Impact of COVID-19 on Energy Economics and Environment

Subjects: Economics

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The impact of the COVID-19 pandemic on the economy and society has gained the interest of academics and policymakers in recent years.

energy environmental pollution COVID-19

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 [1] 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 [2][3][4] 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. [5] 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 [6] 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 research 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 [7][8] 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 [9][10][11][12][13], 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. [14]. 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 [15] 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 [16] confirmed this conclusion. However, during quarantine restrictions, the reduction in harmful emissions is significant.

The authors of [17] 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 [18], Peru's electricity generation changes have reduced greenhouse gas emissions by 60% compared to the usual scenario. Given this research and the results achieved by [19][20], 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 [21] 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. [22] studied the relationship between the transition to renewable energy and the population's health.

In contrast to the studies listed above, researchers [23] 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 [24] and Delhi [25], where a broader list of outcome indicators was presented. The authors of [26] focused on an essential aspect of environmental pollution during the COVID-19 pandemic: changes in air quality parameters in megacities. This research 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 research 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 research was more pronounced than in similar studies. However, another study [27] 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 [28]. 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 [28] 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 [29], 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 [30] analyzed the impact of restrictions on coronavirus control on the environment in chronological order: before, during, and after coronavirus restrictions. In [31], 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 [13] 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., [32][33]) or compared these effects in different regions (e.g., [34][35]).

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 [36] studied the state of industrial enterprises and changes in emissions of harmful gases and substances into the atmosphere. This research 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 [37] investigated long-term mineralization technology as an effective mechanism for reducing CO_2 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 [38] 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 [37]. 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 [38]. 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 [39] indicated the impact of COVID-19 on environmental quality. While one study [40] defined the relationship between the severity of the pandemic and the level of emissions, another [39] 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 research used data from 2019 (the beginning of the spread of coronavirus). A study by a team of scientists from Italy and France [41] 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 [42] investigated the relationship between COVID-19 mortality and environmental quality through the National Air Toxics Assessment of hazardous air pollutants. An interesting study [43] 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 [44] 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 [45] 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. [46].

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. 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 [47] tried to gauge the extent to which scientists are currently studying this area. A review article [48] 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 [49]. 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 [50] 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 [51] focused on the energy vector of economic development in the post-pandemic period in the context of sustainable development, while the authors of [52] 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 [53] provide information on how to turn the short-term positive effects of a pandemic into an opportunity for sustainable development. In this research, the researchers 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 [54] 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 researchers of this research prepared several proposals for business and government for further economic development. However, this research operated using data obtained in China. Instead, a similar study [55] used data from more than 11,000 companies worldwide.

The authors of [56] drew attention to transforming social conditions under the new way of human life during quarantine restrictions. This research 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 [57] 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 [58] 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 [59] 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).

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 researchers of [60] 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 [61][62][63] summarized trends in energy consumption during quarantine restrictions. Furthermore, the researchers of [64] 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 [65][66][67][68], the researchers explored this issue, proposing the use of machine learning algorithms to consider the impact of COVID-19 on processes in energy. The authors of [69] 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 [70][71][72]. 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. [73] 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 [74][75]. Eryilmaz et al. [76] 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 [77] investigated this issue. Bompard et al. [78] 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 [79]. 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 [80].

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 [81]. Mofijur et al. [82] 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 [83].

Regarding municipal buildings, Geraldi et al. [84] 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 [85]. Using a machine learning model, Kim et al. [86] 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 [87] 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 of additional

connection of different energy sources [88][89]. 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 [90] 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 [91].

References

1. Fuentes, R.; Galeotti, M.; Lanza, A.; Manzano, B. COVID-19 and climate change: A tale of two global problems. Sustainability 2020, 12, 8560.
2. Smiianov, V.A.; Vasilyeva, T.A.; Chygryn, O.Y.; Rubanov, P.M.; Mayboroda, T.M. SOCIO-Economic patterns of labor market functioning in the public health: Challenges connected with COVID-19. Wiad. Lek. 2020, 73, 2181–2187. Available online: https://wiadlek.pl/wp-content/uploads/archive/2020/WLek202010114.pdf (accessed on 1 June 2022).
3. Serpeninova, Y.; Makarenko, I.; Plastun, A.; Babko, A.; Gasimova, G. Mapping of the responsible investments instruments in sdg 3 'good health and well-being' financing: EU and US experience. Health Econ. Manag. Rev. 2020, 1, 106–115.
4. Kuzior, A.; Mańka-Szulik, M.; Krawczyk, D. Changes in the management of electronic public services in the metropolis during the COVID-19 pandemic. Pol. J. Manag. Stud. 2021, 24, 261–275.
5. Marinello, S.; Lolli, F.; Gamberini, R. The impact of the COVID-19 emergency on local vehicular traffic and its consequences for the environment: The case of the city of Reggio Emilia (Italy). Sustainability 2021, 13, 118.

6. Rybak, A.; Rybak, A. The impact of the COVID-19 pandemic on gaseous and solid air pollutants concentrations and emissions in the EU, with particular emphasis on Poland. Energies 2021, 14, 3264.
7. Barua, S.; Nath, S.D. The impact of COVID-19 on air pollution: Evidence from global data. J. Clean. Prod. 2021, 298, 126755.
8. Kumar, P.; Hama, S.; Omidvarborna, H.; Sharma, A.; Sahani, J.; Abhijith, K.V.; Debele, S.E.; Zavala-Reyes, J.C.; Barwise, Y.; Tiwari, A. Temporary reduction in fine particulate matter due to 'anthropogenic emissions switch-off' during COVID-19 lockdown in Indian cities. Sustain. Cities Soc. 2020, 62, 102382.
9. Ali, G.; Abbas, S.; Qamer, F.M.; Wong, M.S.; Rasul, G.; Irteza, S.M.; Shahzad, N. Environmental impacts of shifts in energy, emissions, and urban heat island during the COVID-19 lockdown across Pakistan. J. Clean. Prod. 2021, 291, 125806.
10. Paschalidou, A.; Petrou, I.; Fytianos, G.; Kassomenos, P. Anatomy of the atmospheric emissions from the transport sector in Greece: Trends and challenges. Environ Sci Pollut Res Int. 2022, 29, 34670–34684.
11. Latif, M.T.; Dominick, D.; Hawari, N.S.S.L.; Mohtar, A.A.A.; Othman, M. The concentration of major air pollutants during the movement control order due to the COVID-19 pandemic in the Klang Valley, Malaysia. Sustain. Cities Soc. 2021, 66, 102660.
12. Othman, M.; Latif, M.T. Air pollution impacts from COVID-19 pandemic control strategies in Malaysia. J. Clean. Prod. 2021, 291, 125992.
13. Wang, Q.; Li, S. Nonlinear impact of COVID-19 on pollutions—Evidence from Wuhan, New York, Milan, Madrid, Bandra, London, Tokyo and Mexico City. Sustain. Cities Soc. 2021, 65, 102629.
14. Pan, S.; Jung, J.; Li, Z.; Hou, X.; Roy, A.; Choi, Y.; Gao, H.O. Air quality implications of COVID-19 in California. Sustainability 2020, 12, 7067.
15. Lalas, D.; Gakis, N.; Mirasgedis, S.; Georgopoulou, E.; Sarafidis, Y.; Doukas, H. Energy and GHG emissions aspects of the COVID impact in Greece. Energies 2021, 14, 1955.
16. Das, P.; Mandal, I.; Debanshi, S.; Mahato, S.; Talukdar, S.; Giri, B.; Pal, S. Short term unwinding lockdown effects on air pollution. J. Clean. Prod. 2021, 296, 126514.
17. López-Feldman, A.; Chávez, C.; Vélez, M.A.; Bejarano, H.; Chimeli, A.B.; Féres, J.; Robalino, J.; Salcedo, R.; Viteri, C. Environmental Impacts and Policy Responses to COVID-19: A View from Latin America. Environ. Resour. Econ. 2021, 13, 1–6.
18. Hilares, K.; Vargas, R.; Gastelo-Roque, J.A. Impact of COVID-19 on the GHG emissions of the Peruvian Interconnected Electrical System. In Proceedings of the 2020 IEEE 27th International Conference on Electronics, Electrical Engineering and Computing, INTERCON 2020, Virtual

Conference, 23–25 November 2020; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2020.

19. Logan, B.E.; Rossi, R.; Baek, G.; Shi, L.; Oconnor, J.; Peng, W. Energy Use for Electricity Generation Requires an Assessment More Directly Relevant to Climate Change. ACS Energy Lett. 2020, 5, 3514–3517.
20. Ope Olabiwonnu, F.; Haakon Bakken, T.; Anthony Jnr, B. The role of hydropower in renewable energy sector toward CO2 emission reduction during the COVID-19 pandemic. Int. J. Green Energy 2022, 19, 52–61.
21. Wang, Q.; Lu, M.; Bai, Z.; Wang, K. Coronavirus pandemic reduced China's CO2 emissions in short-term, while stimulus packages may lead to emissions growth in medium- and long-term. Appl. Energy 2020, 278, 115735.
22. Letunovska, N.; Saher, L.; Vasylieva, T.; Lieonov, S. Dependence of public health on energy consumption: A cross-regional analysis. E3S Web Conf. 2021, 250, 04014.
23. Bolaño-Ortiz, T.R.; Puliafito, S.E.; Berná-Peña, L.L.; Pascual-Flores, R.M.; Urquiza, J.; Camargo-Caicedo, Y. Atmospheric emission changes and their economic impacts during the COVID-19 pandemic lockdown in Argentina. Sustainability 2020, 12, 8661.
24. Pal, S.; Das, P.; Mandal, I.; Sarda, R.; Mahato, S.; Nguyen, K.A.; Liou, Y.A.; Talukdar, S.; Debanshi, S.; Saha, T.K. Effects of lockdown due to COVID-19 outbreak on air quality and anthropogenic heat in an industrial belt of India. J. Clean. Prod. 2021, 297, 126674.
25. Goel, A. Impact of the COVID-19 pandemic on the air quality in Delhi, India. Nat. Environ. Pollut. Technol. 2020, 19, 1095–1103.
26. Ghosh, S.; Das, A.; Hembram, T.K.; Saha, S.; Pradhan, B.; Alamri, A.M. Impact of COVID-19 induced lockdown on environmental quality in four Indian megacities Using Landsat 8 OLI and TIRS-derived data and Mamdani fuzzy logic modelling approach. Sustainability 2020, 12, 5464.
27. Brimblecombe, P.; Lai, Y. Subtle changes or dramatic perceptions of air pollution in Sydney during COVID-19. Environments 2021, 8, 2.
28. Zhang, L.; Li, H.; Lee, W.J.; Liao, H. COVID-19 and energy: Influence mechanisms and research methodologies. Sustain. Prod. Consum. 2021, 27, 2134–2152.
29. Saravanan, M.; Velmurugan, S.; Bhanupriya, P.; Booma, D.P. Exploitation of artificial intelligence for predicting the change in air quality and rain fall accumulation during COVID-19. Energy Sources Part A Recovery Util. Environ. Eff. 2020.
30. Bai, Y.; Zhou, Y.; Alatalo, J.M.; Hughes, A.C. Changes in air quality during the first-level response to the COVID-19 pandemic in Shanghai Municipality, China. Sustainability 2020, 12, 8887.

31. Oncioiu, I.; Duca, I.; Postole, M.A.; Georgescu, G.C.; Gherghina, R.; Grecu, R.A. Transforming the COVID-19 threat into an opportunity: The pandemic as a stage to the sustainable economy. Sustainability 2021, 13, 2088.
32. Hoang, A.T.; Huynh, T.T.; Nguyen, X.P.; Nguyen, T.K.T.; Le, T.H. An analysis and review on the global NO2 emission during lockdowns in COVID-19 period. Energy Sources Part A Recovery Util. Environ. Eff. 2021, 1–21.
33. Polyakov, M.; Khanin, I.; Bilozubenko, V.; Korneyev, M.; Shevchenko, G. Factors of uneven progress of the european union countries towards a circular economy. Probl. Perspect. Manag. 2020, 19, 332–344.
34. Yusup, Y.; Ramli, N.K.; Kayode, J.S.; Yin, C.S.; Hisham, S.; Isa, H.M.; Ahmad, M.I. Atmospheric carbon dioxide and electricity production due to lockdown. Sustainability 2020, 12, 9397.
35. Balasubramaniam, D.; Kanmanipappa, C.; Shankarlal, B.; Saravanan, M. Assessing the impact of lockdown in US, Italy and France– What are the changes in air quality? Energy Sources Part A Recovery Util. Environ. Eff. 2020.
36. He, C.; Yang, L.; Cai, B.; Ruan, Q.; Hong, S.; Wang, Z. Impacts of the COVID-19 event on the NOx emissions of key polluting enterprises in China. Appl. Energy 2020, 281, 116042.
37. Lai, Q.T.; Habte, L.; Thriveni, T.; Seongho, L.; Ahn, J.W. COVID-19 Impacts on Climate Change—Sustainable Technologies for Carbon Capture Storage and Utilization (CCUS). In Minerals, Metals and Materials Series; Springer Science and Business Media Deutschland GmbH: Berlin, Germany, 2021; pp. 23–28.
38. Boluwade, A. Regionalizing Partitioning Africa's Coronavirus (COVID-19) Fatalities Using Environmental Factors and Underlying Health Conditions for Social-economic Impacts. In Proceedings of the 2nd Novel Intelligent and Leading Emerging Sciences Conference, NILES 2020, Giza, Egypt, 24–26 October 2022; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2020; pp. 439–443.
39. Qiu, W.; He, H.; Xu, T.; Jia, C.; Li, W. The air quality changes and related mortality benefits during the coronavirus disease 2019 pandemic in China: Results from a nationwide forecasting study. J. Clean. Prod. 2021, 308, 127327.
40. Hasan, S.; Rasheduzzaman, M.; Hossain, M.M. Impacts of COVID-19 on the electrical power dynamics and environment of Bangladesh. In Proceedings of the 3rd 2021 International Youth Conference on Radio Electronics, Electrical and Power Engineering, REEPE 2021, Moscow, Russia, 11–13 March 2021; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2021.
41. Magazzino, C.; Mele, M.; Schneider, N. The relationship between air pollution and COVID-19-related deaths: An application to three French cities. Appl. Energy 2020, 279, 115835.

42. Petroni, M.; Hill, D.; Younes, L.; Barkman, L.; Howard, S.; Howell, I.B.; Mirowsky, J.; Collins, M.B. Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States. Environ. Res. Lett. 2020, 15, 0940a9.
43. Ribeiro Ribeiro, A.L.; Alves Sousa, N.W. Besides the climate model, other variables driving the COVID-19 spread in Brazil. J. Clean. Prod. 2021, 737, 140211.
44. Debone, D.; da Costa, M.V.; Miraglia, S.G.E.K. 90 days of COVID-19 social distancing and its impacts on air quality and health in Sao Paulo, Brazil. Sustainability 2020, 12, 7440.
45. Chernysh, Y.; Roubík, H. International collaboration in the field of environmental protection: Trend analysis and COVID-19 implications. Sustainability 2020, 12, 10384.
46. Nguyen, X.P.; Hoang, A.T.; Ölçer, A.I.; Huynh, T.T. Record decline in global CO2 emissions prompted by COVID-19 pandemic and its implications on future climate change policies. Energy Sources Part A Recovery Util. Environ. Eff. 2021.
47. Ranjbari, M.; Shams Esfandabadi, Z.; Zanetti, M.C.; Scagnelli, S.D.; Siebers, P.O.; Aghbashlo, M.; Peng, W.; Quatraro, F.; Tabatabaei, M. Three pillars of sustainability in the wake of COVID-19: A systematic review and future research agenda for sustainable development. J. Clean. Prod. 2021, 297, 126660.
48. Abubakar, L.; Salemcity, A.J.; Abass, O.K.; Olajuyin, A.M. The impacts of COVID-19 on environmental sustainability: A brief study in world context. Bioresour. Technol. Rep. 2021, 15, 100713.
49. Sharma, G.D.; Tiwari, A.K.; Jain, M.; Yadav, A.; Srivastava, M. COVID-19 and environmental concerns: A rapid review. Renew. Sustain. Energy Rev. 2021, 148, 111239.
50. Kar, S.; Ghosh, I.; Show, S.; Sen, A.; Gupta, T.; Chowdhury, P.; Chatterjee, T.; Roychowdhury, A. Impact of coronavirus (COVID-19) outbreak on society, air quality, and economy in India: A study of three “p”s of sustainability in India. Sustainability 2021, 13, 2873.
51. bin Amin, S.; Ahmed, A.; Khan, A.M.; Khan, F. Policy paper on the post COVID-19 sustainable energy options for power generation in Bangladesh. Int. Energy J. 2021, 21, 9–20.
52. Sueyoshi, T.; Ryu, Y.; Yun, J.Y. COVID-19 response and prospects of clean/sustainable energy transition in industrial nations: New environmental assessment. Energies 2021, 14, 1174.
53. Munmun, B.; Garima, A.; Jyoti, P. Impact of COVID-19 lockdown: A move towards sustainable environment. Res. J. Chem. Environ. 2021, 24, 171–181.
54. Zhang, D.; Hao, M.; Morse, S. Is environmental sustainability taking a backseat in China after COVID-19? The perspective of business managers. Sustainability 2020, 12, 10369.
55. Barreiro-Gen, M.; Lozano, R.; Zafar, A. Changes in sustainability priorities in organisations due to the COVID-19 outbreak: Averting environmental rebound effects on society. Sustainability 2021,

12, 5031.

56. Nundy, S.; Ghosh, A.; Mesloub, A.; Albaqawy, G.A.; Alnaim, M.M. Impact of COVID-19 pandemic on socio-economic, energy-environment and transport sector globally and sustainable development goal (SDG). J. Clean. Prod. 2021, 312, 127705.
57. Tsai, W.T.; Lin, Y.Q. Trend analysis of air quality index (Aqi) and greenhouse gas (ghg) emissions in taiwan and their regulatory countermeasures. Environments 2021, 8, 29.
58. Severo, E.A.; de Guimarães, J.C.F.; Dellarmelin, M.L. Impact of the COVID-19 pandemic on environmental awareness, sustainable consumption and social responsibility: Evidence from generations in Brazil and Portugal. J. Clean. Prod. 2021, 286, 124947.
59. Wolff, L.A. Sustainability education in risks and crises: Lessons from COVID-19. Sustainability 2020, 12, 5205.
60. Obst, D.; de Vilmarest, J.; Goude, Y. Adaptive Methods for Short-Term Electricity Load Forecasting during COVID-19 Lockdown in France. IEEE Trans. Power Syst. 2021, 36, 4754–4763.
61. Abu-Rayash, A.; Dincer, I. Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. Energy Res. Soc. Sci. 2020, 68, 101682.
62. Delgado, D.B.d.M.; de Lima, K.M.; Cancela, M.d.C.; Siqueira, C.A.d.S.; Carvalho, M.; de Souza, D.L.B. Trend analyses of electricity load changes in Brazil due to COVID-19 shutdowns. Electr. Power Syst. Res. 2021, 193, 107009.
63. Didenko, I.; Volik, K.; Vasylieva, T.; Lyeonov, S.; Antoniuk, N. Migration, environment, and country safety: Analysis of touchpoints. E3S Web Conf. 2020, 202, 03028.
64. Ruan, G.; Wu, D.; Zheng, X.; Zhong, H.; Kang, C.; Dahleh, M.A.; Sivaranjani, S.; Xie, L. A Cross-Domain Approach to Analyzing the Short-Run Impact of COVID-19 on the US Electricity Sector. Joule 2020, 4, 2322–2337.
65. Samusevych, Y.; Maroušek, J.; Kuzmenko, O.; Streimikis, J.; Vysochyna, A. Environmental taxes in ensuring national security: A structural optimization model. J. Int. Stud. 2021, 14, 292–312.
66. Štreimikienė, D.; Samusevych, Y.; Bilan, Y.; Vysochyna, A.; Sergi, B.S. Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. Environ. Sci. Pollut. Res. 2022, 29, 7917–7935.
67. Vysochyna, A.; Samusevych, Y.; Starchenko, L. Convergence trends of environmental taxation in european countries. E3S Web Conf. 2020, 202, 03031.
68. Ceylan, Z. The impact of COVID-19 on the electricity demand: A case study for Turkey. Int. J. Energy Res. 2021, 45, 13022–13039.

69. Soava, G.; Mehedintu, A.; Sterpu, M.; Grecu, E. The impact of the COVID-19 pandemic on electricity consumption and economic growth in romania. Energies 2021, 14, 2394.
70. Ruan, G.; Wu, J.; Zhong, H.; Xia, Q.; Xie, L. Quantitative assessment of U.S. bulk power systems and market operations during the COVID-19 pandemic. Appl. Energy 2021, 286, 116354.
71. Samusevych, Y.; Vysochyna, A.; Vasylieva, T.; Lyeonov, S.; Pokhylko, S. Environmental, energy and economic security: Assessment and interaction. E3S Web Conf. 2021, 234, 12.
72. Kuznyetsova, A.; Sydorchenko, T.; Zadvorna, O.; Nikonenko, U.; Khalina, O. Assessment of aspects of the COVID-19 crisis in the context of ensuring economic security. Int. J. Saf. Secur. Eng. 2021, 11, 615–622.
73. García, S.; Parejo, A.; Personal, E.; Ignacio Guerrero, J.; Biscarri, F.; León, C. A retrospective analysis of the impact of the COVID-19 restrictions on energy consumption at a disaggregated level. Appl. Energy 2021, 287, 116547.
74. Bahmanyar, A.; Estebsari, A.; Ernst, D. The impact of different COVID-19 containment measures on electricity consumption in Europe. Energy Res. Soc. Sci. 2020, 68, 101683.
75. Sedmíková, E.; Vasylieva, T.; Tiutiunyk, I.; Navickas, M. Energy consumption in assessment of shadow economy. Eur. J. Interdiscip. Stud. 2021, 13, 47–64.
76. Eryilmaz, D.; Patria, M.; Heilbrun, C. Assessment of the COVID-19 pandemic effect on regional electricity generation mix in NYISO, MISO, and PJM markets. Electr. J. 2020, 33, 106829.
77. Norouzi, N. Post-COVID-19 and globalization of oil and natural gas trade: Challenges, opportunities, lessons, regulations, and strategies. Int. J. Energy Res. 2021, 45, 14338–14356.
78. Halynska, Y.; Bondar, T. Combined electricity pricing model taking into account the “green tariff” and traditional factors. E3S Web Conf. 2021, 234, 00019.
79. Bompard, E.; Mosca, C.; Colella, P.; Antonopoulos, G.; Fulli, G.; Masera, M.; Poncela-Blanco, M.; Vitiello, S. The immediate impacts of COVID-19 on European electricity systems: A first assessment and lessons learned. Energies 2021, 14, 96.
80. Mohamed, M.A.; Jin, T.; Su, W. An effective stochastic framework for smart coordinated operation of wind park and energy storage unit. Appl. Energy 2020, 272, 115228.
81. Kang, H.; An, J.; Kim, H.; Ji, C.; Hong, T.; Lee, S. Changes in energy consumption according to building use type under COVID-19 pandemic in South Korea. Renew. Sustain. Energy Rev. 2021, 148, 111294.
82. Mofijur, M.; Fattah, I.M.R.; Alam, M.A.; Islam, A.B.M.S.; Ong, H.C.; Rahman, S.M.A.; Najafi, G.; Ahmed, S.F.; Uddin, M.A.; Mahlia, T.M.I. Impact of COVID-19 on the social, economic, environmental and energy domains: Lessons learnt from a global pandemic. Sustain. Prod. Consum. 2021, 26, 343–359.

83. Chihib, M.; Salmerón-Manzano, E.; Chourak, M.; Perea-Moreno, A.J.; Manzano-Agugliaro, F. Impact of the COVID-19 pandemic on the energy use at the university of almeria (Spain). Sustainability 2021, 13, 5843.
84. Geraldi, M.S.; Bavaresco, M.V.; Triana, M.A.; Melo, A.P.; Lamberts, R. Addressing the impact of COVID-19 lockdown on energy use in municipal buildings: A case study in Florianópolis, Brazil. Sustain. Cities Soc. 2021, 69, 102823.
85. Navon, A.; Machlev, R.; Carmon, D.; Onile, A.E.; Belikov, J.; Levron, Y. Effects of the COVID-19 pandemic on energy systems and electric power grids—A review of the challenges ahead. Energies 2021, 14, 1056.
86. Kim, D.; Yim, T.; Lee, J.Y. Analytical study on changes in domestic hot water use caused by COVID-19 pandemic. Energy 2021, 231, 120915.
87. Tleuken, A.; Tokazhanov, G.; Guney, M.; Turkyilmaz, A.; Karaca, F. Readiness assessment of green building certification systems for residential buildings during pandemics. Sustainability 2021, 13, 460.
88. 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.
89. Kuzior, A.; Kwilinski, A.; Hroznyi, I. The factorial-reflexive approach to diagnosing the executors' and contractors' attitude to achieving the objectives by energy supplying companies. Energies 2021, 14, 2572.
90. 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.
91. Wołowiec, T.; Myroshnychenko, I.; Vakulenko, I.; Bogacki, S.; Wiśniewska, A.M.; Kolosok, S.; Yunger, V.; International Impact of COVID-19 on Energy Economics and Environmental Pollution: A Scoping Review. *Energies* **2022**, *15*, 8407, https://doi.org/10.3390/en15228407.