [CrossRef]
55. Hasan, M.K.; Habib, A.A.; Shukur, Z.; Ibrahim, F.; Islam, S.; Razzaque, M.A. Review on cyber-physical and cyber-security system in smart grid: Standards, protocols, constraints, and recommendations. *J. Netw. Comput. Appl.* **2023**, *209*, 103540. [CrossRef]
56. Abdin, Z.; Mérida, W. Hybrid energy systems for off-grid power supply and hydrogen production based on renewable energy: A techno-economic analysis. *Energy Convers. Manag.* **2019**, *196*, 1068–1079. [CrossRef]
57. Buttler, A.; Spliethoff, H. Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2440–2454. [CrossRef]
58. Lakshminarayana, S.; Ospina, J.; Konstantinou, C. Load-Altering Attacks against Power Grids under COVID-19 Low-Inertia Conditions. *IEEE Open Access J. Power Energy* **2022**, *9*, 226–240. [CrossRef]
59. Shin, W.; Han, J.; Rhee, W. AI-assistance for predictive maintenance of renewable energy systems. *Energy* **2021**, *221*, 119775. [CrossRef]
60. Theodorakos, K.; Agudelo, O.M.; Espinoza, M.; De Moor, B. Decomposition-Residuals Neural Networks: Hybrid System Identification Applied to Electricity Demand Forecasting. *IEEE Open Access J. Power Energy* **2022**, *9*, 241–253. [CrossRef]
61. Manzoor, H.U.; Khan, A.R.; Al-Quraan, M.; Mohjazi, L.; Taha, A.; Abbas, H.; Hussain, S.; Imran, M.A.; Zoha, A. Energy Management in an Agile Workspace using AI-driven Forecasting and Anomaly Detection. In Proceedings of the 2022 4th Global Power, Energy and Communication Conference (GPECOM), IEEE, Cappadocia, Turkey, 14–17 June 2022; pp. 644–649.
62. Farrokhabadi, M.; Browell, J.; Wang, Y.; Makonin, S.; Su, W.; Zareipour, H. Day-Ahead Electricity Demand Forecasting Competition: Post-COVID Paradigm. *IEEE Open Access J. Power Energy* **2022**, *9*, 185–191. [CrossRef]
63. Ajitha, A.; Goel, M.; Assudani, M.; Radhika, S.; Goel, S. Design and development of Residential Sector Load Prediction model during COVID-19 Pandemic using LSTM based RNN. *Electr. Power Syst. Res.* **2022**, *212*, 108635. [CrossRef]
64. Nabavi, S.A.; Motlagh, N.H.; Zaidan, M.A.; Aslani, A.; Zakeri, B. Deep Learning in Energy Modeling: Application in Smart Buildings With Distributed Energy Generation. *IEEE Access* **2021**, *9*, 125439–125461. [CrossRef]
65. Nigel, F.T.; Longe, O.M. Smart Energy Efficient Lighting System for Smart Buildings. In *2021 IEEE PES/IAS PowerAfrica*; Institute of Electrical and Electronics Engineers: Los Alamitos, CA, USA, 2021; pp. 1–5.
66. Lyu, W.; Liu, J. Artificial Intelligence and emerging digital technologies in the energy sector. *Appl. Energy* **2021**, *303*, 117615. [CrossRef]
67. Shu, K.; Ai, X.; Wen, J.; Fang, J.; Chen, Z.; Luo, C. Optimal Energy Management for the Integrated Power and Gas Systems via Real-time Pricing. In Proceedings of the 2018 IEEE Power & Energy Society General Meeting (PESGM), Portland, OR, USA, 5–10 August 2018; pp. 1–5.
68. Tschora, L.; Pierre, E.; Plantevit, M.; Robardet, C. Electricity price forecasting on the day-ahead market using machine learning. *Appl. Energy* **2022**, *313*, 118752. [CrossRef]
69. The World Bank. Harnessing Digital Technologies in Support of the Belt and Road Initiative: A Knowledge Note (Live Wire Series No. 09). 2019. Available online: https://documents1.worldbank.org/curated/en/979981468940285618/pdf/107120-BRI-ADD-SERIES-Live-Wire-Series-09-Knowledge-Note-PUBLIC.pdf (accessed on 2 August 2023).
70. Smajla, I.; Sedlar, D.K.; Vulin, D.; Jukić, L. Influence of smart meters on the accuracy of methods for forecasting natural gas consumption. *Energy Rep.* **2021**, *7*, 8287–8297. [CrossRef]
71. IEA. *Energy Technology Perspectives 2015*; IEA: Paris, France, 2015.
72. Knayer, T.; Kryvinska, N. An analysis of smart meter technologies for efficient energy management in households and organizations. *Energy Rep.* **2022**, *8*, 4022–4040. [CrossRef]
73. Mehmood, F.; Ghani, M.U.; Ghafoor, H.; Shahzadi, R.; Asim, M.N.; Mahmood, W. EGD-SNet: A computational search engine for predicting an end-to-end machine learning pipeline for Energy Generation & Demand Forecasting. *Appl. Energy* **2022**, *324*, 119754.
74. Koroteev, D.; Tekic, Z. Artificial intelligence in oil and gas upstream: Trends, challenges, and scenarios for the future. *Energy AI* **2021**, *3*, 100041. [CrossRef]
75. Li, S.; Wang, Q.; Jiang, X.; Li, R. The negative impact of the COVID-19 on renewable energy growth in developing countries: Underestimated. *J. Clean. Prod.* **2022**, *367*, 132996. [CrossRef]
76. IEA. World Energy Balances Overview. 2021. Available online: https://www.iea.org/reports/world-energy-balances-overview/world (accessed on 14 November 2022).
77. IEA. *Electricity*; IEA: Paris, France, 2023.
78. U.S. Energy Information Administration. *U.S. Energy Fact Explained*; U.S. Energy Information Administration: Washington, DC, USA, 2022.
79. IEA. Global EV Data Explorer. 2022. Available online: https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer (accessed on 14 November 2022).

80. The World Bank. CO_2 Emissions. 2020. Available online: https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?locations=RU (accessed on 15 November 2022).
81. Blokhin, A. The 5 Countries That Produce the Most Carbon Dioxide (CO_2). Investopedia. 2022. Available online: https://www.investopedia.com/articles/investing/092915/5-countries-produce-most-carbon-dioxide-co2.asp (accessed on 5 December 2022).
82. Marohl, B.; Comstock, O. EIA: U.S. Energy Consumption in April 2020 Fell to Its Lowest Level in More than 30 Years. *Fuels Market News*. 2020. Available online: https://fuelsmarketnews.com/eia-u-s-energy-consumption-in-april-2020-fell-to-its-lowest-level-in-more-than-30-years/ (accessed on 15 November 2022).
83. Bashir, M.F.; Ma, B.; Bilal Komal, B.; Bashir, M.A.; Tan, D.; Bashir, M. Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci. Total Environ.* **2020**, *728*, 138835. [CrossRef] [PubMed]
84. Wang, M.; Wang, G.; Sun, Z.; Zhang, Y.; Xu, D. Review of renewable energy-based hydrogen production processes for sustainable energy innovation. *Glob. Energy Interconnect.* **2019**, *2*, 436–443. [CrossRef]
85. Zambrano-Monserrate, M.A.; Ruano, M.A. Does environmental noise affect housing rental prices in developing countries? Evidence from Ecuador. *Land Use Policy* **2019**, *87*, 104059. [CrossRef]
86. Ormaza-Gonzaìlez, F.I.; Castro-Rodas, D.; Statham, P.J. COVID-19 Impacts on Beaches and Coastal Water Pollution at Selected Sites in Ecuador, and Management Proposals Post-pandemic. *Front. Mar. Sci.* **2021**, *8*, 669374. [CrossRef]
87. Patrício Silva, A.L.; Prata, J.C.; Walker, T.R.; Duarte, A.C.; Ouyang, W.; Barcelò, D.; Rocha-Santos, T. Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. *Chem. Eng. J.* **2021**, *405*, 126683. [CrossRef]
88. Rouleau, J.; Gosselin, L.; Blanchet, P. Understanding energy consumption in high-performance social housing buildings: A case study from Canada. *Energy* **2018**, *145*, 677–690. [CrossRef]
89. Ankit Kumar, A.; Jain, V.; Deovanshi, A.; Lepcha, A.; Das, C.; Bauddh, K.; Srivastava, S. Environmental impact of COVID-19 pandemic: More negatives than positives. *Environ. Sustain.* **2021**, *4*, 447–454. [CrossRef]
90. Crippa, M.; Guizzardi, D.; Banja, M.; Solazzo, E.; Muntean, M.; Schaaf, E.; Vignati, E. CO_2 Emissions of All World Countries. 2022. Available online: https://edgar.jrc.ec.europa.eu/report_2022#intro (accessed on 5 December 2022).
91. IEA. *Renewables 2018*; IEA: Paris, France, 2018. Available online: https://www.iea.org/reports/renewables-2018 (accessed on 23 November 2022).
92. Ritchie, H.; Roser, M.; Rosado, P. CO_2 and Greenhouse Gas Emissions. Our World in Data. 2020. Available online: https://ourworldindata.org/co2-and-greenhouse-gas-emissions (accessed on 5 December 2022).
93. Olabi, V.; Wilberforce, T.; Elsaid, K.; Sayed, E.T.; Abdelkareem, M.A. Impact of COVID-19 on the Renewable Energy Sector and Mitigation Strategies. *Chem. Eng. Technol.* **2022**, *45*, 558–571. [CrossRef]
94. Karmaker, C.L.; Ahmed, T.; Ahmed, S.; Ali, S.M.; Moktadir, M.A.; Kabir, G. Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: Exploring drivers using an integrated model. *Sustain. Prod. Consum.* **2021**, *26*, 411–427. [CrossRef]
95. Zhang, D.; Hu, M.; Ji, Q. Financial markets under the global pandemic of COVID-19. *Financ. Res. Lett.* **2020**, *36*, 101528. [CrossRef]
96. Gharib, C.; Mefteh-Wali, S.; Jabeur, S.B. The bubble contagion effect of COVID-19 outbreak: Evidence from crude oil and gold markets. *Financ. Res. Lett.* **2021**, *38*, 101703. [CrossRef] [PubMed]
97. Szczygielski, J.J.; Brzeszczyński, J.; Charteris, A.; Bwanya, P.R. The COVID-19 storm and the energy sector: The impact and role of uncertainty. *Energy Econ.* **2022**, *109*, 105258. [CrossRef] [PubMed]
98. Narayan, P.K. Oil Price News and COVID-19—Is There Any Connection? *Energy Res. Lett.* **2020**, *1*, 1–5. [CrossRef]
99. Huang, W.; Zheng, Y. COVID-19: Structural Changes in the Relationship Between Investor Sentiment and Crude Oil Futures Price. *Energy Res. Lett.* **2020**, *1*, 13685. [CrossRef]
100. Boratyńska, K. A New Approach for Risk of Corporate Bankruptcy Assessment during the COVID-19 Pandemic. *J. Risk Financ. Manag.* **2021**, *14*, 590. [CrossRef]
101. IEA. *COVID-19 Impact on Renewable Energy Growth*; IEA: Paris, France, 2020.
102. IEA. *Status of Power System Transformation 2019*; IEA: Paris, France, 2019; Available online: https://www.iea.org/reports/status-of-power-system-transformation-2019 (accessed on 23 November 2022).
103. Ding, T.; Zhou, Q.; Shahidehpour, M. Impact of COVID-19 on Power System Operation Planning. IEEE Smart Grid Community. 2020. Available online: https://smartgrid.ieee.org/bulletins/may-2020/impact-of-covid-19-on-power-system-operation-planning (accessed on 8 December 2022).
104. Ahuja, D.; Tatsutani, M. Sustainable energy for developing countries. *Surv. Perspect. Integr. Environ. Soc.* **2008**, *2*, 1–48. Available online: https://journals.openedition.org/sapiens/823 (accessed on 14 August 2023).
105. Swain, P.; Jagadish, S.; Mahesh, K.N.S.U. Integration of renewable sources of energy into power grid. In Proceedings of the 2017 IEEE Region 10 Symposium (TENSYMP), Cochin, India, 14–16 July 2017; pp. 3–7.
106. Madurai Elavarasan, R.; Shafiullah, G.; Raju, K.; Mudgal, V.; Arif, M.T.; Jamal, T.; Subramaniam, U. COVID-19: Impact analysis and recommendations for power sector operation. *Appl. Energy* **2020**, *279*, 115739. [CrossRef] [PubMed]
107. Tingting Xu, A.; Weijun Gao, B.; Yanxue Li, C.; Fanyue Qian, D. Impact of the COVID-19 pandemic on the reduction of electricity demand and the integration of renewable energy into the power grid. *J. Renew. Sustain. Energy* **2021**, *13*, 026304. [CrossRef]
108. Morris-Read, R. Google Cloud and Capgemini Collaborate with Malaysia's Largest Electricity Utility. Data Center News. 2021. Available online: https://datacenternews.asia/story/google-cloud-and-capgemini-collaborate-with-malaysia-s-largest-electricity-utility (accessed on 20 June 2023).

109. Rivera, D. Meralco to Scale up Battery Energy Storage Portfolio. The Philippine Star. 2021. Available online: https://www.philstar.com/business/2021/11/02/2138278/meralco-scale-battery-energy-storage-portfolio (accessed on 2 August 2023).
110. Liasi, S.G.; Shahbazian, A.; Bina, M.T. COVID-19 Pandemic; Challenges and Opportunities in Power Systems. IEEE Smart Grid Community. 2020. Available online: https://smartgrid.ieee.org/bulletins/may-2020/covid-19-pandemic-challenges-and-opportunities-in-power-systems (accessed on 2 August 2023).
111. Ghimire, S.; Nguyen-Huy, T.; AL-Musaylh, M.S.; Deo, R.C.; Casillas-Pérez, D.; Salcedo-Sanz, S. A novel approach based on integration of convolutional neural networks and echo state network for daily electricity demand prediction. *Energy* **2023**, *275*, 127430. [CrossRef]
112. Bourhnane, S.; Abid, M.R.; Lghoul, R.; Zine-Dine, K.; Elkamoun, N.; Benhaddou, D. Machine learning for energy consumption prediction and scheduling in smart buildings. *SN Appl. Sci.* **2020**, *2*, 297. [CrossRef]
113. Kahouadji, M.; Lakhal, O.; Yang, X.; Belarouci, A.; Merzouki, R. System of Robotic Systems for Crack Predictive Maintenance. In Proceedings of the 2021 16th International Conference of System of Systems Engineering (SoSE), Västerås, Sweden, 14–18 June 2021; pp. 197–202.
114. Kumari, P.; Kaur, K.; Singh, J. Condition monitoring of power transformer using ANN for IEC based on DGA. *Int. J. Control Theory Appl.* **2016**, *9*, 29–36.
115. Piya, S.; Shamsuzzoha, A.; Khadem, M. Analysis of supply chain resilience drivers in oil and gas industries during the COVID-19 pandemic using an integrated approach. *Appl. Soft Comput.* **2022**, *121*, 108756. [CrossRef]
116. Sircar, A.; Yadav, K.; Rayavarapu, K.; Bist, N.; Oza, H. Application of machine learning and artificial intelligence in oil and gas industry. *Pet. Res.* **2021**, *6*, 379–391. [CrossRef]
117. Power Africa in South Africa | Power Africa | U.S. Agency for International Development. Available online: https://www.usaid.gov/powerafrica/south-africa (accessed on 9 November 2022).
118. Lipinski, T.; Ahmad, D.; Serey, N.; Jouhara, H. Review of ventilation strategies to reduce the risk of disease transmission in high occupancy buildings. *Int. J. Thermofluids* **2020**, *7–8*, 100045. [CrossRef]