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The impact of COVID-19 pandemic on sustainable development goals – A survey

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ABSTRACT

COVID-19 pandemic is the biggest challenge facing humanity after the 1918 Flu pandemic. The pandemic also poses a massive challenge to the achievement of Sustainable Development Goals (SDGs). Meeting this challenge requires a comprehensive investigation of the impact of the pandemic on sustainability. In this work, publications related to the impact of COVID-19 on sustainability in the Web of Science database were explored systematically by using bibliometrics techniques and meta-analysis approach. The results show the research scope is extensive, covering many subjects, whereas the research depth is not enough. Research in developed countries is dominant, although the pandemic poses more significant challenges to the sustainable development of developing countries than of developed countries. Developed countries are committed to studying education sustainability, while developing countries have shown greater attention to economic sustainability during the epidemic. The cluster analysis also shows that the COVID-19 pandemic has brought negative effects on 17 SDGs goals, whereas the pandemic may also bring opportunities to another 14 SDGs goals. At the end of the article, we put forward relevant suggestions for achieving sustainable development goals in the post-epidemic era.

1. Introduction

The newly identified infectious coronavirus (SARS-CoV-2) has spread rapidly in China and other countries worldwide since December 2019 (Zhou et al., 2020). The virus mainly spread from person to person when in close contact through small droplets produced by coughing, sneezing, and talking (Sarkodie and Owusu, 2020). The droplets usually fall on the ground or surface, and people can also get infected by touching the contaminated surface and then touching the face (Srivastava, 2021). Local meteorological studies have found that the types of pollutants (Domingo and Rovira, 2020), temperature (Bashir et al., 2020), humidity (Islam et al., 2021), wind speed (Şahin, 2020), solar radiation (Ahmadi et al., 2020), population density (Coccia, 2020) and other factors also affect the spread of the virus (Rosario et al., 2020). For example, a study in Bangladesh found that warm and humid weather may inhibit coronavirus infection (Haque and Rahman, 2020), making the control and prevention of the epidemic more severe. As of the end of March, confirmed cases of COVID-19 had exceeded 100 million, death cases have been more than 1 million (World Health Organization, 2020c). The world has faced generationally unique health and global economic event. Indeed, “The Sustainable Development Goals Report

2020” issued by the United Nations said: The outbreak of the pandemic in 2020 will cause 71 million people to return to extreme poverty. This is the first increase in the global poverty rate since 1998. Disrupted health care and limited access to food and nutrition services have made the elderly, the disabled, immigrants, and refugees in specific health and socioeconomic conditions who are more likely to be severely affected. In 2020, the number of children dying under five and maternal increased. More than 90% of students cannot go to school in the spring, and more than 370 million children cannot get school meals. The long-term school leave decreased retention and graduation rates, which hurt the development of children and youth, the risks of child labor, child marriage, and child trafficking also increased. The income of 1.6 billion workers in the informal economy fell by 60% in the first month of the crisis. Their work has been severely affected by the pandemic and cannot guarantee a normal life. In terms of economy, according to data from the World Trade Organization (World Health Organization, 2020d). Countries around the world have adopted different isolation and blockade measures (Chaudhry et al., 2020). Although the reduction of human activities has improved air pollution (Wang and Yang, 2021), curb the spread of the epidemic, extensive and longer containment policies based on full lockdowns can deteriorate the economic system with uncertain benefits

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on the health of people (Chakraborty and Maity, 2020). As production and consumption shrink globally, the COVID-19 pandemic has caused unprecedented damage to the global economy and world trade. Due to the loosening of blockade and acceleration of economic activities, there was a rebound in world trade from June to July. But economists have pointed out that any economic recovery may be interrupted by the continuing pandemic (World Health Organization, 2020a).

COVID-19 pandemic and new variants of the virus have highlighted the urgency of the implementation of the 2030 Agenda (Coccia, 2021). Health, social inequality, and other sustainable development goals should be addressed together based on multiple environmental processes that interact simultaneously (Sunyer et al., 2021). The principles underlying the formulation of the SDGs are the key to better recovery after the COVID-19 pandemic. Governments and academia have learned lessons from this pandemic and planned for higher energy utilization from renewable resources and sustainable technologies for improving the environment, economic system, and public health in the long run. The core of these transformations is to obtain high-quality, open, and classified data in time, which help the government formulate effective and fair measures and policies (Bouman et al., 2020).

High-quality shared data is the key to understanding, managing, and mitigating the impact of the pandemic (Wang and Su, 2021). It is essential for formulating short-term response measures and speeding up actions so that countries can return to the track of achieving sustainable development goals. However, the current status of data analysis in countries around the world is not ideal. Some developing areas lack basically healthy, social and economic data (World Health Organization, 2020b).

Bibliometrics is generally considered to be able to understand the development profile of emerging fields (Mehmood et al., 2016), particularly in sustainable social development and the introduction of new areas of cooperation for innovation development (Chernysh and Roubik, 2020). Through a systematic review, it is possible to determine the basic structure, development hotspots, development trends, and other information of the field. Currently, bibliometric research plays an increasingly important role in responding to Public Health Emergency of International (PHEIC). It helps provide information for policy formulation in response to the crisis, accelerate the pace of achieving SDGs in the next decade. Although this method is critical, the bibliometric analysis about COVID-19 pandemic on the achievement of the SDGs is still lacking (Ranjbari et al., 2021). This study draws on the Grounded Theory method described by J.F. Wolfswinkel (Wolfswinkel et al., 2013) and J. Webster (Watson and Webster, 2020) to determine the data source, search terms, initial samples, and refined samples. Use bibliometrics and meta-methods to analyze the basic characteristics of the annual publication volume and subject distribution of the literature, then use the knowledge graph software CiteSpace and VOSViewer for visual analysis to build author cooperation networks, national cooperation networks, institutional cooperation networks, co-cited Timeline view, and keyword co-occurrence network to comprehensively analyze the research hotspots and research trends of COVID-19 on sustainable development.

The main content of this article includes four main chapters. The rest of the research is as follows: The second part study design describes the methodological framework and data sources of this research; the third part result shows the main research results of bibliometrics; the fourth part of conclusions and prospects illustrate influential elements brought by the pandemic to SDGs, also coming up with measures to promote sustainable development.

2. Study design

2.1. Sample, data, and searching strategy

The data in this article comes from Web of Science. Web of Science is a comprehensive academic information database covering most

subjects. It contains various core academic journals in multiple research fields such as natural science, engineering technology, and biomedicine.

Sustainable development is a broad search field. The United Nations divides it into 17 SDGs (United Nations, 2015): No poverty; Zero hunger; Good health and well-being; Quality education; Gender equality; Clean water and sanitation; Affordable and clean energy; Decent work and economic growth; Industry, innovation, and infrastructure; Reduced inequalities; Sustainable cities, and communities; Responsible consumption and production; Climate action; Life under water; Life on land; Peace, justice and strong institutions; Partnerships. It is unrealistic to search the 17 SDGs separately from COVID-19. Many publications irrelevant to the subject surely affect our analysis. Sustainable development mainly includes three main pillars: economy, environment and society (Hák et al., 2016; Pradhan et al., 2017). Therefore, we classify, organize and summarize the 17 SDGs classified by the United Nations. According to the field tags, boolean operators, parentheses, and query sets to create the query (Web of Science, 2018). We used TS= ("2019-nCov" OR "2019 novel coronavirus*" OR "2019 novel-coV" OR "COVID-19" OR "SARS-CoV-2") AND TS= ("sustainability" OR "sustainable" OR "corporate social responsibility ") to search, Here TS = Topic. The limited time is 2020–2021, and the database is Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI). Finally, 1444 documents were retrieved until May 18, and then we conducted bibliometric analysis and meta-analysis.

2.2. Measures of variables

In this section, we use CiteSpace and VOSViewer for data processing. CiteSpace is an information visualization software developed by Dr. Chen using Java language. It can present the structure, regularity, and distribution of scientific knowledge using visualization and then obtain a map of scientific knowledge. CiteSpace mainly includes four main parameters: node types, links, selection criteria, and pruning when performing visual analysis on literature (Li, 2017).

- (1) Node types: In terms of node analysis, according to the different granularity of the subject, CiteSpace provides three levels of co-authorship from micro, meso, and macro: author, institution, and country. The term and keyword are co-word analyses of the text subject. Category performs co-occurrence analysis on the scientific field in the literature. Cited reference, cited author, cited journal is a co-cited analysis of literature.
- (2) Calculation of links strength: In the analysis of the knowledge graph, the standardization of the knowledge unit matrix is expressed by Generalized similarity index:

$$S_G(c_{ij}, s_i, s_j; P) = \frac{2^{1/p} c_{ij}}{(s_i^p + s_j^p)^{1/p}} \quad (1)$$

In Formula (1) and Formula (2), c_{ij} is the number of co-occurrences of i and j , s_i is the frequency of occurrence of i , and s_j is the frequency of occurrence of j .

When $p \rightarrow 0$, Obtain Cosine's standardized formula, which is the default calculation method for the strength of network node association in CiteSpace.

When $p = 1$, Obtain the standardized formulas of Dice and Jaccard algorithm. The generalized similarity coefficients of the two can be expressed as:

$$S_G(c_{ij}, s_i, s_j, 1) = \frac{2Jaccard(c_{ij}, s_i, s_j)}{Jaccard(c_{ij}, s_i, s_j) + 1} = Dice(c_{ij}, s_i, s_j) \quad (2)$$

- (3) Threshold setting: In CiteSpace, Thresholds extract values in three time periods: front, middle, and back. The relationship between the three can be expressed by Formula (3):

$$ccv(i,j) = \frac{cc(i,j)}{\sqrt{c(i)*c(j)}} \tag{3}$$

(4) Pruning method: CiteSpace improves the readability of visual maps by retaining important connections and cropping unnecessary networks. It mainly includes two methods: minimum spanning tree and pathfinder network:

①The minimum spanning tree constructs a minimum spanning tree, which contains the minimum sum of all vertices and weights.

②The pathfinder network selects significant relationships among neighboring networks based on triangular inequalities. The triangle inequality is defined by the formula:

$$w_{ij} \leq \left(\sum_k w_{ik}^r + w_{kj}^r \right)^{1/r} \tag{4}$$

In Formula (4), w_{ij} represents the connection weight between node i and node j . When w_{ij} is greater than the weight of the alternative path, the condition of inequality is violated, and the connection between node i and node j Remove.

(5) Betweenness centrality: Betweenness centrality is proposed by American scholar Freeman (Brandes et al., 2016), which is an important reference index for social network analysis. In Formula (5), it represents the degree of control of a network node on the surrounding resources in the research network. The importance of this node in the network is evaluated by studying the frequency of the node acting as the shortest path intermediary between the other two nodes in the network. Betweenness centrality can be expressed by formula (Fucai, 2017):

$$C_B(n_i) = \sum_j \sum_k \frac{g_{jk}(n_i)}{g_{jk}} \quad (j \neq k \neq i) \tag{5}$$

When the betweenness centrality is greater than 0.1, it means that the node has an important position.

(6) H-Index: H-Index means that the number of citations of X articles in the included paper is greater than or equal to this X value. H-

Index can reflect the quality of the author's article to a certain extent (Hirsch, 2005).

(7) Lotka's Law: Research shows that 60% of authors publish only one article within a given period. As the number of articles increases, the number of authors decreases (Pao, 1986). According to Lotka's Law, the number of articles x and the number of authors y can be expressed by Formula (6):

$$x^r y = C \tag{6}$$

VOSViewer is a software tool used to build a visual bibliometric network. These networks can include journals, researchers, or individual publications, and they can be constructed based on citations, bibliographic coupling, co-citations, or co-author relationships. VOSViewer also provides text mining functions, which can be used to construct and visualize co-occurrence networks of important terms extracted from publications (VOSviewer, 2020).

2.3. Study design and data analysis procedure

Therefore, we further refer to the structured modeling process in F. De Felice's (De Felice et al., 2018), use analysis hierarchy process (AHP) for corresponding analysis and discussion. Structured modeling is mainly divided into the following four steps (see Fig. 1):

- (1) Determine the research objective: The purpose of this stage is to determine the research objective and the appropriate research method through the following questions: the problem described and the reason for choosing this problem, the database to be searched, the start and end time of the search, and the geography of the search area.
- (2) Identifying keywords: At this stage, common keywords are identified, and irrelevant publications are removed from the database to create an initial database.
- (3) Identifying sub-keywords: At this stage, the pyramid search structure is used to determine further sub-keywords involving various fields.
- (4) Create a database: categorize articles according to common keywords and sub-keywords.

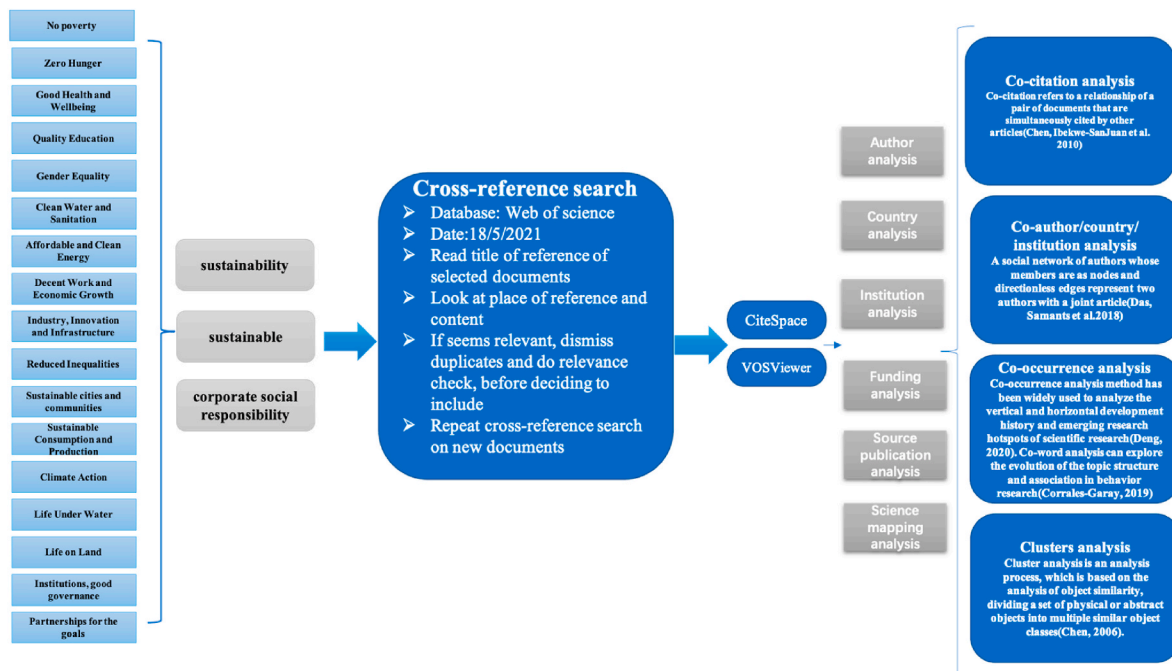


Fig. 1. The step of the document process through CiteSpace and VOSViewer.

3. Results

3.1. Descriptive analysis

As of May 18, Web of Science database already contains 1444 related studies. This reflects academic response rapidly to the possible impact of PHEIC on sustainable development. Although many studies are still published in the form of articles, the diversification of publication forms reflects the adaptation methods of scholars in the research community to ensure the spread of COVID-19 related knowledge as soon as possible. The field is developing faster than people expected. For example, the “deep learning” field in artificial intelligence is one of the fastest-growing fields today, containing approximately 150,000 papers. It took about 20 years for “deep learning” to start research and reach hundreds of articles per year, but research on COVID-19 reached the same number in just ten months.

We refer to the 16 main areas of the ECOOM classification scheme to describe the distribution of publication topics more clearly (Zhang et al., 2016). As can be seen in Fig. 2, Environmental Sciences, Green Sustainable Science Technology, Environmental Studies, and Public Environmental Occupational Health are the subject areas with the largest number of publications. This reflects that during COVID-19 pandemic, environmental sustainability has attracted widespread attention from the academic. The report of ESCAP shows that the occurrence of the COVID-19 pandemic has led to the suspension of human activities, population movements, and demand for resources reduction, providing a much-needed breathing space for the environment and contributing to environmental recovery (United Nations Economic and Social Commission for Asia and the Pacific, 2020). Economics, Management, and Business reflect the economic perspective of pandemic research. The occurrence of the COVID-19 pandemic disrupts the stability of the global economy and disrupts the lives of billions of people around the world. But this is a period of economic transformation. The academic community takes advantage of this opportunity to use the SDGs to guide economic recovery and economic transformation to achieve greener and more inclusive economic development. In addition to the two subject categories of environment and economics, there are also topics such as Public Environmental Occupational Health, Hospitality Leisure Sport Tourism, Education Educational Research, Health Policy Services, etc. These subject categories are not a single category focused on a certain

field, but concentrated interdisciplinary in multiple fields. This shows that the study of sustainable development during the pandemic has become a common concern of multiple disciplines; studies in the dimensions of society, agriculture, energy, and economy have been launched.

3.2. Authors analysis

Co-citation analysis means that two articles appear together in the third cited document’s reference list, and then the two documents form a co-cited relationship. In this section, the author’s co-citation is an analysis derived from the co-citation of the paper (Nerur et al., 2008). Concentric circles represent years of separation of publications in Fig. 3. The size of the circle indicates the author’s central position in the cooperative network. Here, purple indicates older papers and yellow indicates relatively new publications. The author’s co-citation analysis can not only obtain the distribution of highly cited authors in a certain field but also identify the influential scholars in this field. Through the author’s co-citation network, we can understand the research topics of similar authors in a certain field and cluster and their subject areas (Qin et al., 2014). There are many intersecting parts of different research cluster networks. The red and blue arrows in the picture represent the collaborators of a typical group. Some authors cooperate closely and form obvious cooperative groups, but the cooperation is mostly carried out within the group, and the connection between different groups is less. It’s worth noting that several nodes with greater influence in the graph, such as the World Health Organization, United Nations, and European Commission, are not individual scholars, but are displayed in the form of organizations. This reflects regional research plays an important role in this field.

To explore the quality of the author’s publications, we list the top ten centrality authors in Table 1 to view the related information. In Table 1, researchers from China, the United Kingdom, and the United States have a high centrality. The research results of these authors mostly focus on the early clinical research and pathological analysis of the COVID-19 pandemic. Greenhalgh T from the University of Oxford and Cohen J from Universite de Reims Champagne-Ardenne both have high H-index and Centrality.

To explore the productivity of the authors of all articles, we used Lotka’s Law for analysis and conducted K-S test to verify the reliability

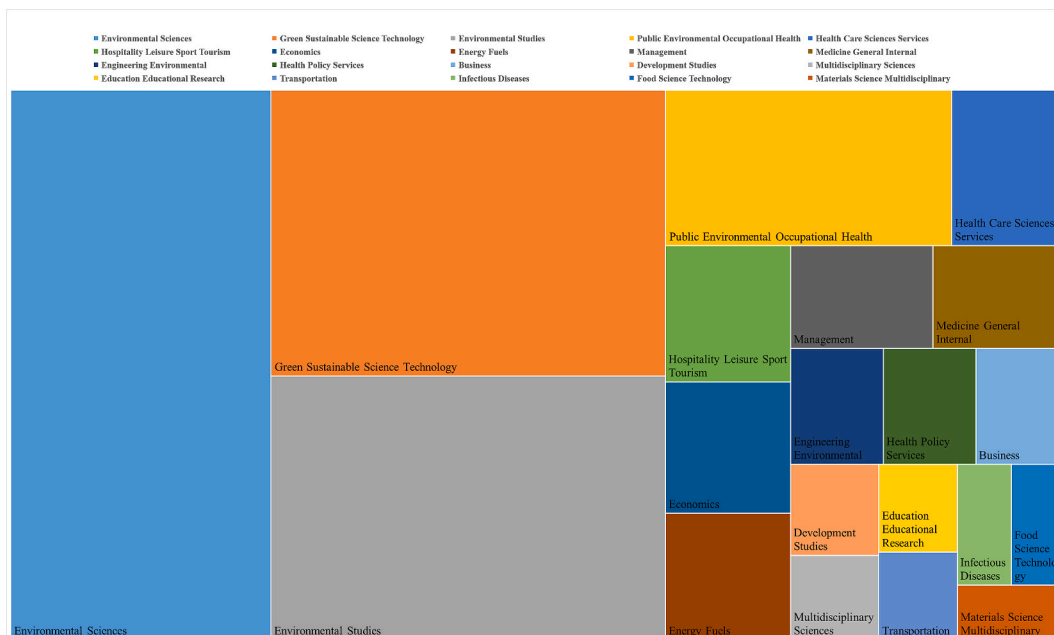


Fig. 2. The number of documents by discipline category.



Fig. 3. The cooperation network of the author.

Table 1

The count of cited papers published by the author (TOP 10).

Author	Count	Centrality	Country	Organization	H-index
LI Q	12	1.28	China	Tongji University	22
World Health Organization	97	0.99	-	-	-
WU Jt	13	0.9	China	Yangzhou University	22
Kampf, Günter	11	0.75	Germany	Medizinische Fakultät der Universität Greifswald	38
Shaw, Rajib K	2	0.65	Japan	Keio University	30
Van Doremalen N	16	0.62	United States	NIH National Institute of Allergy & Infectious Diseases	-
UNITED NATIONS	25	0.52	-	-	-
Klemeš, Jiri Jaromír	9	0.44	Czech Republic	Brno University of Technology	59
Zambrano-Monserrate, Manuel A	9	0.4	Ecuador	Universidad Espíritu Santo, Ecuador	10
Zhou, Peng	11	0.3	China	Wuhan Institute of Virology Chinese Academy of Sciences	25

of Lotka's Law. First, It is pointed out here that each article only considers the first author, and the role of the co-author is negligible. Secondly, we organize the data (data time as of 2021.5.18) in Table 2 and Table 3, use Formula (7) to find $n = -3.7864$, the absolute value is between 1.2 and 3.8, so it meets Lotka's Law. Calculate $c = 0.9102$ by Formula (8) and Formula (9), the critical value is 0.5651. So we get the expression Formula (10), and then in Table 4, the function is tested for goodness of fit by the K-S test. In Table 4, $D_{max} = 0.0018 < 0.5651$. Therefore, the K-S test is passed. It means that the scale of research in this field and the degree of scientific research cooperation between scholars are relatively mature. However, shorter search times and a single database may affect search results.

Table 2

Calculation of author productivity of data mining.

Publications(x)	Authors(y)	Publication count (xy)	Accumulated publication	Accumulated publication	Accumulated Author	Accumulated Author %
1	747	747	747	51.73%	747	70.60%
2	253	506	1253	86.77%	1000	94.52%
3	46	138	1391	96.33%	1046	98.87%
4	8	32	1423	98.55%	1054	99.62%
5	3	15	1438	99.58%	1057	99.91%
6	1	6	1444	100.00%	1058	100.00%

NP = number of publication.

Table 3

Calculation of the exponent n for data mining.

Publications(x)	Authors(y)	X = log(x)	Y = log(y)	XY	XX
1	747	0.0000	2.8733	0.0000	0.0000
2	253	0.3010	2.4031	0.7234	0.0906
3	46	0.4771	1.6628	0.7933	0.2276
4	8	0.6021	0.9031	0.5437	0.3625
5	3	0.6990	0.4771	0.3335	0.4886
6	1	0.7782	0.0000	0.0000	0.6055

x = number of publication; y = author; X = logarithm of x; Y = logarithm of y.

Table 4
The K-S test for data mining.

Publications (x)	Authors(y)	Observation by author	cumulative values	Expected value by author	Cumulative values	Differences of each pair
1.0000	747.0000	0.7060	0.7060	0.9102	0.9102	-0.2042
2.0000	253.0000	0.2391	0.9452	0.0660	0.9762	-0.0310
3.0000	46.0000	0.0435	0.9887	0.0142	0.9904	-0.0017
4.0000	8.0000	0.0076	0.9962	0.0048	0.9952	0.0011
5.0000	3.0000	0.0028	0.9991	0.0021	0.9972	0.0018
6.0000	1.0000	0.0009	1.0000	0.0010	0.9982	0.0018

NP = number of publication; Observation by author = author productivity of data mining; Sn(x) = observed cumulative frequency; Fo(x) = theoretical cumulative frequency; D = | Fo(x)- Sn(x) |.

$$n = \frac{N \sum XY - \sum X \sum Y}{N \sum X^2 - (\sum X)^2} \tag{7}$$

$$c = \frac{1}{\sum_1^{p-1} \frac{1}{x^n} + \frac{1}{(n-1)p^{n-1}} + \frac{1}{2p^n} + \frac{n}{24(p-1)^{n+1}}} \tag{8}$$

$$\text{critical value} = \frac{1.63}{\sum \sqrt{Y}} \tag{9}$$

$$f(x) = \frac{0.9102}{x^{3.7864}} \tag{10}$$

3.3. Country analysis

Different countries/regions have different research capabilities, which affect the geographic distribution of research work. In this section, we determine the distribution of countries/regions according to the author’s institutional address stated in the title of the publication. In terms of counting, we adopt the full distribution scheme. That is, the national publication count indicates how many papers the country/region has contributed. Fig. 4 shows the global distribution of COVID-19 in terms of sustainable development, and the shade of the color represents the number of documents issued by the country. In addition to Antarctica, research on COVID-19 has been extended to six other continents. From the perspective of the total number of intercontinental countries, except for the few countries in Africa participating in the study, the number of countries in North America, Europe, East Asia, South America, and other regions participating in the study is relatively even. In terms of national development level, the United States has the darkest color in the picture with the largest number of documents. Other developing countries in South America, Africa, and other countries have

fewer documents. The highest intensity of COVID-19 research began in China. Given the early demand for disease treatment, China is in a leading position in the research of COVID-19. Therefore, scholars from China have published more articles on the overall research of COVID-19. China’s first mover advantage makes its publications the basis of highly cited journals in this new field. With the arrival of COVID-19 in the United States and Europe, these countries have gradually increased their contribution to the number of publications, and China’s research on COVID-19 has also stabilized. However, the picture shows that in the research on COVID-19 for sustainable development, Chinese publications do not occupy a leading position in the world. On the contrary, European countries have more publications. Therefore, we infer that this may be related to the gradual transfer of the COVID-19 virus itself to the West and the greater attention of developed countries to the realization of sustainable development goals.

In terms of investigating joint research work in different countries/regions, we use CiteSpace to draw a map of national cooperation. In Fig. 5, each node represents the number of papers published by a country/region, and the strength of the connection between the nodes represents the strength of cooperation between the two countries/regions. As can be seen in Fig. 5, the global cooperation map is mainly divided into five research groups centered on the United States, England, Germany, Italy, China. The United States has close cooperation with Germany, Italy, Brazil, and other countries. These countries are distributed in Europe, Africa, and there is no obvious difference in the intensity of cooperation, which shows that geographical location is not a factor that affects the cooperation in this research group. Research groups with China as the core mainly cooperate closely with Central Asian and East Asian countries such as Thailand, Malaysia, and Saudi Arabia. This shows that Asian countries are more inclined to conduct cooperative research with countries that are more geographically

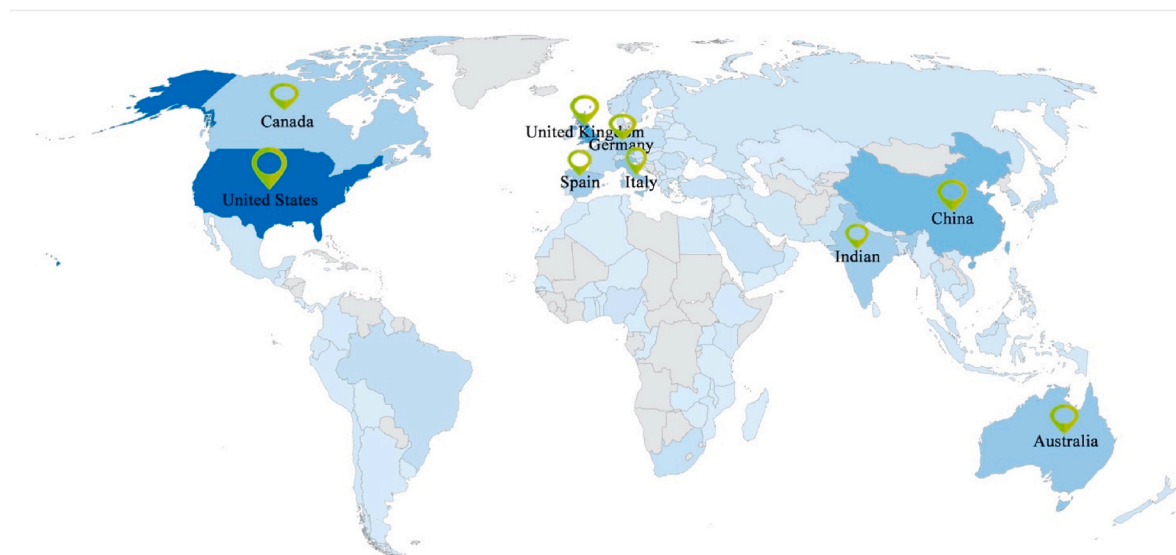


Fig. 4. Country/Region coloring map by the number of documents.

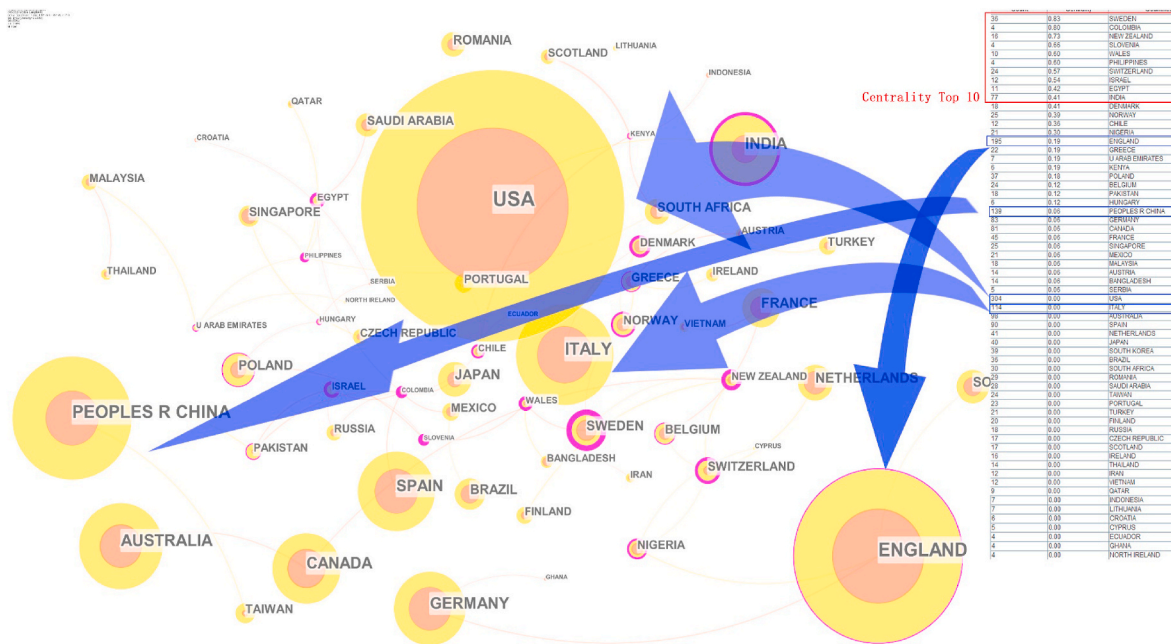


Fig. 5. The cooperation network of country/region.

similar. A noteworthy phenomenon is that although China has a high count, its centrality is low, which may reflect the quality of publications in Asian countries to a certain extent. Research groups centered on England have close cooperation relations with Italy, France, Switzerland, Finland, and other European countries. The link strength between nodes within the group is relatively high. Most of these countries are member states of the European Union. After the outbreak, although research sites such as EMBL-EBI have been closed, academics in various countries have adopted a network remote work model to maintain existing data resources. So that researchers can quickly respond to the COVID-19 pandemic. In addition to the above-mentioned research groups, we also found an interesting phenomenon. India has both high count and centrality in the figure, but India has fewer cooperation links with other

countries and is in a relatively isolated state.

3.4. Institutions analysis

The number of articles issued by research institutions and the frequency of citations reflects a certain extent the research scale and research capabilities of the field. The study found that research institutions in the United Kingdom, the United States, and China have more publications. In terms of types of institutions, the main body of research is universities, foundations, and research institutes account for only a small proportion. Universities have become the main research force in this field, and the knowledge base and subject innovation from a good inheritance and dissemination in universities.

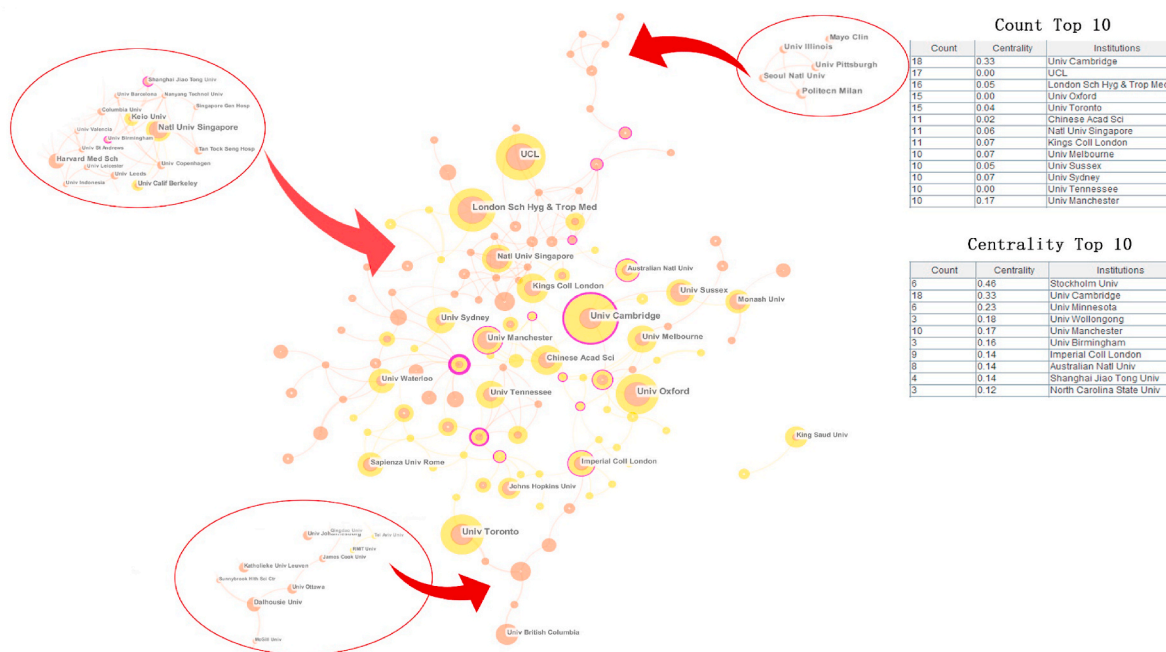


Fig. 6. The cooperation network of institutions.

To further explore the research on the sustainable development of institutions during the COVID-19 pandemic, in Fig. 6, We can find that University of Cambridge, The University of Manchester all have high centrality and count, they are representative research groups in the map. These groups reflect some of the characteristics of current institutional cooperation: first, geographic location has not become a restriction that affects cooperation between institutions, and institutions in Europe and North America have developed closer ties. Second, the cooperation between institutions focusing on different research topics, such as medical institutions and comprehensive universities, has been extensively carried out.

3.5. Science mapping analysis

(1) Co-citation analysis

The cited documents in the original records constitute the knowledge base of the research field. The cluster analysis and evolution research of the knowledge is the basis for distinguishing the research frontiers in this field, which can reveal the research frontiers and thematic turning points, clarify the connections between frontiers and fields. This study uses the data collected by Web of Science to draw a visual map of the “impact of COVID-19 on sustainable development” based on the document co-citation network. It can be seen from the figure that the final cluster is obtained: 0#future outbreak, 1#balancing detection policy, 2#post-epidemic period, 3#urban parameter,4#supply chain,5#coronavirus pandemic, 6#residential building, 7#potential anthropogenic component. Fig. 7 shows that the co-cited map mainly focuses on two parts. The first is the pathological analysis at the beginning of the epidemic. Although this part is the basis for subsequent research, it is no longer the main body of sustainable development research at the current stage. Social policy research in the post-epidemic era represented by 0#, #2, and #3 has a relatively complex network. There are many nodes with high centrality in the group, and the connections between and

within groups are relatively close.

To further explore the cited documents in each cluster, we analyze the top ten centrality publications of the six clusters in Table 5. The study found that the cited literature is mostly based on early medical analysis. Given the early demand for disease treatment, China is in a leading position in the research of COVID-19. The average centrality of Chinese publications in the table is 0.7975. China’s first-mover advantage makes its publications become the basis of co-cited papers in this field. It can be seen from the table that scholars in the United States and China began to work on the COVID-19 virus, which laid the foundation for subsequent studies on the impact of sustainable development.

(2) Keyword analysis

As a refined expression of research topics in academic papers, keywords can reveal the distribution and evolution of research topics to a certain extent, can intuitively reflect the changes in hot areas, analytical perspectives, and research methods in different time series, and reveal the inherent knowledge of the subject area contact (Qin et al., 2014). Given this, we use keyword analysis to identify the main research directions and hotspots of the impact of COVID-19 on sustainable development and make judgments on the development and changes of the research field.

We use VOSViewer to perform a visual analysis of keywords. Finally, we obtain the keyword visualization map as shown in Fig. 8. In the map, similar categories are distributed according to the same color. The green and yellow clusters mainly about “disease treatment”. Publications in this part mainly focus on the medical treatment plan for COVID-19 and the improvement of the medical system. In this part, the distribution of keyword nodes is relatively dense, which reflects the importance of scholars on medical protection in the early stage of the pandemic; Among the cyan clusters dominated by “air quality” and “pollution”, the keywords belong to environmental pollution. The European Space Agency (ESA) used the Copernicus Sentinel-5P satellite to observe that

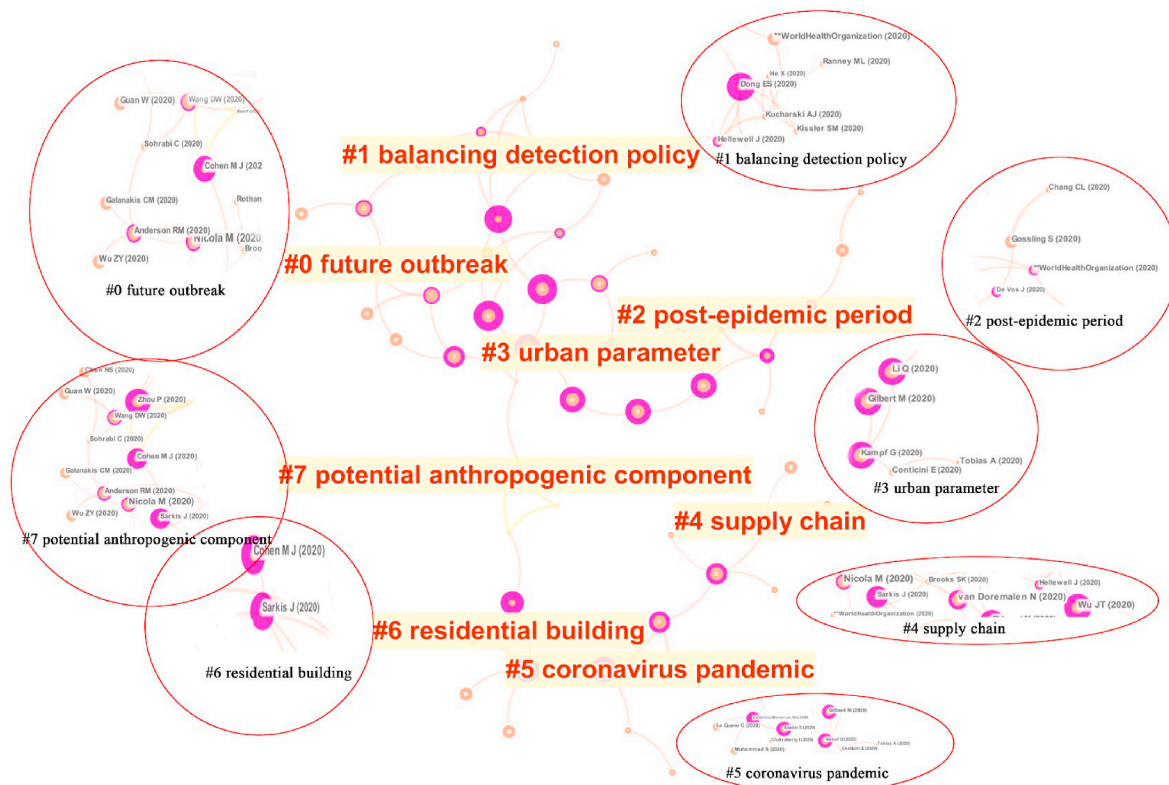


Fig. 7. The cluster view of the cited-reference network.

Table 5
Top ten reference information.

Document title	Author	Country	Count	Centrality
Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents	Kampf, G	Germany	20	0.86
Clinical Characteristics of 138 Hospitalized Patients with 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China	Wang, D	China	17	0.68
COVID-19 as a factor influencing air pollution?	Dutheil, F	France	10	0.65
First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community	Ahmed, W	Australia	6	0.61
SARS-CoV-2 in wastewater: potential health risk, but also data source	Lodder, W	Netherlands	7	0.6
Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak	Wang, P	China	6	0.53
COVID-19 pandemic and environmental pollution: A blessing in disguise?	Muhammad, S	China	27	0.52
A novel coronavirus outbreak of global health concern	Wang, C	China	11	0.48
An investigation of transmission control measures during the first 50 days of the COVID-19 epidemic in China	Tian, H	China	7	0.45
COVID-19 Pandemic Repercussions on the Use and Management of Plastics	Prata, J.C	Portugal	9	0.42

nitrogen dioxide emissions over Italy have fallen sharply in the first two and a half months of 2020 (European Space Agency, 2020c). This means that the reduction in industrial and transportation activities caused by the lockdown may reduce pollution emissions. Keywords such as “education”, “teaching”, and “university” are prominent among the purple clusters, which are concentrated in the fields of education and teaching. The blue cluster is a relatively single cluster related to energy, including keywords such as “energy demand” and “transport”. The red cluster uses “sustainable development goal” as the central word. The keywords of this cluster involve more fields and overlap with the blue cluster and the purple cluster. Including “climate change” in the environmental field, “corporate social responsibility” and “tourism” in the social field, and “supply chain” in the economic field.

To explore the similarities and differences in research hotspots between developing and developed countries, we selected Italy and India, which are more representative in the picture, as representatives for analysis. The keywords related to Italy are mainly “education” and “air quality”. Keywords related to India are “emission”, “air quality”, and “death”. The impact on the environment seems to be a research hotspot of common concern for the two countries. However, the developed countries represented by Italy seem to have greater enthusiasm for research on the sustainability of education in the epidemic. For example, psychological distress caused by home isolation (Bonati et al., 2021; Passavanti et al., 2021), the development of higher education (Tejedor

et al., 2021), etc. The development of distance education is a topic of common concern for many scholars. The outbreak of the epidemic has promoted the development of digital classrooms to a certain extent (Chauhan et al., 2021; Naddeo et al., 2021). On the contrary, developing countries represented by India are more concerned about the economic sustainability of the epidemic, such as energy consumption (Su and Urban, 2021; Wang and Han, 2021), financial markets (Youssef et al., 2021), etc.

We further refine the “three pillars” of sustainable development mentioned in the second part—economy, environment, and society:

- (1) Economic criteria: refers to the business environment, economic growth, cost and productivity, employment, connectivity, and wealth;
 - a. Impact of COVID-19 on business

WTO estimates that global trade fell by about 27% during the pandemic, and the economic growth rate dropped to 3% (World Trade Organization, 2020a). The adverse effects of COVID-19 on the economy mainly come from two aspects (Mofijur et al., 2021): First, the exponential growth of confirmed cases has caused investors to question the instability of the financial and capital markets (T. Buck, 2020). The Dow Jones Industrial Average and Nasdaq in the United States, China’s Shanghai Composite Index in the Asian market, and South Korea’s KOSPI all showed varying degrees of decline. Second, the strict control policies shown in Fig. A1 have greatly reduced transportation activities such as railways and aviation, which put pressure on consumption and productive economic activities. Prolonged lockdown measures also increased the risk of corporate and government debt, and financial imbalances may extend the time for economic recovery from the COVID-19 crisis (Donthu and Gustafsson, 2020).

b. Impact of COVID-19 on supply chain

Due to the characteristics of long-term disruption and increasing propagation of the pandemic, transportation-related sectors have been hit hardest (World Health Organization, 2020a). Ensuring the supply chain of PPE helps reduce mortality and plays an important role in maintaining medical and health services (Rowan and Laffey, 2020). Therefore, ensuring the integrity of supply chain and logistics management is the focus of academic research (Ivanov, 2020). Among them, “low income country” is a more concerned keyword. This is because the transportation industry is an important source of income for low income countries (World Trade Organization, 2020a). During the pandemic, demand for basic commodities in various countries surged, factories closed, panic buying, and changes in consumer preferences have severely affected low income countries (Ivanov, 2020). Coupled with the weak economic foundation, lack of medical protective equipment and other reasons, low income countries are facing more severe risks (Nordhagen et al., 2021).

c. Impact of COVID-19 on employee

During the pandemic, about 330 million employees worldwide were required to be isolated and unable to work normally. The layoffs and increased working hours are taken by companies have affected the income of many employees (Dey and Loewenstein, 2020). Declining personal incomes and increasing uncertainty have reduced people’s spending, leading to further business closures and unemployment (Ghosh, 2020). As the unemployment rate rises, blacks, Asians, and minority ethnicities face more serious unemployment problems during the lock-in period of COVID-19 (Hu, 2020). Also, lack of social support and panic about the pandemic have led to impaired employee well-being and increased the risk of mental illness (Chen, 2020).

d. Impact of COVID-19 on agriculture

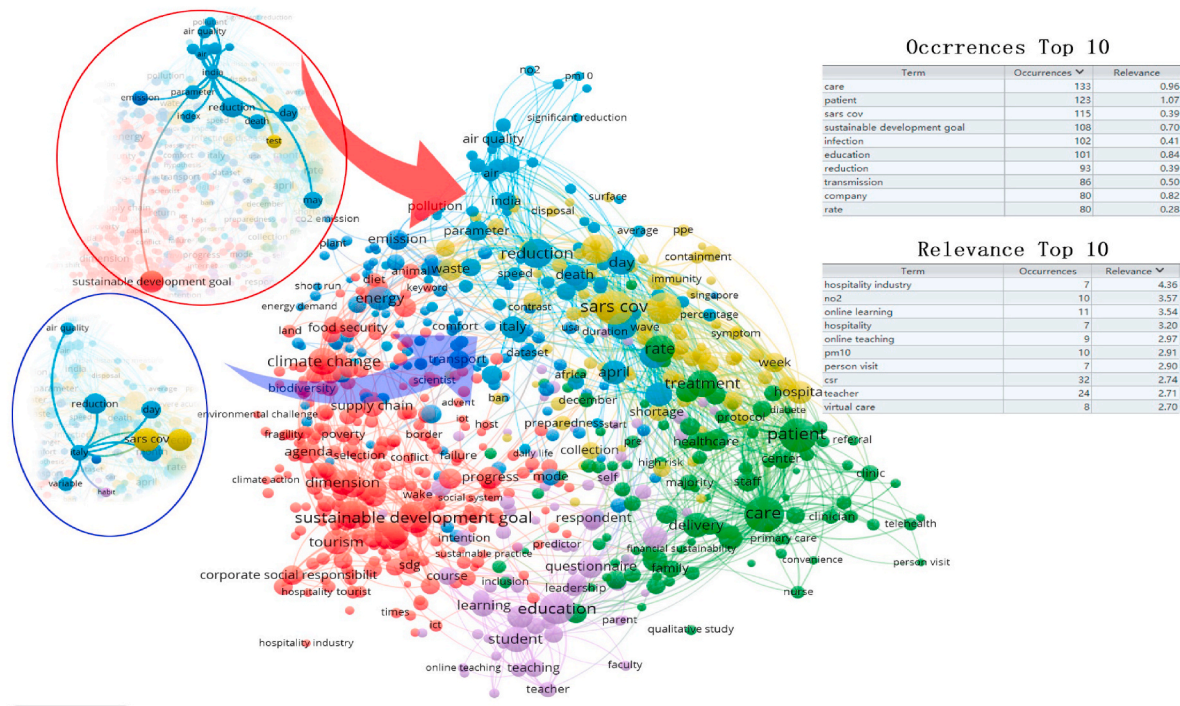


Fig. 8. The cluster view of the keyword network.

As the COVID-19 pandemic spreads, the global agricultural system and food security are being challenged. Restricted movement and insufficient labor are likely to damage crop yields. Besides, quarantine measures have also affected the supply or acquisition of agricultural necessities such as fertilizers and pesticides (Ayanlade and Radeny, 2020). The Food and Agriculture Organization reported that agriculture in developing countries is most affected by COVID-19, and loss of income and local supply chain disruption have led to increased food insecurity in many developing countries (Elleby et al., 2020).

e. Impact of COVID-19 on energy

During the pandemic, the energy sectors of countries around the world were also significantly affected. Travel bans, border closures and changes in work practices have reduced the need for conventional transportation fuel (Madurai Elavarasan et al., 2020). Fig. A2 shows the energy demand of the global economy has been affected by COVID-19 to varying degrees. The proportion of renewable energy may increase due to its low production cost and the choice of access to many power systems (Khan et al., 2020). Keywords such as “energy” and “fossil fuel” represent that the occurrence of the COVID-19 pandemic provides a brand new development opportunity for the energy transition (Klemes et al., 2021). The report of the UN Environment Programme shows that COVID-19 has caused a serious impact on the fossil fuel industry, while renewable energy is more cost-effective than ever. Countries in economic recovery give priority to clean energy as the “most cost-effective” investment. Besides, the consumption of renewable energy can promote sustainable economic growth and environmental improvement, enhance the image of the country on a global scale, and open up international trade opportunities with environmentally friendly countries (Khan et al., 2021). Therefore, promoting the use of renewable energy can bring about economic prosperity, create a better environment and achieve SDGs (Pradhan et al., 2020).

(2) Social standards: refers to social performance, including the quality of life of humans and communities. The integration of

economic development, social equity, and environmental protection.

a. Impact of COVID-19 on education

Since the outbreak of COVID-19, people’s daily lives have been inevitably disrupted (Tang et al., 2020). Most countries have announced temporary school closures, as shown in Fig. A3, which has affected more than 91% of students worldwide (United Nations, 2020). Long-term home isolation increases the risk of mental illness among students. According to a survey in China, approximately 24.9% of college students feel anxious (Liang et al., 2020). The pandemic not only affected students and teachers, but also produced undesirable consequences related to digital learning, internet facilities, childcare, and food security (Arora, 2020). However, it is worth noting that these effects are not absolute. During the pandemic, the education system uses technology or social media (Caldevilla-Domínguez et al., 2021) to overcome the digital divide in learning. Ireland uses smart communities to achieve telecommuting (Doyle et al., 2021), which is conducive to the realization of the “quality education” in the SDGs.

b. Impact of COVID-19 on tourism

International travel, tourism demand and the hotel industry have become highly sensitive to the impact of COVID-19 (Chang et al., 2020). Some countries and regions have implemented entry and exit bans, thereby reducing people’s willingness to travel (Higgins-Desbiolles, 2020). World Tourism Organization data shows that 70% fall in international arrivals for the first eight months of 2020 (World Trade Organization, 2020b). These negative effects are obvious, but keywords with high relevance such as “sustainable tourism” represent the new development direction of tourism. The current tourism crisis caused by COVID-19 can benefit the development of sustainable tourism, promote the reduction of crowded tourist attractions, facilitate social isolation. WTO defines that the development of “sustainable tourism” can contribute to the future survival of the industry (World Trade Organization, 2020b).

c. Impact of COVID-19 on technology

During the COVID-19 pandemic, artificial intelligence played an important role in identifying, tracking, and predicting the pandemic (Kumar et al., 2020). Compared with conventional tests, it can provide medical staff with faster and cheaper diagnoses. The science and technology department composed of data science, machine learning and artificial intelligence effectively handle these projects: medical imaging, disease tracking, drug development, and others. Drones and robots are used to transport food and medicine, to disinfect in public places (Bullock et al., 2020). Telemedicine reduces the risk of cross-contamination caused by close contact. In the long run, it may bring greater benefits in dealing with the challenges of daily or emergency medical situations (Smith et al., 2020).

- (3) Environmental standards: related to the natural environment, such as energy, pollution, air quality, and other “green” factors.
- a. Impact of COVID-19 on air condition

Since the outbreak of the pandemic, authorities in various countries have taken measures to ban most transportation and stop avoidable outdoor human activities (Wang and Li, 2021). NASA and ESA issued evidence that since the outbreak of COVID-19, the quality of the global environment has improved. The high frequency of keywords such as “air quality”, “air pollution”, and “air” reflects that the research on air condition has become a hot topic in the academic field. Among the publications in this section, research on China and India occupies a large proportion. This may be related to China’s being a hot spot in the early stage of the pandemic and India’s relatively serious pollution status. According to the study of The Copernicus Atmosphere Monitoring Service, in most areas of China, surface particulate matter has been reduced by about 20–30% (European Space Agency, 2020d). NO₂ concentration of major cities in India (take Mumbai and Delhi as examples) has decreased by about 40–50% year-on-year (European Space Agency, 2020a). Fig. A4 shows that the NO₂ concentration in Madrid, Milan and Rome dropped by about 45%, while the NO₂ concentration in Paris dropped sharply by 54%. This time coincides with the isolation and closure policy implemented by European countries (European Space Agency, 2020b). The current mainstream thinking in the research community believes that strict quarantine measures have a positive impact on environmental protection (Wang and Su, 2020), but some scholars have shown that in the case of unfavorable weather, reducing transportation and industrial emissions do not help avoid serious air pollution, and greater efforts should be made to promote the sustainable development of the environment (Espejo et al., 2020).

b. Impact of COVID-19 on noise emission

Noise emission is one of the greatest environmental risks to public health. It is defined as harmful sounds produced by commercial or industrial activities and human activities (such as transportation, railway and road traffic, and airplanes) (Zambrano-Monserrate et al., 2020). During the pandemic, home isolation reduced private and public transportation and stopped commercial and entertainment activities. These changes resulted in a significant drop in noise levels. As shown in Fig. A5, since the implementation of blockade measures in some cities, the noise vibration caused by human activities has been reduced by about one-third (Bressan, 2020). However, it should be pointed out that the environmental benefits achieved during COVID-19 are at the cost of huge economic losses, which cannot be sustained in the long term. The government must take action to balance the relationship between economic growth and environmental protection (Wang and Zhang, 2021).

c. Impact of COVID-19 on waste disposal

Data from the International Solid Waste Association shows that

medical waste contaminated by COVID-19 has increased by 30%–50%. Second, the intensive and emergency purchase of disposable products has increased production and consumption, thereby increasing household waste. Due to the dispersion of cases and infected persons, large-scale waste management is very difficult during the pandemic, which poses a greater threat to developing countries with poor sustainable waste management strategies. Although many governments in developing countries are taking active measures to contain and reduce the spread of COVID-19, they still lack a strategy for managing solid waste such as PPE during and after the pandemic (Nzediegwu and Chang, 2020).

Through keyword analysis, we sorted out the impact of COVID-19 on the 17 sustainable goals in Table 6 according to positive influence and negative impact.

4. Conclusions and prospects

This work systematically reviewed the updated publication related to COVID-19 pandemic and sustainability in the Web of Science database by using bibliometrics techniques and meta-analysis approach. The four findings of this research are as follows:

- (1) During the COVID-19 epidemic, the popularity of sustainable development research has shown an upward trend. The number of publications means that as the pandemic spreads globally, more countries are affected, which in turn has led to more and more researchers starting to pay attention to the impact of this pandemic on sustainable development. In terms of discipline distribution, Environmental Sciences is the most popular research direction. This research also involves interdisciplinary subjects such as Public Environmental Occupational Health, Hospitality Leisure Sport Tourism, Education Educational Research, Health Policy Services, etc.
- (2) Universities in different geographic regions have become the main body of research. Researchers have evaluated the short-term and long-term impact of the pandemic on the SDGs from different perspectives. Due to the first-mover advantage, Chinese institutions have more publications in the study of COVID-19. However, in terms of sustainable development during the pandemic, Chinese institutions no longer have obvious advantages. UK and US research institutions are more active.
- (3) Developed countries dominate the research, although research on the impact of COVID-19 on sustainability in developing countries needs more needed. The United States has the largest number of publications. Countries in Europe and North America also have more publications, which seems to reflect the extensive concern of developed countries on sustainable development research during the pandemic. The visual map shows that the cooperation between countries is relatively close, and five research groups centered on the United States, the United Kingdom, China, Australia, and India have been formed.
- (4) The keyword co-occurrence network and the co-citation map reveal the research hotspots and future trends of the impact of COVID-19 on sustainable development. Environmental sustainability is a common research topic of these countries, but developed countries seem to invest more in education sustainability, while developing countries pay more attention to economic sustainability. We make a preliminary classification of publications according to economy, environment, and society and then perform cluster analysis on keywords with high relevance in each standard. Finally, 11 sub-categories were obtained: business, supply chain, employee, agriculture, energy, education, tourism, technology, air condition, noise emission, waste disposal. Studies have found that although the current pandemic has had an impact on the 17 goals, On the contrary, it brings new development opportunities to the 14 SDGs: Zero Hunger, Quality

Table 6
The two-sided impact of the epidemic on 17 SDGs.

SDGs	Positive influence	Negative impact
No poverty	I. Not sure	I. Vaccine fairness II. Nutritional status
Zero Hunger	I. Food integration	I. Health burden II. Food insecurity I. Mental health
Good Health and Wellbeing	I. Rebuild healthy foundation II. Raise health awareness III. Optimize lifestyle	II. Medicine supply III. Shocking the health system
Quality Education	I. School food supply innovation II. Distance Education III. Health education IV. Innovative nursing education	I. Youth out of school II. Weight gain in children III. Increased risk of juvenile delinquency
Gender Equality	I. Narrowing the gender gap in family responsibilities	I. Increased violence against women and girls II. Work in the informal economy makes women more likely to be unemployed III. Women's rights IV. Different pay for equal work
Clean Water and Sanitation	I. Not sure	I. Reduced clean water II. Reduced hand washing facilities III. Increased risk of disease spread IV. Water supply interruption risk
Affordable and Clean Energy	I. Sustainable economic recovery II. Help disadvantaged consumers stay in touch III. Clean energy transition IV. Increased demand for clean energy investment V. Reduce unemployment VI. Reduce greenhouse gas emissions VII. Improve self-consumption in renewable energy communities	I. Unstable power supply II. Sustainability of household energy demand III. Private sector investment
Decent Work and Economic Growth	I. Not sure	I. Financial market turmoil II. Industrial production interruption III. Commodity prices fall IV. Economic growth derailed
Industry, Innovation and Infrastructure	I. Stimulate productive investment II. Create career opportunities	I. Reduced infrastructure to withstand disasters and climate change
Reduced Inequalities	I. Vaccine inequality	I. Increase in unemployment II. Hate speech about vulnerable groups I. Food supply
Sustainable cities and communities	I. The government promotes solutions for informal settlements II. City branding	II. Sustainable development of smart cities III. Sustainable tourism
Sustainable Consumption and Production	I. Sharing and sustainable consumption II. Sustainable consumption transformation III. Environmental degradation	I. Food safety issues and responsibilities
Climate Action	I. Green jobs and sustainable and inclusive growth II. Speed up the decarbonization process	I. Long-term systemic transformation is challenged II. Behavioral bias and climate change risks

Table 6 (continued)

SDGs	Positive influence	Negative impact
Life Under Water	III. Slow down the greenhouse effect I. Rejuvenate the ocean II. Marine bacteria speed up virus surveillance	I. Environmental protection meeting postponed
Life on Land	I. Promote the modernization of environmental governance II. Stop the degradation of global ecosystems	I. Outbreak produces medical waste
Institutions, good governance	I. Slow down the war	I. The conflict between human rights and the right to health II. The right to know of the disadvantaged III. Increase in refugees
Partnerships for the goals	I. International Organization Launches Solidarity Response Fund II. Establish a shared data platform III. Underdeveloped countries get debt relief opportunities	I. Developing countries lack sufficient domestic resources and fiscal space

Education, Quality Education, Quality Education, Gender Equality, Affordable and Clean Energy, Industry, Innovation and Infrastructure, Reduced Inequalities, Sustainable cities and communities, Sustainable Consumption and Production, Climate Action, Life Under Water, Life on Land, Institutions, good governance, Partnerships for the goals.

This study also entails some limitations that might be the future direction for researchers. First, in terms of data selection, due to the selection of the database, some publications may be missing, which may affect our final analysis results. Second, some of the reviewed studies utilized may contribute to recall and response bias. Third, Although Lotka's law is used in the author's productivity analysis, it lacks SD and other descriptive statistics. At last, The impact of the epidemic on sustainable development is constantly changing over time, and the existing literature does not reflect this change promptly. Although preprints and early versions of scientific articles represent a way to quickly disseminate information, we did not include these articles as our data source because of their lack of independent quality control. This may affect the results of keyword clustering.

In consideration of the above findings, this paper believes that efforts can be made from the following aspects to achieving sustainable development goals in the post-epidemic period.

- (1) Suggestions for sustainable economic development (for SDG7, SDG8, SDG9, SDG10, SDG12)
 - a. The continued spread of the pandemic may lead to a new round of economic recession and financial collapse. Therefore, the government needs to carry out long-term plan to redevelop the economy and inject new vitality into the economy (Nicola et al., 2020), so that promote the flourishing of sustainable business models (Diao et al., 2021).
 - b. Enterprises and individuals need new operating models to meet frequently changing needs and maintain the agility and efficiency of business systems (Papadopoulos et al., 2020), promote sustainable management to limit the consumption of natural resources.
 - c. Focus on sustainable urbanization strategies, such as biodiversity protection, energy and water utilization (Wang and Wang, 2020), waste recycling, and economic and social development (Bontempi et al., 2021).

- (2) Suggestions for sustainable environmental development (for SDG6,SDG13,SDG14,SDG15)
 - a. The reduction of human activities has brought positive benefits to the environment in the short term, which provides a theoretical basis for governments to formulate policies. Governments around the world need to take further actions to balance the relationship between economic recession and environmental improvement (Shakil et al., 2020). The hardest-hit areas of the pandemic, especially the developing countries among them, need to focus on waste management issues (Shammi and Tareq, 2020).
 - b. Through integrating pandemic preparedness into sustainable development planning and ensuring that the interplay between biodiversity, agriculture, and society (Fenner and Cernev, 2021).
- (3) Suggestions for sustainable social development (for SDG1,SDG2, SDG3,SDG4,SDG5,SDG11,SDG16,SDG17)
 - a. The COVID-19 pandemic shows that all sectors of society should implement advanced technologies to respond to changes.
 - b. Cooperation between policymakers, health care workers and researchers can build meaningful partnerships, construct disaster-resistant and sustainable human settlements (Acuto

et al., 2020), Overcome vaccine racism and distribute vaccines more equitably to low- and middle-income countries (Anand et al., 2021).

Author contribution statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing – original draft preparation, Supervision, Writing-Reviewing and Editing. Rui Huang: Methodology, Software, Data curation, Investigation Writing – original draft, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

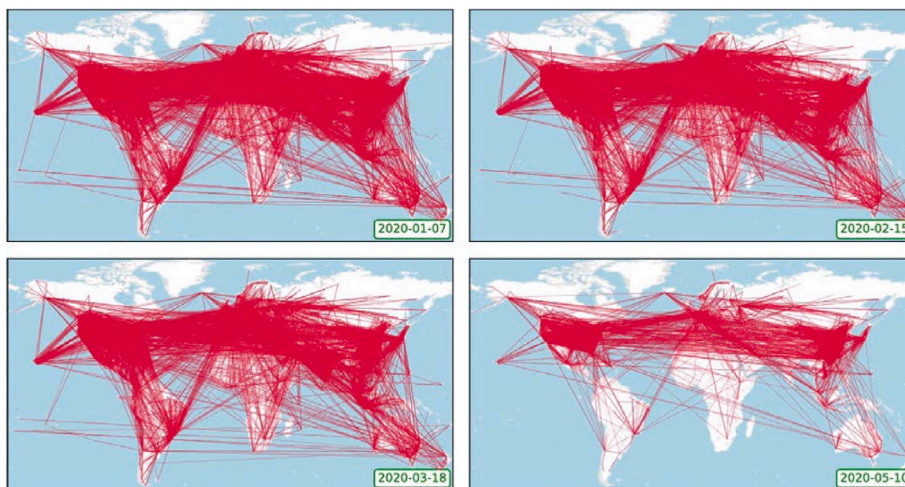


Fig. A1. Evolution of the global airport network on four select dates before and during the COVID-19 pandemic (Sun et al., 2020).

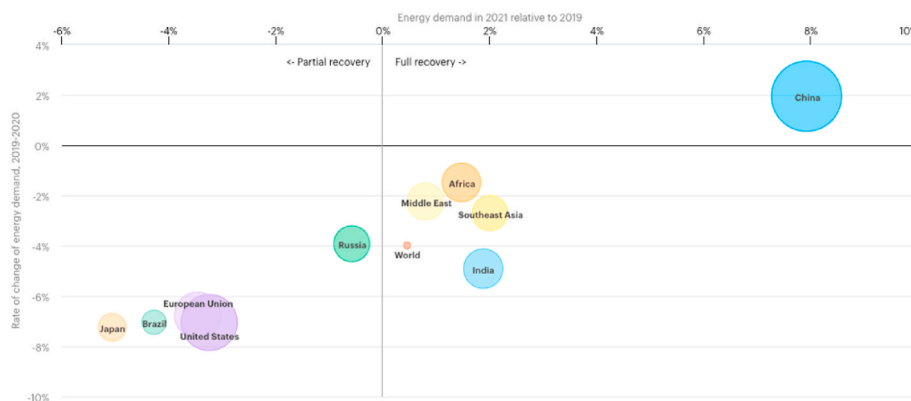


Fig. A2. Rate of change of energy demand in 2020 and 2021 energy demand relative to 2019 levels(International Energy Agency, 2021).

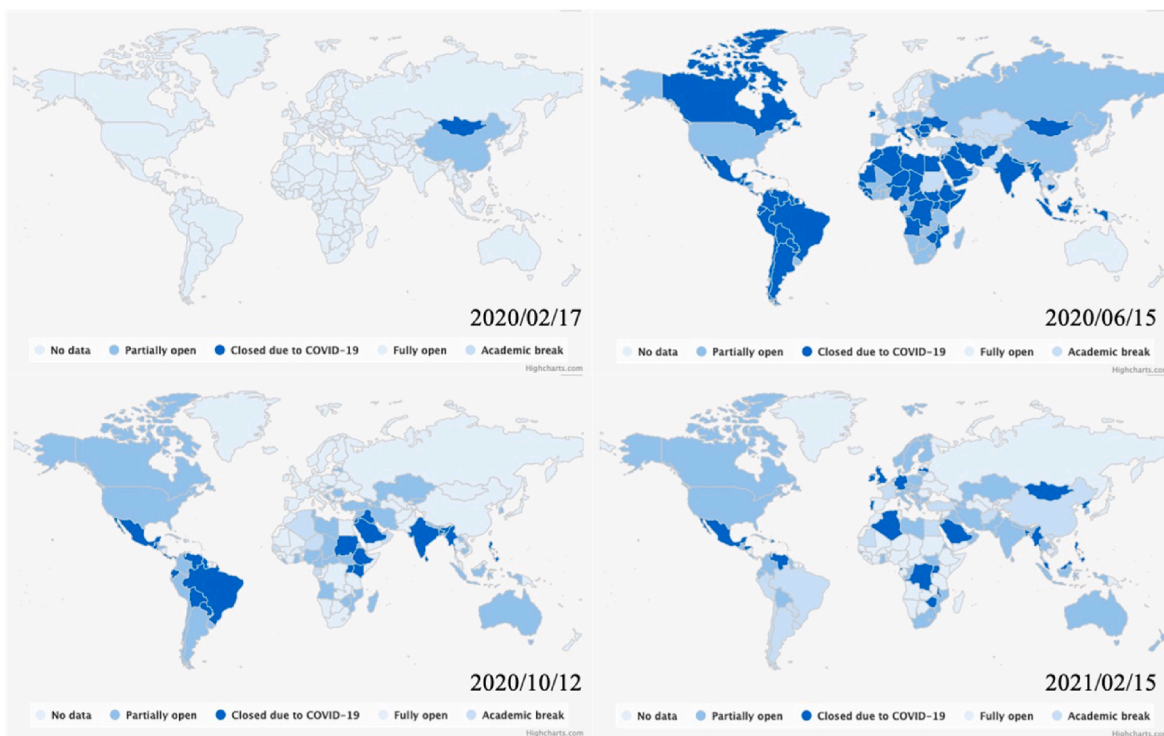


Fig. A3. Global impact of COVID-19 on school closures(United Nations Educational Scientific and Cultural Organization, 2020).

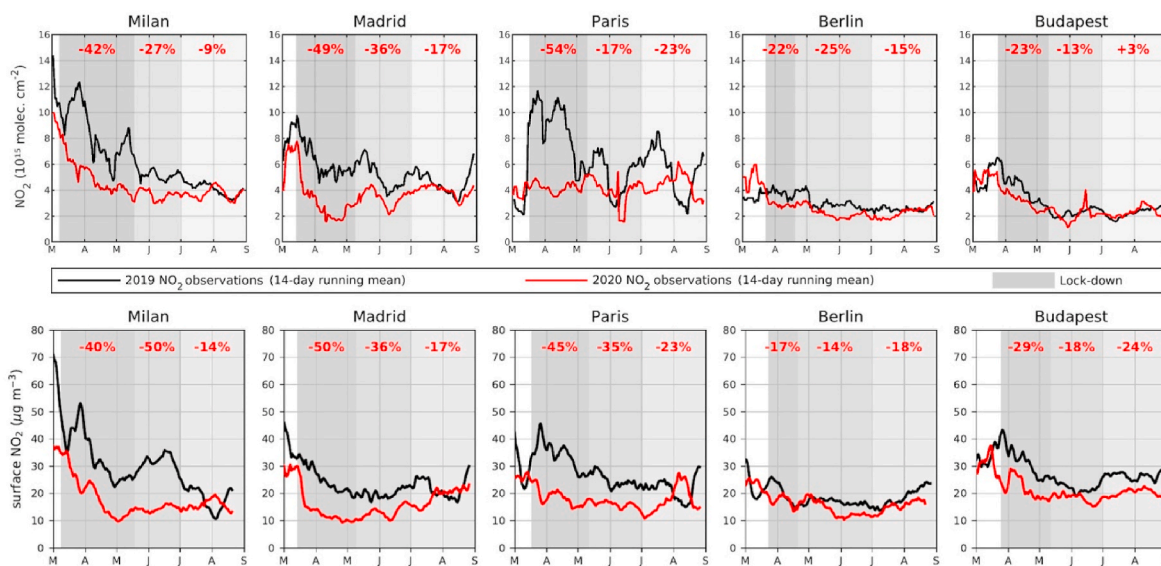


Fig. A4. Nitrogen dioxide concentrations were observed over major European cities(European Space Agency, 2020b).

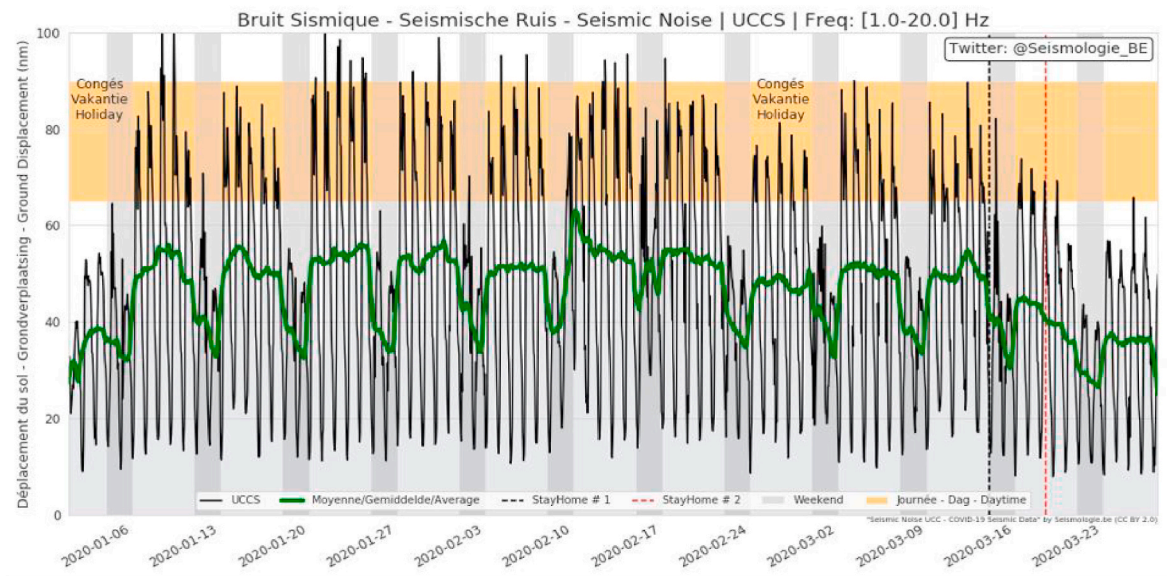


Fig. A5. Human-made seismic noise showing in seismograph from the Royal Observatory of Belgium(Bressan, 2020).

References

- Acuto, M., et al., 2020. Seeing COVID-19 through an urban lens. *Nature Sustain.* 3, 977–978.
- Ahmadi, M., et al., 2020. Investigation of effective climatology parameters on COVID-19 outbreak in Iran. *Sci. Total Environ.* 729, 138705.
- Anand, U., et al., 2021. Novel coronavirus disease 2019 (COVID-19) pandemic: from transmission to control with an interdisciplinary vision. *Environ. Res.* 197, 111126.
- Arora, A.K., Srinivasan, R., 2020. Impact of pandemic COVID-19 on the teaching-learning process: a study of higher education teachers. *J. Manag.* 13, 43–56.
- Ayanlade, A., Radeny, M., 2020. COVID-19 and food security in Sub-Saharan Africa: implications of lockdown during agricultural planting seasons. *npj Sci. Food* 4, 13.
- Bashir, M.F., et al., 2020. Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci. Total Environ.* 728, 138835.
- Bonati, M., et al., 2021. Psychological distress among Italians during the 2019 coronavirus disease (COVID-19) quarantine. *BMC Psychiatr.* 21, 20.
- Bontempi, E., et al., 2021. Sustainable materials and their contribution to the sustainable development goals (SDGs): a critical review based on an Italian example. *Molecules* 26, 1407.
- Bouman, T., et al., 2020. Insights from early COVID-19 responses about promoting sustainable action. *Nature Sustain.* 4, 194–200.
- Brandes, U., et al., 2016. Maintaining the duality of closeness and betweenness centrality. *Soc. Network.* 44, 153–159.
- Bressan, D., 2020. Coronavirus Lockdowns Cause Worldwide Decrease in Man-Made Seismic Noise.
- Bullock, J., et al., 2020. Mapping the landscape of artificial intelligence applications against COVID-19. *J. Artif. Intell. Res.* 69, 807–845.
- Caldevilla-Domínguez, D., et al., 2021. Twitter as a tool for citizen education and sustainable cities after COVID-19. *Sustainability* 13, 3514.
- Chakraborty, I., Maity, P., 2020. COVID-19 outbreak: migration, effects on society, global environment and prevention. *Sci. Total Environ.* 728, 138882.
- Chang, C.L., et al., 2020. A charter for sustainable tourism after COVID-19. *Sustainability* 12, 3671.
- Chaudhry, R., et al., 2020. A country level analysis measuring the impact of government actions, country preparedness and socioeconomic factors on COVID-19 mortality and related health outcomes. *EclinicalMedicine* 25, 100464.
- Chauhan, S., et al., 2021. Examining Continuance Intention in Business Schools with Digital Classroom Methods during COVID-19: a Comparative Study of India and Italy. *Behaviour and Information Technology*, pp. 1–24.
- Chen, C.-C., 2020. Psychological tolls of COVID-19 on industry employees. *Ann. Tourism Res.* 103080.
- Chernysh, Y., Roubik, H., 2020. International collaboration in the field of environmental protection: trend analysis and COVID-19 implications. *Sustainability* 12, 10384.
- Coccia, M., 2020. An index to quantify environmental risk of exposure to future epidemics of the COVID-19 and similar viral agents: theory and practice. *Environ. Res.* 191, 110155.
- Coccia, M., 2021. The impact of first and second wave of the COVID-19 pandemic in society: comparative analysis to support control measures to cope with negative effects of future infectious diseases. *Environ. Res.* 197, 111099.
- De Felice, F., et al., 2018. A bibliometric multicriteria model on smart manufacturing from 2011 to 2018. *IFAC-PapersOnLine* 51, 1643–1648.
- Dey, M., Loewenstein, M.A., 2020. How many workers are employed in sectors directly affected by COVID-19 shutdowns, where do they work, and how much do they earn? *Mon. Labor Rev.* 2020, 1–21.
- Diao, Y., et al., 2021. Influence of population density, temperature, and absolute humidity on spread and decay durations of COVID-19: a comparative study of scenarios in China, England, Germany, and Japan. *One Health* 12, 100203.
- Domingo, J.L., Rovira, J., 2020. Effects of air pollutants on the transmission and severity of respiratory viral infections. *Environ. Res.* 187, 109650.
- Donthu, N., Gustafsson, A., 2020. Effects of COVID-19 on business and research. *J. Bus. Res.* 117, 284–289.
- Doyle, A., et al., 2021. Building resilient, smart communities in a post-COVID Era: Insights from Ireland. *Int. J. E Plann. Res.* 10, 18–26.
- Elleby, C., et al., 2020. Impacts of the COVID-19 pandemic on the global agricultural markets. *Environ. Resour. Econ.* 76, 1067–1079.
- Espejo, W., et al., 2020. Environment and COVID-19: pollutants, impacts, dissemination, management and recommendations for facing future epidemic threats, 747, 141314. European Space Agency, 2020a. Air Pollution Drops in India Following Lockdown. European Space Agency.
- European Space Agency, 2020b. Air Pollution in a Post-COVID-19 World.
- European Space Agency, 2020c. Air Pollution Remains Low as Europeans Stay at Home.
- European Space Agency, 2020d. COVID-19: Nitrogen Dioxide over China.
- Fenner, R., Cernev, T., 2021. The implications of the covid-19 pandemic for delivering the sustainable development goals. *Futures* 128, 102726.
- Fucai, C.X.H., 2017. Research on optimization of spatial structure of tourism system based on social network theory, 00 *J. Tianshui Normal Univ.* 1, 118–123.
- Ghosh, I., 2020. The Road to Recovery: Which Economies Are Reopening?.
- Hák, T., et al., 2016. Sustainable Development Goals: a need for relevant indicators. *Ecol. Indicat.* 60, 565–573.
- Haque, S.E., Rahman, M., 2020. Association between temperature, humidity, and COVID-19 outbreaks in Bangladesh. *Environ. Sci. Pol.* 114, 253–255.
- Higgins-Desbiolles, F., 2020. Socialising tourism for social and ecological justice after COVID-19. *Tourism Geogr.* 22, 610–623.
- Hirsch, J.E., 2005. An index to quantify an individual's scientific research output. *Proc. Natl. Acad. Sci. U.S.A.* 102, 16569–16572.
- Hu, Y., 2020. Intersecting ethnic and native-migrant inequalities in the economic impact of the COVID-19 pandemic in the UK. In: *Research in Social Stratification and Mobility*, vol. 68, p. 100528, 100528.
- International Energy Agency, 2021. Rate of Change of Energy Demand in 2020 and 2021 Energy Demand Relative to 2019 Levels, by Region.
- Islam, N., et al., 2021. COVID-19 and climatic factors: a global analysis. *Environ. Res.* 193, 110355.
- Ivanov, D., 2020. Predicting the impacts of epidemic outbreaks on global supply chains: a simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transport. Res. E Logist. Transport. Res.* 136, 101922.
- Khan, S.A.R., et al., 2021. A state-of-the-art review and meta-analysis on sustainable supply chain management: future research directions. *J. Clean. Prod.* 278, 123357.
- Khan, S.A.R., et al., 2020. Determinants of economic growth and environmental sustainability in South Asian Association for Regional Cooperation: evidence from panel ARDL. *Environ. Sci. Pollut. Control Ser.* 27, 45675–45687.
- Klemes, J.J., et al., 2021. COVID-19 pandemic facilitating energy transition opportunities. *Int. J. Energy Res.* 45, 3457–3463.

- Kumar, A., et al., 2020. A review of modern technologies for tackling COVID-19 pandemic. *Diabetes & metabolic syndrome* 14, 569–573.
- Li, J.C., C, 2017. *CiteSpace: Text Mining and Visualization in Scientific Literature*, second ed. Capital University of Economics and Business Press.
- Liang, S.W., et al., 2020. The psychological impact of the COVID-19 epidemic on guangdong college students: the difference between seeking and not seeking psychological help. *Front. Psychol.* 11, 2231.
- Madurai Elavarasan, R., et al., 2020. COVID-19: impact analysis and recommendations for power sector operation. *Appl. Energy* 279, 115739, 115739.
- Mehmood, R., et al., 2016. Clustering by fast search and find of density peaks via heat diffusion. *Neurocomputing* 208, 210–217.
- Mofijur, M., et al., 2021. Impact of COVID-19 on the social, economic, environmental and energy domains: lessons learnt from a global pandemic. *Sustain. Prod. Consumption* 26, 343–359.
- Naddeo, A., et al., 2021. Identifying factors that influenced wellbeing and learning effectiveness during the sudden transition into eLearning due to the COVID-19 lockdown. *Work* 68, 45–67.
- Nerur, S.P., et al., 2008. The intellectual structure of the strategic management field: an author co-citation analysis. *Strat. Manag. J.* 29, 319–336.
- Nicola, M., et al., 2020. The socio-economic implications of the coronavirus pandemic (COVID-19): a review. *Int. J. Surg.* 78, 185–193.
- Nordhagen, S., et al., 2021. COVID-19 and small enterprises in the food supply chain: early impacts and implications for longer-term food system resilience in low- and middle-income countries, 141. *World Development*, p. 105405.
- Nzediegwu, C., Chang, S.X., 2020. Improper solid waste management increases potential for COVID-19 spread in developing countries. *Resour. Conserv. Recycl.* 161, 104947.
- Pao, M.L., 1986. An empirical examination of Lotka's Law. *J. Am. Soc. Inf. Sci.* 37, 26–33.
- Papadopoulos, T., et al., 2020. The use of digital technologies by small and medium enterprises during COVID-19: implications for theory and practice. *Int. J. Inf. Manag.* 55, 102192.
- Passavanti, M., et al., 2021. The psychological impact of COVID-19 and restrictive measures in the world. *J. Affect. Disord.* 283, 36–51.
- Pradhan, P., et al., 2017. A systematic study of sustainable development goal (SDG) interactions. *Earth's Future*. 5, 1169–1179.
- Pradhan, S., et al., 2020. Present and Future Impact of COVID-19 in the Renewable Energy Sector: a Case Study on India. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, pp. 1–11.
- Qin, X.N., et al., 2014. The knowledge mapping of domestic ecological security research: bibliometric analysis based on citispace. *Sheng Tai Xue Bao/Acta Ecol. Sin.* 34, 3693–3703.
- Ranjbari, M., et al., 2021. Three pillars of sustainability in the wake of COVID-19: a systematic review and future research agenda for sustainable development. *J. Clean. Prod.* 297, 126660.
- Rosario, D.K.A., et al., 2020. Relationship between COVID-19 and weather: case study in a tropical country. *Int. J. Hyg Environ. Health* 229, 113587.
- Rowan, N.J., Laffey, J.G., 2020. Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID19) pandemic – case study from the Republic of Ireland. *Sci. Total Environ.* 725, 138532.
- Şahin, M., 2020. Impact of weather on COVID-19 pandemic in Turkey. *Sci. Total Environ.* 728, 138810.
- Sarkodie, S.A., Owusu, P.A., 2020. Impact of meteorological factors on COVID-19 pandemic: evidence from top 20 countries with confirmed cases. *Environ. Res.* 191, 110101.
- Shakil, M.H., et al., 2020. COVID-19 and the environment: a critical review and research agenda. *Sci. Total Environ.* 745, 141022.
- Shammi, M., Tareq, S.M., 2020. Environmental catastrophe of COVID-19: disposal and management of PPE in Bangladesh. *Global Social Welfare* 8, 133–136.
- Smith, A.C., et al., 2020. Telehealth for global emergencies: implications for coronavirus disease 2019 (COVID-19). *J. Telemed. Telecare* 26, 309–313.
- Srivastava, A., 2021. COVID-19 and air pollution and meteorology-an intricate relationship: a review. *Chemosphere* 263, 128297.
- Su, C., Urban, F., 2021. Circular economy for clean energy transitions: a new opportunity under the COVID-19 pandemic. *Appl. Energy* 289, 116666.
- Sun, X., et al., 2020. Dissection of a singularity: the impact of COVID-19 on aviation. *J. Int. Logistics Trade* 18, 113–125.
- Sunyer, J., et al., 2021. Environment and the COVID-19 pandemic. *Environ. Res.* 195, 110819.
- T Buck, M.A., Chazan, G., Cookson, C., 2020. Coronavirus Declared a Pandemic as Fears of Economic Crisis Mount.
- Tang, B., et al., 2020. An updated estimation of the risk of transmission of the novel coronavirus (2019-nCoV), 5, 248–255.
- Tejedor, S., et al., 2021. Higher education response in the time of coronavirus: perceptions of teachers and students, and open innovation. *J. Open Innovation: Technology, Market, and Complexity* 7, 1–15.
- United Nations, 2015. 17 Goals to Transform Our World.
- United Nations, 2020. The Sustainable Development Goals Report 2020, p. 68.
- United Nations Economic and Social Commission for Asia and the Pacific, 2020. Focus Recovery Efforts to Build Back Better with Oceans and Nature in Mind. Urges UN Forum.
- United Nations Educational Scientific and Cultural Organization, 2020. Educational Disruption and Response.
- VOSviewer, 2020. VOSviewer Web Start. Leiden University.
- Wang, Q., Han, X., 2021. Spillover effects of the United States economic slowdown induced by COVID-19 pandemic on energy, economy, and environment in other countries. *Environ. Res.* 196, 110936.
- Wang, Q., Li, S., 2021. Nonlinear Impact of COVID-19 on Pollution – Evidence from Wuhan, vol. 65. *Sustainable Cities and Society*, New York, Milan, Madrid, Bandra, London, Tokyo and Mexico City, p. 102629.
- Wang, Q., Su, M., 2020. A preliminary assessment of the impact of COVID-19 on environment – a case study of China. *Sci. Total Environ.* 728, 138915.
- Wang, Q., Su, M., 2021. Integrating Digital Technologies and Public Health to Fight Covid-19 Pandemic: Key Technologies, Applications, Challenges and Outlook of Digital Healthcare. *Int. J. Environ. Res. Publ. Health* 18, 6053.
- Wang, Q., Wang, S., 2020. Preventing carbon emission retaliatory rebound post-COVID-19 requires expanding free trade and improving energy efficiency. *Sci. Total Environ.* 746, 141158.
- Wang, Q., Yang, X., 2021. How do pollutants change post-pandemic? Evidence from changes in five key pollutants in nine Chinese cities most affected by the COVID-19. *Environ. Res.* 197, 111108.
- Wang, Q., Zhang, F., 2021. What does the China's economic recovery after COVID-19 pandemic mean for the economic growth and energy consumption of other countries? *J. Clean. Prod.* 295, 126265.
- Watson, R.T., Webster, J., 2020. Analysing the past to prepare for the future: Writing a literature review a roadmap for release 2.0. *J. Decis. Syst.* 29, 129–147.
- Web of Science, 2018. Web of Science All Databases Help.
- Wolfswinkel, J.F., et al., 2013. Using grounded theory as a method for rigorously reviewing literature, 22, 45–55.
- World Health Organization, 2020a. Frequently Asked Questions: the WTO and COVID-19.
- World Health Organization, 2020b. International Tourism Down 70% as Travel Restrictions Impact All Regions.
- World Health Organization, Timeline, 2020c. WHO's COVID-19 Response.
- World Health Organization, 2020d. Trade Shows Signs of Rebound from COVID-19, Recovery Still Uncertain.
- World Trade Organization, 2020a. Frequently Asked Questions: the WTO and COVID-19.
- World Trade Organization, 2020b. Trade Shows Signs of Rebound from COVID-19, Recovery Still Uncertain.
- Youssef, M., et al., 2021. Dynamic connectedness between stock markets in the presence of the COVID-19 pandemic: does economic policy uncertainty matter? *Financial Innovation* 7, 13.
- Zambrano-Monserrate, M.A., et al., 2020. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* 728, 138813.
- Zhang, L., et al., 2016. Diversity of references as an indicator of the interdisciplinarity of journals: taking similarity between subject fields into account. *J. Assoc. Inform. Sci. Technol.* 67, 1257–1265.
- Zhou, P., et al., 2020. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature* 579, 270–273.