energies

Review

International Impact of COVID-19 on Energy Economics and Environmental Pollution: A Scoping Review

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Abstract: The impact of the COVID-19 pandemic on the economy and society has gained the interest of academics and policymakers in recent years. Our paper aims to investigate and systemize the evidence from 1901 publications belonging to the top 1% of worldwide topics by prominence. This paper helps estimate a pandemic's short-run and longer-run effects on energy economics and environmental pollution. By systematizing the literature, we analyze key parameters influencing the deviation of previous worldwide economic and environmental development trajectories due to the COVID-19 pandemic. This paper examines research on the consequences of COVID-19 in five dimensions, particularly the impact of COVID-19 on (1) the environment and climate change, (2) sustainable development, (3) renewable energy and energy policy, and (4) methodology for forecasting and evaluating the energy sector and economic sectors. Our results indicate that the pandemic crisis's impact on achieving sustainable development goals in the context of energy change and pollution is controversial and complex. On the one hand, scientists are unequivocal about the positive impact of the COVID-19 pandemic on improving air quality and reducing CO_2 emissions. Nevertheless, the long-term effects are threatened by gaps between countries in economic prosperity and different vaccination rates. Most studies have found that only a joint social effort and international collaboration can move to a clean energy system. In addition, using the Scopus database and modern tools of machine analysis, we determine leading authors in the subject area of "renewable energy, sustainability, and the environment", as well as the top networks and scientific communities that appear within energy. The analysis of this manuscript can be helpful to policymakers and stakeholders in developing comprehensive energy efficiency programs and energy-saving strategies to achieve SDG targets.

Keywords: energy; environmental pollution; COVID-19; sustainable development

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1. Introduction

The COVID-19 pandemic has become an unexpected global problem that has affected all spheres of life. Social distancing, the spread of remote work practices, and the redistribution of expenditures from state budgets have shifted the emphasis to long-term decisions in the socioeconomic and environmental spheres [1–3]. As a result of the changes, there has been a transformation of views on the relationship between profitability and sustainability, setting new priorities in management decisions and rethinking the importance of government and state institutions (e.g., the idea of a 'socioecological contract'). At the same time, it remains fundamentally important to take collective measures to develop the economy, ensure comprehensive economic growth and global security, and achieve SDG targets.

This article aims to summarize the scientific achievements on the impact of the COVID-19 pandemic on the economy, energy, and the state of the environment, published in Scopus's scientometric database. The main policy challenge is maintaining a balance across economic, social, and environmental goals in the long run, aligning with sustainable development goals. The economic system has long depended on climate policy to combat climate change. At the same time, the modern economy is heavily dependent on energy. Energy is a central issue of economic development. An inefficient energy system hinders economic growth. However, energy is also actively involved in achieving climate policy goals and focuses on environmentally friendly technologies. In particular, this is reflected in the increase in energy production from renewable sources. Thus, the areas selected for research, namely, economics, energy, and pollution, are closely interlinked and should be studied as a whole. Moreover, combining these areas is a tool for the sustainable development of individual countries, regions, and the world. It is in the context of the unity of these concepts that this study is carried out.

The study of publishing activity is a well-chosen tool for systematizing existing knowledge because it allows a comprehensive look at the problem. The analysis of publications allows penetrating deeply into the issue's essence and finding out how much the subject is studied and how significant interests are in the scientific community. In addition, this approach allows identifying and comparing research results on a particular issue, and then determining at what stage the scientific community is in solving the problem. This article consists of five sections. In Section 2, the authors present a literature review of scientific publications on the impact of the COVID-19 pandemic on energy economics and environmental pollution. Section 3 introduces the methodology of the research. Section 4 contains a result of a cluster analysis of publications on renewable energy, sustainability, and the environment. The conclusions complete this article.

2. Literature Review

2.1. Impact of COVID-19 on the Environment and Climate Change

The global coronavirus crisis has significantly affected the global economy, the social sector, and the environment. Leading scientific editions have published many theoretical articles and the results of applied research on the nature and consequences of a pandemic impact. This section reviews scientific publications on the changes the economy, energy system, and environment have undergone in sustainable development. The study of the impact of the COVID-19 pandemic on climatic parameters is of considerable scientific interest. Pandemics and climate change are two serious problems that cause significant economic and social damage. However, can one problem at least partially solve another one? Analysis of scientific publications has shown that this problem is highly relevant. There are currently a significant number of publications that explore this issue. It is advisable to identify papers that can attract the scientific community's attention. In particular, one study [4] aimed to determine the appropriateness of solving climate problems through a pandemic. In conclusion, the authors argued that, although the pandemic has positively impacted the climate and contributed to energy policy goals, it has been too expensive. Such a situation is explained by significant social and economic losses resulting from reduced economic activity. Thus, international climate policy provides more cost-effective mechanisms to combat climate change and is used successfully. The authors of [5–7] also comprehensively studied this problem, investigating the relationship between the consequences of the pandemic lockdown and air pollution, public health, and economic growth.

Some scientists have studied the impact of the coronavirus pandemic on the environment more closely and thoroughly. Marinello et al. [8] used the scoping approach when assessing the impact of changes in human activities on the environment due to COVID-19. Many scientists often use the following air pollution metrics to investigate this issue: NO_2, PM10, PM2.5, and, to a lesser extent, SO_2, CO, and O_3. The authors of [9] analyzed the impact of social isolation due to the COVID-19 pandemic on the emission of the most dangerous gases that pollute the air. As a result of the statistical data processing study, it was impossible to identify a general European trend toward decreasing the concentration of harmful gases in the atmosphere. This indicated the presence of different effects caused by the pandemic, which vary from country to country. Global and interregional studies are more complex in terms of obtaining homogeneous results. However, given the possible time lag between social exclusion and reduced emissions, this study predicted five scenarios for reducing greenhouse gas emissions. The most optimistic scenario assumed that a decrease in CO, NO_2, and PM2.5 emissions could be achieved by maximums of 51%, 95%, and 28%, respectively. Furthermore, other studies [10,11] used factual data and offered the results of structural analysis of emission reductions by their sources, as well as tracked changes in air pollution during the period of declining social mobility

The authors of [12–16], using the examples of Greece, Pakistan, Malaysia, and China, respectively, analyzed the amount of greenhouse gas emissions and their impact on climatic conditions during a pandemic, including lockdown periods and quarantine easing. The state of emissions in the United States (in California) was analyzed by Pan et al. [17]. These studies focused on a specific country or region, making their results more homogeneous. This is because national restrictions are relatively the same within a country; similarly, the reduction in economic activity and mobility has led to similar results within a country. The results in [18] were interpreted according to the presence or absence of a long-term effect of the pandemic on air quality and climatic conditions. The study concluded that the positive long-term impact of the pandemic on climate change should not be expected. After periods of severe quarantine restrictions, society returned to the usual pattern of behavior and economic activity, minimizing the short-term positive results caused by COVID-19. The authors of [19] confirmed this conclusion. However, during quarantine restrictions, the reduction in harmful emissions is significant.

The authors of [20] arrived at somewhat different conclusions, i.e., that there is an increase in pressure on forests and other ecosystems during the lockdown in Latin America. At the same time, there is a positive trend to reduce urban pollution.

According to [21], Peru's electricity generation changes have reduced greenhouse gas emissions by 60% compared to the usual scenario. Given this study and the results achieved by [22,23], it is advisable to assess the impact of energy generation on the state of the climate in more detail, including during the production of energy from renewable sources. The authors of [1] researched the reduction in emissions of harmful substances into the air due to decreasing fossil fuels for energy production in China. Such studies remain relevant and expand the subject of research. Letunovska et al. [24] studied the relationship between the transition to renewable energy and the population's health.

In contrast to the studies listed above, researchers [25] have also considered the climatic effects of the COVID-19 pandemic in the context of energy asymmetry. A similar problem in another geographical region was the subject of research in East India [26] and Delhi [27], where a broader list of outcome indicators was presented. The authors of [28] focused on an essential aspect of environmental pollution during the COVID-19 pandemic: changes in air quality parameters in megacities. This study is socially significant, as another point of view on the issue was presented. Researchers focused not only on the emissions of harmful gases but also on changes in the region's state of climate due to changes in the traditional model of economic activity. A result of this study was the actual short-term impact of the lockdown on the environment and temperature. The identified relationship between the concentration of harmful substances in the air and the volume of economic activity in this study was more pronounced than in similar studies. However, another study [29] suggested that caution should be exercised in assessing the environmental impact of COVID-19, as many other factors need to be considered, such as forest fires and other adverse events that can significantly affect air composition. This means that studying the impact of COVID-19 on air quality is vital to determine precisely how the pollution indicators for different pollutants have changed, i.e., to monitor the dynamics of harmful substances concentration [30]. The significant results obtained in terms of improving the air condition and specific climatic parameters can be explained by the location of the study.

A more significant impact of the pandemic and its environmental limitations is typical for studies based on data obtained in industrial areas where pollution is constantly high. As a result, the authors also focused on the antagonism of economic and climatic goals. Instead, the authors of [30] suggested using such a situation to further the design and construction of the production infrastructure rather than a negative situation. Despite the significant number of studies on similar topics relevant and of considerable scientific interest, approaches to studying the problem and research methodology differ significantly.

In [31], the authors investigated local changes in air quality and determined the impact of COVID-19 on precipitation and the state of the ozone layer. Instead, the authors of [32] analyzed the impact of restrictions on coronavirus control on the environment in chronological order: before, during, and after coronavirus restrictions. In [33], the authors used a macroeconomic model to assess the impact of the economic shocks of supply and demand generated by the COVID-19 crisis on the climate issue of the Member States of the European Union. Furthermore, another study [16] investigated this issue using a nonlinear model. This approach significantly distinguished it from others. Because a significant number of studies focused on the impact of COVID-19 on a limited (small) area, of particular interest are studies that conducted a global assessment (e.g., [34,35]) or compared these effects in different regions (e.g., [36,37]).

Since the most significant air pollutants are enterprises, industries emit many harmful substances into the atmosphere and supersaturate the air with them. The authors of [38] studied the state of industrial enterprises and changes in emissions of harmful gases and substances into the atmosphere. This study was consistent with the results of many other scientific publications and demonstrated the positive effect of COVID-19 on air quality. The value of the study is that the objects studied were located in a large area of the People's Republic of China, i.e., the geographical location of the study was immense.

The issues of industry, its state, and development are also related to thorough research aimed at developing technologies that will be useful to reduce the harmful effects on the environment both during the pandemic and after it ends. The authors of [39] investigated long-term mineralization technology as an effective mechanism for reducing CO2 emissions and combating climate change.

One of the most common research areas related to the spread of COVID-19 is determining the relationship between natural (climatic) conditions and the number of infected people. In particular, the authors of [40] analyzed the relationship between air quality and the spread of COVID-19 in African countries. They clustered countries according to the level of morbidity depending on the concentration of harmful substances in African countries' air [39]. The authors of a similar study (Lipfert and Wyzga, 2021) did not find a long-term relationship between environmental quality and the number of diseases on COVID-19 [40]. The authors concluded that the spread of the virus is much more influenced by other factors, such as social conditions and the environment. However, the results of Chinese researchers [41] indicated the impact of COVID-19 on environmental quality. While one study [42] defined the relationship between the severity of the pandemic and the level of emissions, another [41] used similar results as a basis for assessing the positive impact of the spread of coronavirus, i.e., the reduction in mortality due to poor living conditions (natural factors). However, this study used data from 2019 (the beginning of the spread of coronavirus). A study by a team of scientists from Italy and France [43] used data on particulate matter in the air. It showed the presence of threshold values, the exceeding of which would lead to the spread of COVID-19 because it weakens the human body. The authors of [44] investigated the relationship between COVID-19 mortality and environmental quality through the National Air Toxics Assessment of hazardous air pollutants. An interesting study [45] analyzed the spread of coronavirus in Brazil and showed some coronavirus drivers. Another study in Brazil calculated the economic effects of the coronavirus on the health system. On the basis of the results, the authors of [46] argued that a wide range of effects should be considered, not just the costs associated with deaths or their avoidance. They claimed that it is necessary to consider reducing the cost of hospitalization of patients with comorbidities (e.g., cardiovascular system) as a function of reduced hospitalizations due to improved environmental conditions.

In the current COVID-19 pandemic, scientific collaboration is of particular importance to respond quickly to global challenges and threats. This is why a particular study [47] is of scientific interest, as it characterized the state and trends in international scientific cooperation on combating climate change. In addition, it is crucial to synchronize the efforts and decisions of different countries to control the coronavirus and maximize the positive climatic effects caused by it, as addressed by Nguyen et al. [48].

Studies of the impact of the coronavirus pandemic on the environment and climate change were carried out in different conditions. The research geography is diverse, and the initial conditions, such as air pollution levels, available and used energy resources, energy system characteristics, and energy consumption, were different. This explains the differences in the individual conclusions of scientists. However, the general conclusion is common and appears in one form or another in most publications. This conclusion can be summarized as the positive impact of the coronavirus pandemic being temporary, lasting as long as the coronavirus restrictions are in place. During the restoration of usual economic activity, the emissions of harmful substances and greenhouse gases return to typical values. Such results conclude that reducing economic activity and artificial restrictions are ineffective in combatting climate change and protecting the natural environment. Accordingly, government representatives, businesses, scientists, and stakeholders must continue seeking economic incentives to conduct business responsibly using environmentally friendly technologies instead of restrictive measures that negatively affect economic activity.

2.2. COVID-19 and Sustainable Development

The results of studies of changes in air quality and the impact of the COVID-19 pandemic on climatic conditions have provided additional, previously missing information on the necessary actions to combat climate change and its consequences. Therefore, many scientists have paid attention to these issues. However, the literature linking COVID-19 to sustainable development is fragmented. The authors of [49] tried to gauge the extent to which scientists are currently studying this area. A review article [50] listed the direct and indirect effects of the coronavirus on sustainable development. Moreover, the paper systematically investigated the pandemic problem and determined the areas of life with a need to change approaches to achieve sustainable development. It is also worth paying attention to the review study in [51]. The authors systematized the situation with coronavirus infection. They showed the consequences of its spread following a review of many scientific papers. Thus, they sought to provide a systemic vision of the problem to individuals and institutions whose activities are related to combating the coronavirus and its consequences.

In contrast to the previous study, the authors of [52] used evidence to assess the impact of COVID-19 on the environment, social sector, and economy. The results of the study were the potential consequences of the problem for different sectors of the economy. The authors offered practical recommendations for overcoming the effects of the crisis in various sectors of the economy. One of the critical sectors of the modern economy is energy. The operation of energy systems worldwide has undergone significant changes under the influence of COVID-19. Moreover, energy is vital for sustainable development. The production of safe and environmentally friendly energy creates the basis for change aimed at forming and implementing long-term programs to improve environmental, social, and economic standards of living. The authors of [53] focused on the energy vector of economic development in the post-pandemic period in the context of sustainable development, while the authors of [54] offered a nontrivial view of energy development, arguing that there is a link between the country's energy development level and its ability to withstand the threat of coronavirus.

The results in [55] provide information on how to turn the short-term positive effects of a pandemic into an opportunity for sustainable development. In this paper, the authors studied the environmental aspects that have a positive impact through blocking and strategies to preserve a green and clean environment for a long time. However, whether the environmental benefits of COVID-19 will be used in the future remains a big question. The authors of [56] studied this issue using the example of China's economy. They noted that, during the pandemic, the emphasis on business shifted to the social side. However, environmental aspects were also considered less critical by company executives. For sustainable development in the future, it is essential not to lose the ecological results that have already been achieved. This is why the authors of this study prepared several proposals for business and government for further economic development. However, this study operated using data obtained in China. Instead, a similar study [57] used data from more than 11,000 companies worldwide.

The authors of [58] drew attention to transforming social conditions under the new way of human life during quarantine restrictions. This study aimed to determine the changes necessary in the sustainable development strategy as a result of the coronavirus pandemic. Furthermore, the study examined which existing sustainable development plans are broken. Another study [59] was typical of the pandemic period. The authors paid attention to indicators of climate improvement but focused on further actions, i.e., how to unite all those interested in achieving climate and sustainable development goals to cooperate as efficiently and quickly as possible. Overall, this will help maintain the positive effects of COVID-19 on the environment. One of the crucial activities to combat the effects of the pandemic is cooperation within the scientific community on sustainable development research. International teams of scientists are investigating this issue. In addition, it is important to see how the population's environmental awareness, awareness of sustainable consumption, and social responsibility have changed, as this is the basis for further sustainable development policies. The authors of [60] explored this issue in Brazil and Portugal on the Baby Boomer, X, and Y generations. The results of this study may be related to the research topic in [61] on educating the future in the context of sustainable development.

On the basis of scientific studies discussed in this section, it is possible to conclude the connection between energy independence and the efficiency of the use of energy resources and the country's ability to face global challenges, particularly the pandemic. Energy networks with a significant share of renewable energy can increase the energy independence of energy-poor countries. In the long term, renewable energy will positively affect the resistance of such countries to economic and social threats. In addition, energy systems with a significant share of renewable energy turned out to be more flexible in responding to demand, and their use was more economically justified. These arguments should be considered in the discussions regarding determining the priorities for further development of the energy industry. After analyzing many publications, it is possible to say that the COVID-19 pandemic has revealed the connection of energy not only with the achievement of SDG #7 (affordable and clean energy) and SDG #13 (climate action), but also with SDG #3 (good health and wellbeing).

2.3. COVID-19 and Methodology for Forecasting and Evaluating the Energy Sector

Energy has been significantly affected by the COVID-19 pandemic. One of the most significant effects on energy is a change in consumption structure. It is important to note that the methodology of forecasting and determining supply and demand in current conditions may be ineffective because existing forecasting models use a calendar, meteorological information, and historical data. Quarantine restrictions have made this approach inappropriate. Thus, developing a new forecast energy demand model or adapting existing ones is necessary. The authors of [62] suggested two ways to adapt existing approaches to forecasting demand. It is vital to pre-systematize factual data for use in such studies. The authors of [63–65] summarized trends in energy consumption during quarantine restrictions. Furthermore, the authors of [66] proposed a mechanism to improve the monitoring and exchange of energy consumption data during a pandemic.

Therefore, there is a widespread and accepted opinion in the scientific community about the need to adjust existing or develop new strategic planning methods in energy. In particular, it is necessary to make strategic investment decisions. In [67–70], the authors explored this issue, proposing the use of machine learning algorithms to consider the impact of COVID-19 on processes in energy. The authors of [71] used linear regression models based on data from Romania to identify and characterize the long-term relationship between GDP and electricity consumption. They argued that, in the context of the COVID-19 pandemic, their study may be helpful for energy and policy optimization and economic growth in Romania and the European Union. The effect of COVID-19 on the energy system was also investigated in [72–74]. The authors focused on energy system security, electricity generation, demand, and prices. Furthermore, the authors noted differences in the results of the study in different regions. García et al. [75] used a completely different approach to studying the impact of COVID-19. They determined changes in energy consumption at the level of the household consumer. As a result, they identified five short- and medium-term consumer behavior profiles. Energy consumption profiles are an area that has caused significant publishing activity, as specifically researched in [76,77]. Eryilmaz et al. [78] investigated changes in the structure of energy production during a pandemic.

Along with studies of energy consumption and production changes, market mechanisms for responding to these changes play a significant role in research. Norouzi et al. and Halynska [79] investigated this issue. Bompard et al. [80] systematically analyzed the consequences of crisis phenomena such as COVID-19. They defined the behavior profiles of household and commercial consumers and focused on decision-making assistance for policymakers, regulators, and system operators in times of crisis [81]. When the behavioral models of energy consumers and the energy demand change, studying the practices of energy solutions that can quickly respond to such changes is especially relevant [82].

Social distancing, with the spread of remote work practices due to the pandemic, has changed energy consumption according to the type of use of buildings and institutions. Energy consumer habits usually change gradually, but the spread of COVID-19 forced people to change their lives and cost-sharing significantly. Energy consumption in most industrial and office buildings is declining, while energy consumption in residential buildings is increasing [83]. Mofijur et al. [84] reached a similar conclusion. The author argued that the demand for energy in residential areas has increased due to the reduced mobility of the population and the transition to teleworking while reducing the industrial and commercial use of energy. Developing comprehensive energy conservation programs is worth noting the reduction in energy consumption in higher-education buildings [85].

Regarding municipal buildings, Geraldi et al. [86] noted a raw energy consumption intensity during lockdown periods and in the absence of activity in homes. Conducting an energy audit in municipal buildings allows us to understand consumption trends and determine the list of energy-saving measures depending on the purpose of the building. Changes in electricity consumption in recent years have occurred depending on the type of buildings and the terrain. There has been a decrease in electricity consumption in the industrial and commercial sectors and an increase in energy load in the private sector. In addition, energy load centers transform from large cities to peripheral settlements [87]. Using a machine learning model, Kim et al. [88] simulated the need for resource consumption depending on the number of active cases of COVID-19. They determined that it is increasing at a specific rate. Current trends suggest the need to restructure or develop new energy systems and green building certification systems [89] to effectively manage energy demand at the level of a specific local area. This situation stimulates the accelerated implementation of deep energy modernization projects and the large-scale implementation of effective tools to reduce energy consumption in public buildings. In addition, distance work and online learning create new demands on constructing the energy network of residential areas and developing measures to increase digital and energy-saving competence. Energy networks of residential buildings must be provided with appropriate technical conditions for uninterruptible power supply with the possibility o f additional connection of different energy sources [90,91]. Today's challenges request to create new forms of interaction between consumers, distribution network operators, and energy suppliers to achieve an uninterrupted and reliable energy supply for design energy networks. Jiang et al.'s [92] study focused on measures to stabilize energy demand.

In general, it is worth paying attention to scientific publications that systematize existing research in forecasting, modeling, and methodology for assessing processes in energy. A valuable tool to achieve this is bibliometric analysis.

Changes in business and household energy consumption during the coronavirus pandemic have provided real-time data on grid load and consumer behavior. Such global data could not be obtained experimentally. In earlier studies, predictive models were used for this purpose. However, the accuracy of the modeling depends on the correctness of the assumptions underlying the model. The pandemic has lifted restrictions on scientists and practitioners in the energy sector. The developed consumer behavior patterns make it possible to determine critical aspects of the future energy system. Reducing and canceling coronavirus restrictions does not mean returning to typical behavioral patterns of consumption. In particular, services for joint work and online meetings have significantly increased their importance in business. Furthermore, some employees, even after lifting restrictions related to COVID-19, continue to work remotely.

Further research is needed on how changing consumer behavior patterns can accelerate the decentralization of the power system, the implementation of distributed power generation, and the creation of autonomous microgrids that flexibly respond to changes in demand [93], including through improved load forecasting algorithms on the power grid.

2.4. Impact of COVID-19 on Renewable Energy and Energy Policy

The effects of the COVID-19 pandemic on the world economy and oil price fluctuations have significantly impacted the renewable energy sector [94–98]. Shah et al. [99] used data from Denmarto to determine essential predictors of renewable energy: the rigidity of the lockdown and the daily number of confirmed deaths from COVID-19. At the same time, the index of economic support does not significantly affect renewable electricity production. Halbrügge et al. [100] compared the European energy market during the COVID-19 pandemic with previous years and determined a decrease in electricity consumption and an increase in the share of renewable energy sources. Using publicly available data to analyze the performance of electricity systems and markets, the authors concluded that the number of hours with negative electricity prices is growing, decreasing market prices. Bhuiyan et al. [101] obtained similar results and claimed that most renewable energy producers reduced their renewable energy supply in 2020 (excluding the Chinese energy market). The authors found a clear correlation between reducing energy production and the percentage of the country's urban population.

Therefore, countries such as Brazil, the United States, the United Kingdom, and Germany have experienced the most remarkable economic decline in energy production. Furthermore, Huse et al. [102] identified a moderate increase in consumer energy consumption in Brazil and developed government programs to promote energy efficiency among the population. The European electricity and natural gas markets generally behaved similarly during the COVID-19 crisis [103,104]. Sözen et al. [105] used the Turkish energy market data and identified a reduction in energy production based on natural gas by 6.27% and coal by 7.19% in 2020 compared to 2019. Merging the effects of the pandemic on the world economy and fluctuations in oil prices caused by nationwide blockades worldwide significantly impacted the renewable energy sector. The general investment and state policy of regulating the activities of fuel and energy enterprises, the volume of consumption, the ratio of supply and demand, and price variations in the world market determine energy prices [106]. Olubusoye et al. [107] prove the importance of considering the level of uncertainty in the energy market and the state of the information field when forecasting variations in energy prices.

However, the impact of the pandemic on renewable energy also had unexpected results [108,109]. Peters et al. [110] demonstrated a link between reduced air pollution and high levels of clear sky insolation (case study—Delhi, India). As the number of airborne particles in the air decreases, more sunlight is incident on solar panels. Hariharan [111] identified similar relationships. The findings of these studies can be used in planning solar parks.

The analysis of the impact of the pandemic crisis on achieving sustainable development goals in the context of energy change and environmental pollution is controversial and systemically complex [112]. There are unequivocal conclusions among scientists about the positive impact of the COVID-19 pandemic on improving air quality and reducing CO_2 emissions [3]. Furthermore, long-term effects are threatened by gaps between countries in the transition to a climate-clean energy system and the availability of various opportunities for the transformation of the energy sector in terms of the implementation of renewable energy and the gradual abandonment of coal electricity [113]. In addition, it should be borne in mind that not all new smart and high-tech projects are energy-efficient [114]. The redistribution of budgets to combat the effects of COVID-19 has significantly impacted the development of renewable energy production capacity. Resource savings and broken supply chains substantially slow the transition to sustainable energy and restrain the positive trends toward green and low-carbon energy progress [115–118]. A survey conducted [119] among 200 politicians and stakeholders from 55 countries provided an optimistic scenario for the growth of the number of implemented projects to transition to low-carbon energy and transport sectors. However, the intensity of efforts to decarbonize the economy will vary from industry to country. As for China, Gosens and Jotzo [120] noted the lack of significant positive dynamics to reduce carbon emissions due to the pandemic and little effort to develop renewable energy in the country. Most investment has been made in the fossil fuel industry. Incorporating concrete renewable energy actions into China's long-term development programs and upgrading high-emission infrastructure would significantly accelerate global sustainable development goals. After all, according to the authors of the above study, China consumes half of the world's coal and is the cause of 28% of global carbon emissions. This situation threatens the achievement of international climate goals. This indicates the need to clarify measures to coordinate international action and develop common energy policies, taking into account each country's post-pandemic socioeconomic and environmental status and the rate of vaccination. States' energy policy should be based on constant analysis and a search for new energy opportunities with the balance of energy conservation and growing energy needs. Moreover, energy policy should be based on transparency [121] and avoiding energy efficiency gaps [122].

Steffen et al. [123] offered several principles for responding to the COVID crisis for energy policymakers. Energy policy responses should depend on the planning horizon but should not change the desire to build a carbon-neutral energy system. The result of the short- and medium-term response should be the development of new energy projects that would help withstand possible future crises and ensure a clean energy transition. Hoang et al. [124] made a similar conclusion in identifying renewable energy development as the main priority of any energy planning horizon. Schmidt et al. [125] used financial leverage and implemented a self-adjusting thermostatic policy strategy to stimulate the transition of consumers to renewable energy. The strategy was based on conducting competitive auctions for renewable energy to compensate for the increase in interest rates. Steffen and Schmidt [126] noted the importance of involving multilateral development banks in financing renewable power-generation technologies projects in developing countries. According to [127,128], current energy policy should include tools that make it flexible and adaptable to changing environments.

The analysis of scientific publications allows concluding that during the COVID-19 pandemic, the demand for renewable energy increased because, as mentioned above, energy networks with a significant share of renewable energy are more adaptable to crisis conditions and reduce the load on the centralized energy system. This is the reason to support renewable energy development and initiate new projects. Price fluctuations for oil and natural gas also create prerequisites for increasing renewable energy production. However, despite the expected increase in systemic investments in development programs and renewable energy projects, there is no growth. State support for renewable energy remains close to stable. At the same time, the efforts of investors and the attention of government institutions are directed mainly toward nonrenewable energy, as investing in renewable energy has time and infrastructure constraints. The possibility of the rapid global spread of renewable energy technologies is doubtful because, for this, the appropriate infrastructure must be created, and consumers must be ready to participate more actively in the energy market. This takes time and requires substantial effort from all stakeholders. In addition, the expectation that the crisis will pass and everything will return to its place has not contributed to the emergence of new large-scale renewable energy projects. In such a situation, the policy is not revised to increase expenditure or develop new incentives for renewable energy development. If the crisis is expected to be protracted and a return to normal status is impossible in the short term, then the energy policy needs immediate revision. Actual confirmation of this thesis can be seen in the EU's reaction to the loss of Russian energy carriers. Changing the energy policy is a chance to eliminate the disparity in the results of implementing renewable energy technologies by different countries. Mutually agreed policies and actions of governments in this direction will increase their energy and economic security and positively affect climate policy goals.

2.5. Impact of COVID-19 on Economic Sectors

The unpredictable development of the COVID-19 pandemic has significantly impacted the established socioeconomic ties and mechanisms of interaction with contractors. Analysis and evaluation of some indirect economic effects of COVID-19 on energy and environmental pollution have been highlighted in the scientific literature. The impact of the COVID-19 pandemic on the economy and the social sector needs to be studied to determine the trajectory of further economic and social development. Kuzmenko et al. [129] considered regional features in analyzing and forecasting socioeconomic growth. Boianovsky [130], on the basis of a review of the scientific literature, examined the historical trajectory of economic science in Brazil and summarized how the study of economic problems has changed due to the COVID-19 pandemic. The author compared trends in economic research in Brazil and the development of the economy around the world.

Considerable attention has been drawn to the study of transformations of different industries during the pandemic. Not all industries have equally felt its impact. There is a list of sectors in which changes were particularly significant. In particular, such areas include healthcare, which has taken the brunt of the coronavirus. Smiianov et al. [2] investigated socioeconomic patterns of labor market functioning in public health in the context of the ability of the medical system to respond to modern challenges.

Many researchers used smart transportation models to study the effects of COVID-19 on sectoral energy saving due to changes in demand for air transport, rail, and road traveling [131–133]. The COVID-19 pandemic has positively impacted the environment by reducing greenhouse gas emissions in the transport sector of the economy. The positive effect was partially offset by the negative impact of consumers switching from public transport to road transport to reduce the risk of COVID-19 infection and prevent the spread of the disease. Rebuilding the transport sector will take a long time. It will require significant investment in technical modernization to implement environmentally friendly solutions and find ways to save money with the possibility of achieving profitable activities [131].

The tourism industry suffered significant losses during the pandemic. Reducing tourist flows improves air quality, positively affecting health and highlighting new tourist destinations and selection criteria [134]. However, the economies of the countries with the largest share of revenues from tourist services in the structure of GDP suffered significant losses. According to the United Nations World Tourism Organization (UNWTO), in 2020, international tourism and related industries lost 2.4 trillion USD. Due to the uneven vaccination against COVID-19, the losses from the stagnation of the tourism business are declining in most developed countries and increasing in developing countries. Local eco-tourism, national nature parks, and landscape protection zones are effective alternatives to international tourism [135]. Loizia et al. [136], exploring the coastal areas of Cyprus, comprehensively approached the assessment of the impact of COVID-19 on the environment through the prism of the tourism industry. The researchers based the analysis on the clean coast index and waste accumulation indicators. In general, the pandemic temporarily improved all these indicators. This study concluded that developing strategies for managing coastal areas with their subsequent transformation into SMART zones is necessary to achieve a sustainable positive impact and create environmentally friendly recreation areas. In summary, the following post-COVID-19 trends in the tourism industry should be noted: further development of digital tourism and cultural space; improving access to online programs, virtual tours of museums around the world and architectural monuments; creation of new partnerships in the field of culture and sustainable tourism; construction of new models of intersectoral cooperation. Temporary lockdowns and general constraints in a pandemic have a short-term effect on improving the area's air quality. Nevertheless, long-term positive environmental change and climate change require common political and cultural societal modifications [137]. Public marketing of domestic eco-tourism options and promoting common socioeconomic and environmental priorities of social development will allow countries to act in one plane to achieve sustainable development. Duguma et al. [138] reflected the additional indirect effects of COVID-19 on energy and environmental pollution in agricultural research. The pandemic has altered the established food supply chain and food demand, affecting the most vulnerable. Developing smart village strategies involves applying new approaches in the energy sector based on creating energy cooperatives, renewable energy sources, and digital transformation [139]. In addition, the concept of smart villages includes involving the local population in using digital tools and the principles of the circular economy in managing agricultural processes. Stojanova et al. [140] claimed that improving environmental and socioeconomic processes in the public and private sectors is necessary to restart agricultural development. It is an excellent response to the new challenges of the local community.

Analysis of scientific publications on the impact of the COVID-19 pandemic on the economy revealed the most problematic industries, including tourism, transport, healthcare, and food. Transport and tourism were affected by the imposed restrictions on the movement of the population. The healthcare industry was not ready for the catastrophic increase in patients. The food industry suffered from the destruction of logistics chains, significantly impacting the least well-off sections of the population.

3. Materials and Methods

Our approach to this scoping review was based on the methodology developed by Arksey and O'Malley [141]. We also considered more recent variations of this review when studying the effects of the COVID-19 pandemic [142,143]. For our research purpose, we investigated the following question: What is known about the global impact of COVID-19 on energy economics and environmental pollution, and what research clusters exist?

To identify relevant works, we used an array of Scopus database publications from scival.com as of 23 June 2021. To do this, we included in our study publications for 2016–2022 (through the built-in site search filter), grouped by ASJC topic T.1114223 "Environmental Pollution; Medical Waste; COVID-19". Topic T.1114223 belongs to the top 1% of worldwide topics by prominence. This array contained 1901 publications on 23 June 2021. The total field-weighted citation impact for the array of publications was 5.85.

Furthermore, in this dataset, we selected all publications by subject area energy, the share of which in the total number of publications was 5.6%. The final array of publications we filtered was dated 2019–2021. These publications formed the basis of our study. Figure 1 shows the methodology of our research.

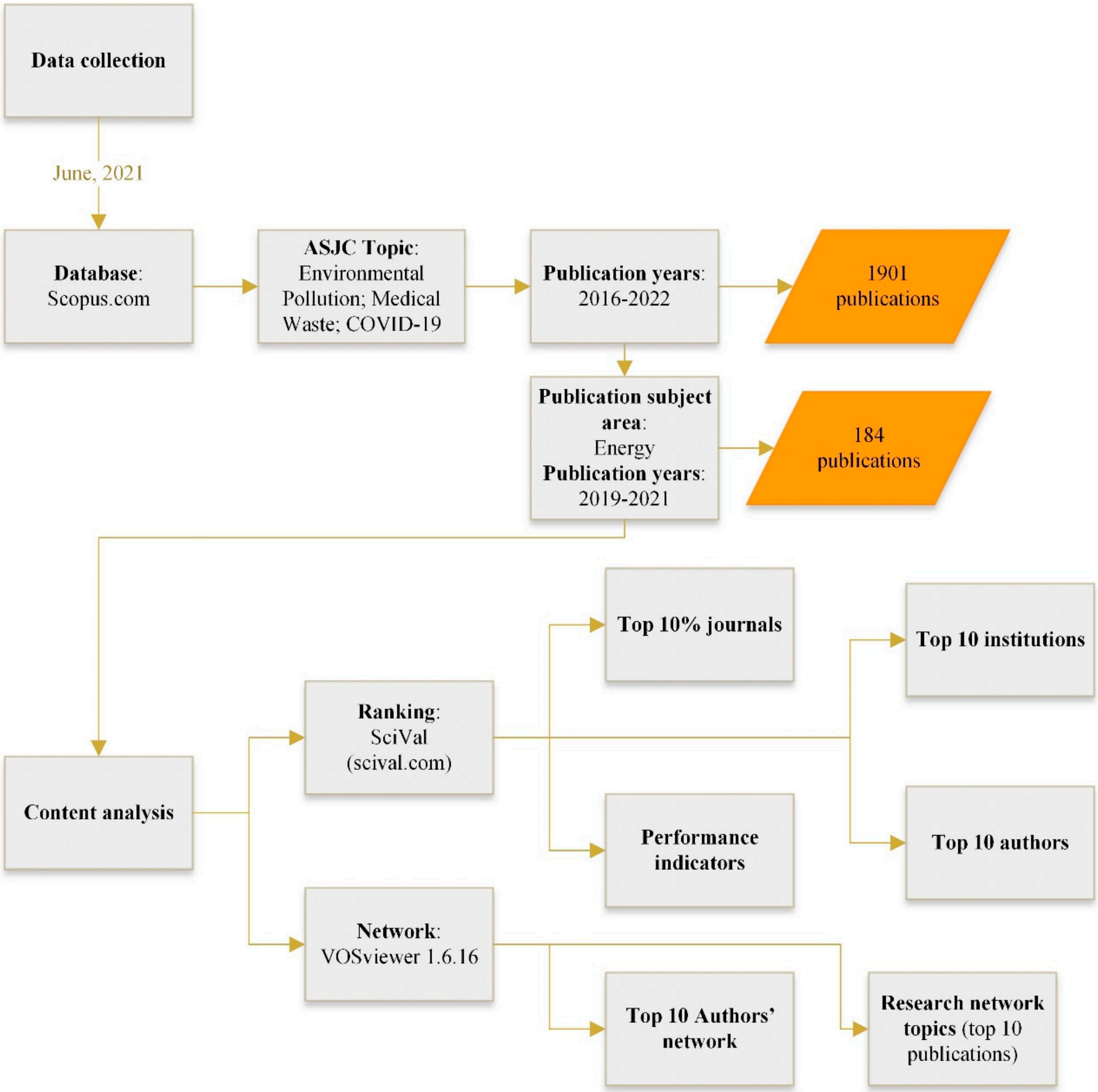

Figure 1. A diagram of the general research methodology.

We visualized the content of our study on the basis of data from the SciVal platform (scival.com) using applications such as Microsoft Visio Professional 2019 and VOSviewer 1.6.16 (vosviewer.com) as tools for analysis and visualization in the Python 3.6.12, Python Software Foundation (Delaware, United States) software environment. In particular, we used the open-source Python library HoloViews (holoviews.org) to build the chord chart. Our chord chart shows relationships for the top 10 organizations (by the number of publications in the sample) with three or more publications with the same foreign organization.

Furthermore, we created the visualization of thematic clusters of journals using the open-source code project Matplotlib 3.4.2 (matplotlib.org, accessed on 5 June 2021). To form such clusters, we used the methods of machine analysis of natural language [144]. To this end, we processed annotations of publications in our sample using the capabilities of the NLTK 3.6.2 library (www.nltk.org). We excluded journal articles without annotations (six papers published in four different journals) and ten conference proceedings from our array of publications. Thus, we used 168 articles published in 35 journals for this analysis.

4. Results

4.1. The Research Topics for Cluster Analysis

We not only relied on the built-in capabilities of the SciVal platform during publication topics analysis, but also used machine techniques for cluster analysis of publications' topics. In general, the publications in our sample were labeled as several thematic areas of energy economics on the SciVal platform. Most publications relied on renewable energy, sustainability, and the environment (see Table 1). Furthermore, the impact of the nuclear energy and engineering field on the scientific community is understandable, given the average number of citations per author. In this area, the most cited was a publication analyzing the impact of COVID-19 on electricity and oil demand in China [145].

Table 1. Publications by the subject area of renewable energy, sustainability, and the environment (within energy area), 2019–2021.

Subject Area	Scholarly Output	The Number of Authors	The Average Number of Citations per Author	Field-Weighted Citation Impact (SciVal)
Energy	184	731	1.98	4.71
Renewable energy, sustainability and the environment	156	622	1.94	4.16
Energy engineering and power technology	83	322	1.68	3.63
Fuel technology	50	185	2.45	4.74
Nuclear energy and engineering	34	120	3.48	5.87
General energy	20	90	2.57	10.25
Energy (miscellaneous)	12	53	0.66	3.47

Based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

In total, 46.3% of publications in our array belonged to the top 10% of journals (by CiteScore ™ 2020). Researchers published their papers on this topic mainly in three journals (see Table 2): Sustainability (38 publications), Journal of Cleaner Production (18), and Energy Sources, Part A: Recovery, Utilization, and Environmental Effects (17). However, among the publications of the top 10% of journals, the most cited was the work published in Renewable and Sustainable Energy Reviews. In this publication, researchers assessed the energy and environmental impacts caused by COVID-19 [146]. However, in our array of publications, Nature Energy was the journal with the highest value of CiteScore™ 2020 (equal to 68.7).

Table 2. Scholarly output by Scopus source within energy (subject area: renewable energy, sustainability, and the environment), 2019–2021.

Scopus Source	Authors	The Average Number of Citations per Author	2020 CiteScore™
Sustainability	165	0.88	3.90
Journal of Cleaner Production	91	0.53	13.10
Energy Sources, Part A: Recovery, Utilization and Environmental Effects	60	1.13	3.40
Sustainable Cities and Society	70	3.38	10.70
Energies	50	0.58	4.70
Energy Research and Social Science	48	6.65	9.50
Applied Energy	42	2.79	17.60
International Journal of Energy Research	18	1.72	5.00
Environments—MDPI	16	0.19	4.10
Renewable and Sustainable Energy Reviews	25	6.60	30.50

Based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

Using text mining analysis of annotations in our array of publications, we grouped all journals into five thematic clusters (see Figure 2). According to the study, the fourth cluster was the largest. The keywords "air, pollution, lockdown, quality, impacts, and changes" could describe research-related publications in 37% of the array. A complete list of journals with their topics is given in Appendix A (Table A1).

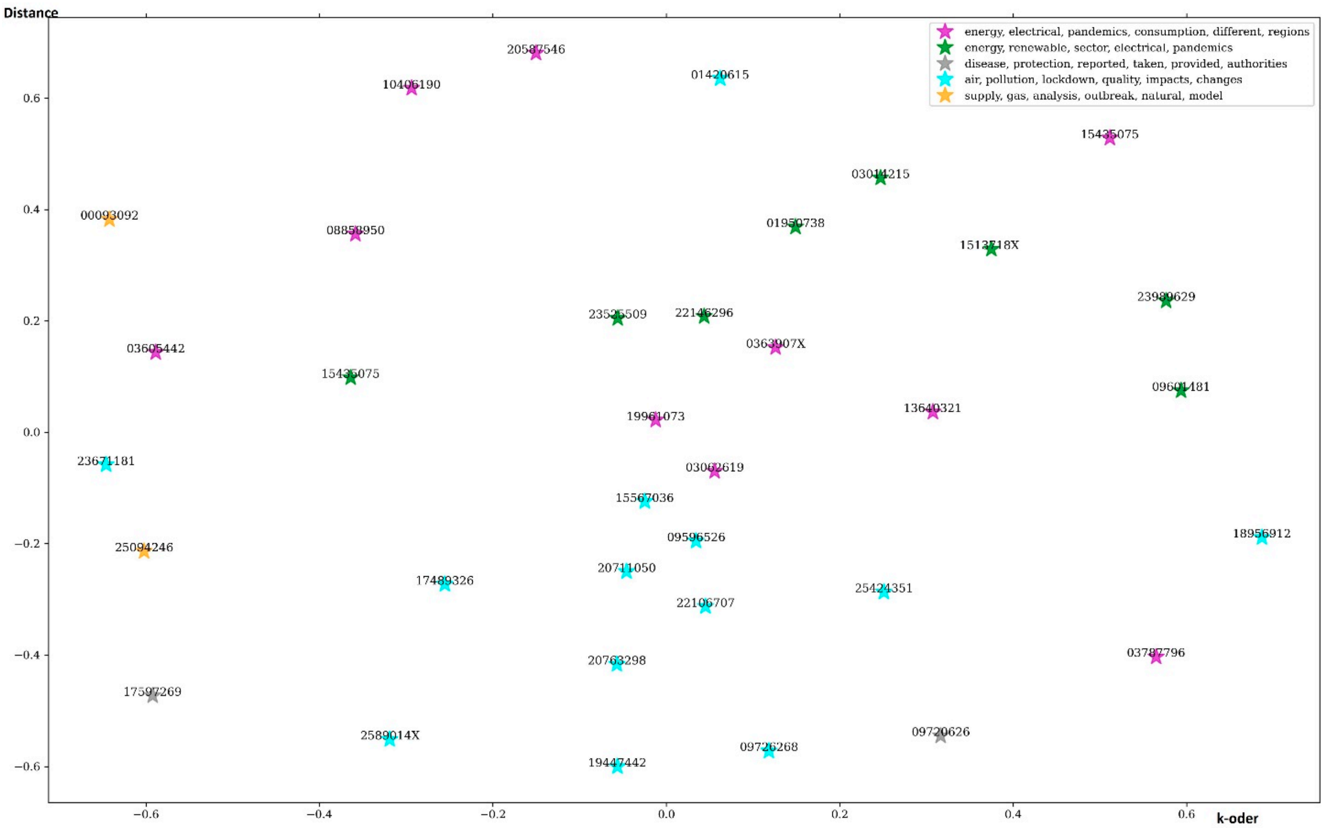

Figure 2. Thematic clusters of journals (by ISSN) within energy using DBSCAN algorithm, 2019–2021. A list with explanations about the numbers found inside the figures is available in Appendix A (Table A1). Source: based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.; subject area: renewable energy, sustainability, and the environment.

4.2. The Research Results of Institutions

According to quantitative indicators of the publishing activity of institutions, the absolute leader in this field was Brno University of Technology (Czech Republic), followed by two institutions from Vietnam and one from Singapore. Five papers of the researchers from these institutions are given in our array.

However, looking at the ranking of organizations by the number of citations per publication, it is possible to see radical differences. The leader, in this case, was an institution from the Philippines (De La Salle University-Manila), followed by one institution from Egypt (Port Said University), and three institutions from the United States (National Bureau of Economic Research, Northwestern University, and Arkansas Technical University).

Looking at the rating of institutions by the total number of citations, two of them had the maximum value of citations by subject area energy (230 each): Agency for Science, Technology, and Research and Brno University of Technology (see Table 3).

Table 3. Top 10 institutions by the number of citations in Scopus within energy (subject area: renewable energy, sustainability, and the environment), 2019–2021.

Institution	Citations	Scholarly Output	Citations per Publication
Brno University of Technology	230	6	38.3
Agency for Science, Technology, and Research	230	5	46.0
De La Salle University-Manila	194	2	97.0
Aarhus University	84	4	21.0
Port Said University	81	1	81.0
Swiss Federal Institute of Technology Zurich	79	3	26.3
Massachusetts Institute of Technology	74	4	18.5
Ontario Tech University	73	2	36.5
Yale University	66	2	33.0
Potsdam Institute for Climate Impact Research	63	2	31.5

Based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

Overall, 42.9% of publications in our array were performed within international cooperation. As a rule, these publications were the most cited. Among the leaders in the number of works performed in international cooperation were institutions such as Brno University of Technology (Czech Republic), Agency for Science, Technology, and Research (Singapore), University of Technology Sydney (Australia), and Aarhus University Denmark). Areas of cooperation for the top 10 institutions by the number of published works are presented in the chord diagram (see Figure 3). The University of Technology Sydney stands out for the number of foreign institutions co-authoring the publications. Researchers at this university worked with 22 institutions in writing their study (in our array of publications). Looking at the regional focus of research, studies on this topic were conducted around the world. However, the European and Asian regions prevailed.

4.3. Analysis of the Authors' Research

The studies of the top 10 most-cited authors in our array were devoted to studying the anthropogenic impact on the environment, energy, and social life in the context of COVID-19. The authors considered the consequences of increased emissions into the atmosphere and discharges of plastic waste, the economy of innovation in clean energy, and fluctuations in energy consumption (see Table 4). We also analyzed the geographical distribution of the 10 most-cited publications. The authors from 18 countries conducted collaborative research, but we identified only cross-border links for eight countries (see Figure 4). Using VOSviewer in our analysis, we identified two clusters of countries. The first cluster contained works from six countries. The results of the spatial classification show that this was mainly the European–Australian cooperation area. This cluster was primarily associated with studies on the environment's negative impact under COVID-19. The second cluster contained studies from only two countries: Germany and Switzerland. Moreover, it is worth noting that the most significant number of contacts with foreigners had researchers from Germany. Authors from the second cluster published scientific papers on the economics of the energy transition during the COVID-19 crisis. They emphasized the short-term positive effects (reduction of greenhouse gases) and the long-term impact of economic shocks caused by the COVID-19 pandemic. They proposed strategic measures to mitigate the shocks and the negative effects of COVID-19 [123,147].

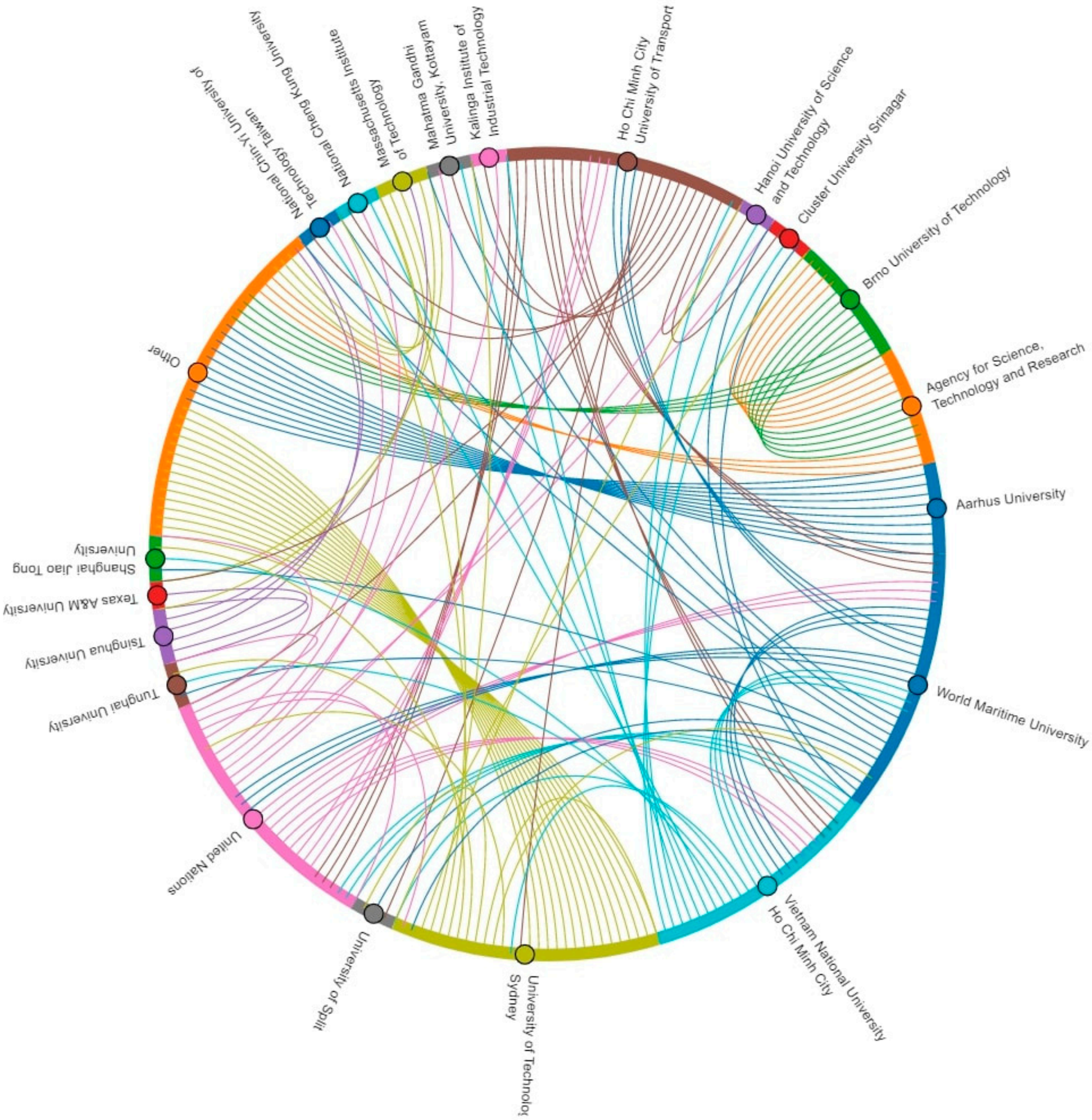

Figure 3. A chord diagram of top networks that appeared within energy (subject area: renewable energy, sustainability, and the environment), 2019–2021. Source: based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

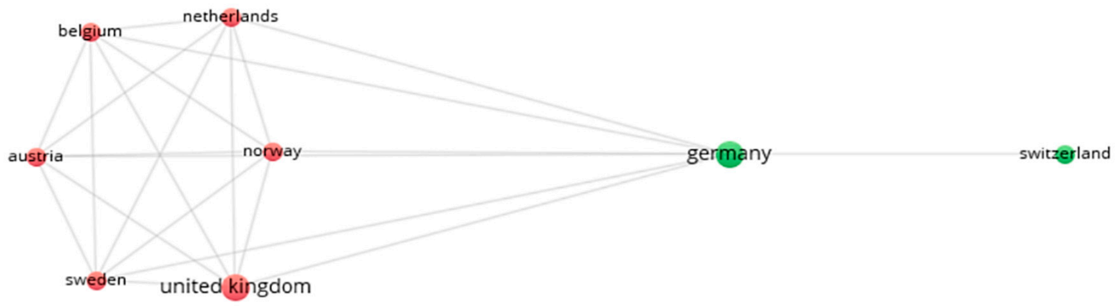

Figure 4. Network map for spatial measurement of research top 10 publications within energy (subject area: renewable energy, sustainability, and the environment), 2019–2021. Source: based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

Table 4. Top 10 authors by the number of citations in Scopus within energy (subject area: renewable energy, sustainability, and the environment), 2019–2021.

Name	Country	Citations	Scholarly Output	Most Cited Publication
Klemeš, Jiří Jaromír	Czech Republic	230	5	Minimizing the present and future plastic waste, energy, and environmental footprints related to COVID-19
Jiang, Peng	China	230	5	Minimizing the present and future plastic waste, energy, and environmental footprints related to COVID-19
Fan, Yee Van	Czech Republic	230	5	Minimizing the present and future plastic waste, energy, and environmental footprints related to COVID-19
Tan, Raymond R.	Philippines	163	1	Minimizing the present and future plastic waste, energy, and environmental footprints related to COVID-19
Ghoneim, Ehab Mahmoud	Egypt	81	1	Antivirus-built environment: lessons learned from the COVID-19 pandemic
Megahed, Naglaa Ali	Egypt	81	1	Antivirus-built environment: lessons learned from the COVID-19 pandemic
Schmidt, Tobias S.	Switzerland	79	3	Navigating the clean energy transition in the COVID-19 crisis
Steffen, Bjarne	Switzerland	79	3	Navigating the clean energy transition in the COVID-19 crisis
Abu-Rayash, Azzam	Canada	73	2	Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic
Dincer, Ibrahim	Canada	73	2	Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic

Based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

To understand the impact of these publications and the emerging themes of the authors' research networks on the scientific community, we constructed a network citation map for the top 10 publications using VOSviewer (see Figure 5). As a result, we obtained three clusters of publication topics. The first and most prominent cluster of topics contained 27 keywords. This cluster focused on management and waste disposal, recycling, the impact of COVID-19 on public health, and the spread and transformation of the virus. The second cluster contained 25 keywords. This cluster presented terms related to energy economics, green economy, and machine forecasting of the environmental impact in the conditions of COVID-19. In energy economics, researchers considered energy efficiency, energy policy, energy use, and energy utilization [148–150]. In the green economy, scientists were interested in renewable energy, sustainable development, and green investment [151–153]. According to the result of the analysis, the third cluster consisted of 23 keywords. This cluster contained publications on air pollution, air quality, and environmental monitoring (Appendix B, Table A2).

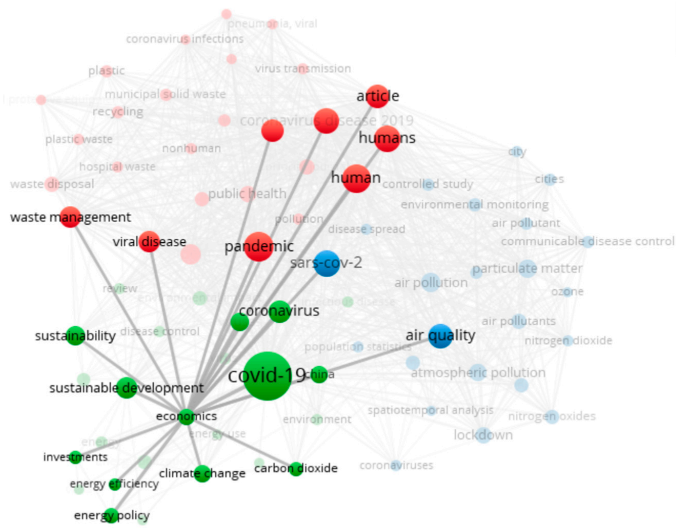

Figure 5. Network map of research topics for the top 10 publications within energy (subject area: renewable energy, sustainability and the environment), 2019–2021. Source: based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

5. Conclusions

This article examined some selected papers about the global impact of COVID-19 on the energy economy and environmental pollution. Modern tools of machine analysis allow us to identify and group clusters and topics of publications, analyze and compare the scientific directions of institutions, and determine leading authors' research. Our main scientific findings suggest that these publications about the global impact of COVID-19 on the energy economy and pollution indicated both positive and negative consequences. The positive consequences included the short-term reduction of greenhouse gases and, consequently, the fulfillment of the goals of the green energy course in most countries of the world. However, the positive effects of the COVID-19 and the proven higher efficiency of decentralized energy systems with renewable energy over those using fossil fuels led to positive trends in the development of renewable energy. This is caused by significant investments and time required for the global spread of renewable energy technologies and positive expectations regarding the end of the pandemic and the lifting of quarantine restrictions, which will allow the energy sector to return to its pre-pandemic status. Hence, further research on the influence of expectations regarding the end of the crisis on changes in energy policy is of interest. At the same time, the impact of COVID-19 was characterized by significant social and economic losses. The COVID-19 pandemic has had a global impact on all sectors of the economy. However, the healthcare system, transport, tourism, and the food industry were most affected. Economic recovery requires effective investment infusions to revive economic activity and technically modernize to transform existing infrastructure solutions and increase energy efficiency. The cluster analysis results show that most research was devoted to the impact of lockdown on air pollution and air quality. According to the results of the network map citing the top 10 publications, we can predict the further development of three scientific areas: exploration related to the management and disposal (disposal) of waste, recycling (recycling), the impact of COVID-19 on public health, and spread and transformation of the virus; research in the areas of the energy economy, green economy, and machine forecasting of the environmental impact in the conditions of COVID-19; investigation of renewable energy, sustainable development, and green investment.

Author Contributions: Conceptualization and methodology, S.K., T.W., S.B. and A.M.W.; software, S.K. and V.Y.; analysis and interpretation of the data, S.K., I.M. and I.V.; approval of the final version, S.K., I.M. and I.V.; funding acquisition, S.K. and I.V. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. The cluster analysis results of journal annotations within energy (subject area renewable energy, sustainability, and the environment), 2019–2021.

Scopus Source	ISSN	Cluster	Cluster Key Words
Applied Energy	03062619	1	Energy, electrical, pandemics, consumption, different, regions
Biofuels	17597269	3	Disease, protection, reported, taken, provided, authorities
Bioresource Technology Reports	2589014X	4	Air, pollution, lockdown, quality, impacts, changes
Chemistry and Technology of Fuels and Oils	00093092	5	Supply, gas, analysis, outbreak, natural, model
Electric Power Systems Research	03787796	1	Energy, electrical, pandemics, consumption, different, regions
Electricity Journal	10406190	1	Energy, electrical, pandemics, consumption, different, regions
Energies	19961073	1	Energy, electrical, pandemics, consumption, different, regions
Energy	03605442	1	Energy, electrical, pandemics, consumption, different, regions
Energy Policy	03014215	2	Energy, renewable, sector, electrical, pandemics
Energy Research and Social Science	22146296	2	Energy, renewable, sector, electrical, pandemics
Energy Sources, Part A: Recovery, Utilization, and Environmental Effects	15567036	4	Air, pollution, lockdown, quality, impacts, changes
Environmental Innovation and Societal Transitions	15435075	1	Energy, electrical, pandemics, consumption, different, regions
Environmental Progress and Sustainable Energy	19447442	4	Air, pollution, lockdown, quality, impacts, changes
Environmental Research Letters	17489326	4	Air, pollution, lockdown, quality, impacts, changes
Environments—MDPI	20763298	4	Air, pollution, lockdown, quality, impacts, changes
IEEE Transactions on Power Systems	08858950	1	Energy, electrical, pandemics, consumption, different, regions
International Energy Journal	1513718X	2	Energy, renewable, sector, electrical, pandemics
International Journal of Electrical Power and Energy Systems	01420615	4	Air, pollution, lockdown, quality, impacts, changes
International Journal of Energy Research	0363907X	1	Energy, electrical, pandemics, consumption, different, regions
International Journal of Green Energy	15435075	2	Energy, renewable, sector, electrical, pandemics
Joule	25424351	4	Air, pollution, lockdown, quality, impacts, changes
Journal of Cleaner Production	09596526	4	Air, pollution, lockdown, quality, impacts, changes
Journal of Energy Resources Technology, Transactions of the ASME	01950738	2	Energy, renewable, sector, electrical, pandemics
Minerals, Metals, and Materials Series	23671181	4	Air, pollution, lockdown, quality, impacts, changes
Nature Energy	20587546	1	Energy, electrical, pandemics, consumption, different, regions
Nature Environment and Pollution Technology	09726268	4	Air, pollution, lockdown, quality, impacts, changes
Nature Sustainability	23989629	2	Energy, renewable, sector, electrical, pandemics
Problemy Ekorozwoju	18956912	4	Air, pollution, lockdown, quality, impacts, changes
Process Integration and Optimization for Sustainability	25094246	5	Supply, gas, analysis, outbreak, natural, model
Renewable and Sustainable Energy Reviews	13640321	1	Energy, electrical, pandemics, consumption, different, regions
Renewable Energy	09601481	2	Energy, renewable, sector, electrical, pandemics
Research Journal of Chemistry and Environment	09720626	3	Disease, protection, reported, taken, provided, authorities
Sustainability (Switzerland)	20711050	4	Air, pollution, lockdown, quality, impacts, changes
Sustainable Cities and Society	22106707	4	Air, pollution, lockdown, quality, impacts, changes
Sustainable Production and Consumption	23525509	2	Energy, renewable, sector, electrical, pandemics

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Appendix B

Table A2. The clusters for the top 10 publications within energy (subject area renewable energy, sustainability and the environment), 2019–2021.

Cluster	Cluster Key Words
1	Article, challenge, concept, coronavirus, coronavirus infections, covid, disease 2019, disposal, epidemic, human, humans, management, municipal solid waste, nonhuman, pandemic, plastic, plastic waste, pneumonia, pollution, potential impact, public health, recycling, viral, viral disease, virus transmission, waste disposal, waste management
2	Carbon dioxide, China, climate change, coronaviruses, COVID-19, disease control, economics, economy, energy, energy efficiency, energy policy, energy use, energy utilization, environment, environmental, environmental impact, green economy, green investment, infectious disease, investments, machine forecasting, renewable energy, review, sustainability, sustainable development
3	air pollutant, air pollution, air quality, ANNs, atmospheric pollution, cites, city, communicable disease control, concentration, controlled study, disease spread, environmental footprint, environmental monitoring, limit, lockdown, nitrogen dioxide, nitrogen oxides, ozone, ozone air pollutants, particulate matter, population statistics, SARS-CoV-2, spatiotemporal analysis

Based on the SciVal database (www.scival.com); data source: Scopus (downloaded on 23 June 2021); copyright: Elsevier B.V.

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