Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Analysis of the scientific production of the effect of COVID-19 on the environment: A bibliometric study

Luis-Alberto Casado-Aranda *, Juan Sánchez-Fernández, María I. Viedma-del-Jesús

Department of Marketing and Market Research, University of Granada, Campus Universitario la Cartuja, 18011, Granada, Spain

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ABSTRACT

The fight against COVID-19 since January 2020 has become the top priority of more than 200 countries. In order to offer solutions to eradicate this global pandemic, the scientific community has published hundreds of articles covering a wide range of areas of knowledge. With the aim of synthesizing these publications, academics are resorting to bibliometric analyses from the perspectives of the disciplines such as biology, medicine, socioeconomics and tourism. Yet no bibliometric analysis has explored the diffuse and little-known growth of COVID-19 scientific publications in the field of environmental studies. The current study is the first of this type to fill this research gap. It has resorted to SciMAT software to evaluate the main topics, authors and journals of publications on the subject of COVID-19 combined with environmental studies spanning the period between 1 December 2019 and 6 September 2020. The search yielded a collection of 440 articles published in scientific journals indexed on by Web of Science and Scopus databases. These publications can be broken down into six main themes: (i) a sharp reduction in air pollution and an improvement of the level of water pollution; (ii) the relationship of wind speed (positive), ultraviolet radiation (positive) and humidity (negative) with the rate of infections; (iii) the effect of the pandemic on the food supply chain and waste habits; (iv) wastewater monitoring offers a great potential as an early warning sign of COVID-19 transmission; (v) artificial intelligence and smart devices can be of great use in monitoring citizen mobilization; and (vi) the lessons gleaned from the pandemic that help define actions to mitigate climate change. The results of the current study therefore offer an agenda for future research and constitute a starting point for academics in the field of environmental studies to evaluate the effects of COVID-19.

1. Introduction

The struggle initiated in January 2020 to combat the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2 or COVID-19) has become the top priority for more than 200 countries. The pandemic is putting a massive strain on, among others, health care personnel, law enforcement agencies, public administrations and information and communication professionals. In order to offer solutions to this global health problem, the scientific community is also facing one of the most important challenges in recent times. It is responding by publishing hundreds of articles every day in a variety of fields, from medicine and epidemiology to psychology and the environment. Many also appear in the field of economics due to the severe financial consequences of the virus. The ongoing scientific contributions confirm that the academic response to COVID-19 is both massive and multifaceted (Bonilla-Aldana et al., 2020; Felice and Polimeni, 2020; Nowakowska et al., 2020). A revealing fact in this regard is that since the pandemic's outset, the number of scientific papers on COVID-19 have doubled every 15 days (Torres-Salinas, 2020).

This sheer volume of the scientific output in response to the pandemic renders it difficult even when resorting to accurate keywords to pinpoint information from the databases such as PubMed, Web of Science and Scopus. In order to facilitate the search for scientific information related to COVID-19, academics are following two different alternative paths. The first, applied by academics from various branches, consists of carrying out comprehensive reviews and bibliometric analyses so as to synthesize and simplify the results. This is the case, for example, of the bibliometric survey by Nowakowska et al. (2020) attempting to identify, based on the systematic analysis of 2062 peer-reviewed and pre-print papers, the main subjects, authors and nationalities of COVID-19 articles published within the first three months of pandemic. Felice and Polimeni (2020), adopting a similar

* Corresponding author.
E-mail addresses: lcasado@ugr.es (L.-A. Casado-Aranda), sanchezf@ugr.es (J. Sánchez-Fernández), iviedma@ugr.es (M.I. Viedma-del-Jesús).

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approach, distinguished the main affiliations, authors, journals and collaborative links of COVID-19 papers between December 2019 and April 2020. Bonilla-Aldana et al. (2020) and Radanliev et al. (2020) proceeded further by evaluating the scientific literature on coronavirus types and potential vaccine treatments. Verma and Gustafsson (2020) in the sphere of socioeconomics conducted a bibliometric study of COVID-19 literature in the domains of business and management so as to identify current areas of research and propose future lines of research. Sigala (2020), in the field of tourism, likewise undertook a critical review on the impacts and implications of COVID-19 so as to offer solutions to reset the industry. At the same time, efforts are being conducted to build COVID-19-oriented databases of scientific papers to continually update the scientific contributions to the subject. Examples are the databases of the World Health Organization (2020) and the Centers for Disease Control and Prevention (2020).

In this period of pandemic, the audiovisual and written media bear the responsibility (now more than ever) to disseminate true and quality information, and prevent the proliferation of hoaxes and fake news in the face of an uncertain future. Nevertheless, the spread of fake news and misunderstandings is occurring, more than ever, and at a very rapid pace. This is due to the growth of accessibility to internet, the popularity of social media and the nature of how it works (i.e., post sharing) combined with the appetite of the media to increase their visibility via click-baiting techniques and sensational headlines. In their effort to avoid misconceptions, information and communication professionals have turned to scientific texts on virology, epidemiology, law, economics or psychology to attempt to transfer the scientific results through their newsletters in a simple, informative and accessible manner. Journalists from the newspaper El País (De Benito, 2020), for example, reported on the findings of crucial scientific research with the aim to explain the drugs available to treat COVID-19. The New York Times (Debgupta, 2020), likewise based on scientific data, offered a guide on how to attend to supermarket food purchases. The World Health Organization (2020) also reported on how to cope with the stress related to COVID-19. This reporting on the effect of COVID-19 at pharmacological, nutritional and psychological levels contrasts with the little data advanced by the international media as to the consequences of COVID-19 on the environment. Exceptions are reports by the BBC (Henriques, 2020) that offered scientific details from other pandemics to answer the query "Will COVID-19 have a lasting impact on the environment?" The online newspaper Eldiario.es (García-Charton, 2020) likewise delved into the environmental consequences of new methods of consumption, migration and mobility subsequent to the crisis. It is also noteworthy that different media reported opposite data as to COVID-19's biomedical-environmental origin and ecological consequences (Anónimo 2020; O'callaghan, 2020).

Due to the low quality of the current information regarding the main environmental consequences of COVID-19 and the diffuse and little-known growth of reports on the subject, a descriptive and visual quantification of scientific research on the virus and its effect on the environment would be of assistance to information professionals and environmental academics to gain an objective perspective of the evolution, current scope and main results to include in their reporting and research. This task would lend a hand to information professionals to disseminate the effects of COVID-19 on the environment consistently and clearly and depict the encroaching phenomenon of the coming months. Although certain bibliometric analyses on COVID-19 exist in a general level (e.g., Bonilla-Aldana et al., 2020; Chahrour et al., 2020; Felice and Polimeni, 2020; Hossain, 2020; Nowakowska et al., 2020; Torres-Salinas, 2020), no study has explored the evolution of publications related to COVID-19 or identified its main thematic axes and environmental consequences in the specific area of the environment.

Prior environmental research resorting to bibliometric analyses have examined the characteristics and implications of the patterns in shale gas literature between 1990 and 2014 (Wang and Li, 2017) or have attempted to identify a research profile on the natural gas acquired from these types of deposits (Wang and Li, 2016). Closer to the current COVID-19 topic are studies delving into the effects of temperature and relative humidity on the viability of previous types of coronavirus (Casanova et al., 2010; Chan et al., 2011). Other studies have focused on the survivability of earlier strains of coronavirus in water and wastewater (Gundy et al., 2008; Ye et al., 2016). Recent environmental literature is placing great weight on the antecedents and consequences of COVID-19 on the environment and its interaction with human activities (e.g., Sims and Kasprzyk-Hordern, 2020; Wang and Su, 2020; Xie and Zhu, 2020). The intention of the current study is to offer a first straightforward report on the evolution of publications combining the effect of COVID-19 on the environment since the outset of the pandemic, as well as to identify the main lines of research that are surging as a result of the crisis and establish a research agenda for environmental scholars. The study specifically pursues five objectives:

(i) quantification of the volume of production of COVID-19-related scientific articles in the field of environment studies including peer-reviewed publications indexed in the main databases (i.e. Web of Science and Scopus) spanning 1 December 2020 to 6 September 2020. Environmental studies is a multidisciplinary field which systematically delves into human interaction with the environment. It specifically draws together principles from the physical sciences, commerce/economics, and humanities and social sciences to address complex contemporary environmental issues (Soulé and Press, 1998).
(ii) identification of the main authors and scientific journals publishing research on COVID-19 and the environment.
(iii) describe and visually depict the most relevant lines and sublines of research on COVID-19 and the environment.
(iv) advance an agenda for future research and thus serve as a starting point for academics in the field of environmental science and media professionals to evaluate the effects of COVID-19 on the environment.
(v) make use for the first time of the open source SciMAT bibliometric software to delve into COVID-19 and its effects on the environment.

This study is not only a first in the evolution of COVID-19 research from the specific perspective of environmental studies, but will be of extreme utility for information professionals to disseminate objective and quality coverage on the effects of the virus on the environment. Furthermore, the results will offer insight into the authors, research journals and themes worth considering in future environmental research.

2. Methods

The databases Web of Science Core Collection and Scopus served for this study. The information gleaned from them was from a consultation carried out on 6 September 2020.

The query equation for Scopus was the following:

ALL (("2019-nCoV" OR "Covid-19″ OR "COVID-19″ OR "SARS-CoV-2″ OR "coronavirus" OR "corona virus")) AND (LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "EART")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2020))

For the Web of Science, the query was:

TS = ("2019-nCoV" OR "Covid-19″ OR "COVID-19″ OR "SARS-CoV-2″ OR "coronavirus" OR "corona virus") AND LANGUAGE: (English) AND TYPE: (Article OR Review)

Filtred by: Web of Science Categories: Green Sustainable Science Technology OR Environmental Sciences OR Environmental Studies. Period: December 2019 to September 2020.

The initial search yielded over 2618 papers in English, of which 714

were duplicates (i.e., indexed in both databases) and thus excluded from further analysis. The corpus was then narrowed down to articles within the scope of environmental studies so as to eliminate contributions linked to COVID-19 treatments, or others related to the implications of the virus on public health. This manual screening process led to a collection of 440 documents published between 1 December 2019 and 6 September 2020.

The data analysis was carried out with SciMAT software (Cobo et al., 2011), a technique serving to examine the social, intellectual and conceptual framework of a specific field. Based on the two files extracted from consulting the Scopus and Web of Science databases, the SciMAT software: (i) sorted and ranked all the 440 documents by year of publication, number of citations, and titles of journals; and (ii) carried out a co-word analysis aiming to identify emerging themes related to COVID-19 stemming from the realm of environmental research (Cobo et al., 2012). Thus the co-word analysis applied text-mining techniques to the titles, abstracts, and keywords leading to the design, based on fundamental bibliometric indicators such as the number of publications, of a strategic diagram illustrating the main themes of interest related to the issue of environment in COVID-19 research.

To accurately detect the main topics garnered from the co-word analysis, the authors specifically followed the steps outlined in the study by Cobo et al. (2011) consisting of isolating the author and journal keywords after an initial manual elimination of the documents not directly linked to the environment. The second step was to collect the relevant information from the raw data of these documents. As noted by Cobo et al. (2011), this information is gathered by analyzing the co-occurrence of keyword frequency. Individually, this frequency of two keywords is extracted from the corpus by computing the number of documents in which the two keywords appear together. The third step is to calculate the similarities between the items collected in the second step. The similarities are calculated from keywords co-occurrence frequency. Following the recommendation of Cobo et al. (2011), an equivalence index is the most appropriate means to normalize the frequency of co-occurrence. The fourth step was to determine the clusters that serve to identify subgroups of linked keywords that signal topics of interest. Likewise, following the method suggested by Cobo et al. (2011), the Simple Center Algorithm (with the values 1 and 4 representing the minimum and maximum size of the network) was applied to detect the themes of relevance. Finally, the values of the "number of citations" and "number of documents" served to measure the quality of the strategic diagram.

3. Results

3.1. The scientific production linking COVID-19 and the environment

The results of the bibliometric analysis applying the Web of Science and Scopus databases yielded a corpus of 440 articles published in peer-reviewed scientific journals since the outset of the pandemic (December 2019) combining the subject of COVID-19 and the environment. 72% were identified through Scopus. The remaining 28% were through both Scopus and Web of Science. Of note is that 96% indexed through the Web of Science finds are of open access, while 78.55% of this type were identified through Scopus.

3.2. Relevant journals and authors with publications on COVID-19 and the environment

The recent interest of the effects triggered by the international COVID-19 health crisis on the environment is evidenced in environmental journals such as *Science of the Total Environment, International Journal of Environmental Research, Public Health, Sustainability* or *Environmental Research*. Similar research is also reflected in economics and environment publications such as *Environmental and Resource Economics* and *Canadian Journal of Agricultural Economics* (Table 1). The authors with the greatest number of publications the effects of COVID-19 on the environment are primarily Chinese and American universities and research institutes (Table 2).

Table 1
Listing of the journals with the greatest number of COVID-19-related environmental studies spanning 1 December 2020 to 6 September 2020.

Journal	Number of publications
Science of the Total Environment	116
International Journal of Environmental Research and Public Health	36
Sustainability	24
Environmental and Resource Economics	20
Aerosol and Air Quality Research	13
Environmental Research	12
Air Quality, Atmosphere and Health	10
Canadian Journal of Agricultural Economics	9
Environment, Development and Sustainability	6
Environmental Pollution	6
Global Journal of Environmental Science and Management - GJESM	6
Atmosphere	5
Journal of Air Transport Management	5

3.3. Main research topics linking COVID-19 and the environment

3.3.1. Strategic diagram

The two-dimensional graph generated by SciMAT software (Fig. 1), a

Table 2
Listing of the authors, affiliations and countries with the greatest number of COVID-19-related environmental studies spanning 1 December 2020 to 6 September 2020.

Author	Affiliation and Country	Number of publications
Wang, Yangjun	China CDC Key Laboratory of Environment and Population Health, National Institute of Environmental Health, Chinese Center for Disease Control and Prevention (China)	7
Zhang, Xian	Department of Civil and Environmental Engineering, University of Massachusetts Lowell, One University Ave., Lowell, MA 01854 (USA)	5
Li, Yuguo	Department of Mechanical Engineering, The University of Hong Kong, Hong Kong (China)	5
Zhang, Jiajia	China CDC Key Laboratory of Environment and Population Health, National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, 100021 (China)	4
Zhang, Kimball	Department of Epidemiology, Human Genetics and Environmental Sciences, School of Public Health, The University of Texas Health Science Center at Houston, Houston, TX 77030 (USA)	4
Wang, Qingging	School of Economics and Management, China University of Petroleum (East China), Qingdao, Shandong 266580 (China)	4
Kumar, Saroj	Department of Environmental Engineering, Delhi Technological University, Delhi, 110042 (India)	4
Bibby, Kyle	Civil and Environmental Engineering and Earth Sciences, University of Notre Dame, 156 Fitzpatrick Hall, Notre Dame, IN 46556 (USA)	4
Li, Jiayu	Key Laboratory of Environmental Remediation and Ecological Health, Ministry of Education; Research Center for Air Pollution and Health, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou, 310058 Zhejiang People's (China)	4
Briz-Redón, Álvaro	Statistics Office, City Council of Valencia, c/ Arquebisbe Mayoral, 2, 46002 Valencia, Valencia (Spain)	3

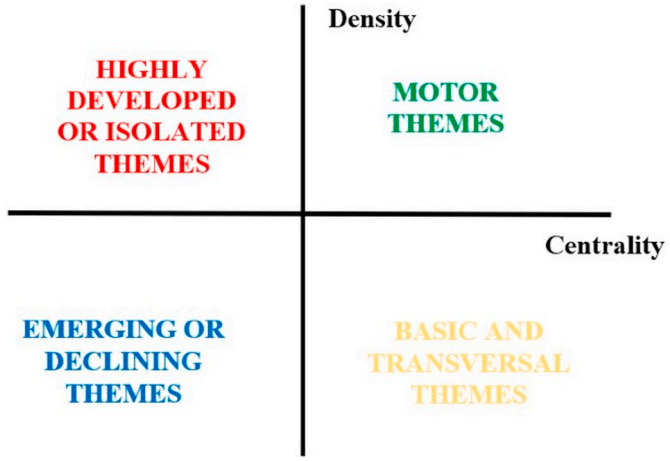

Fig. 1. Quadrants of a strategic diagram.

strategic diagram, plots themes according to their density and centrality. The higher the density, the greater the internal strength of the network and level of theme development. Centrality corresponds to the degree of interaction of a network with other networks. Its value therefore depicts the importance of a theme within a field (Cobo et al., 2011). The combination of high and low levels of density and centrality allows a division of the diagram into four sectors. The topics of the upper right quadrant, called driving topics, are characterized by strong centrality and high density and form the basis of the structure of the research. Those in the upper left quadrant bear well-identified internal links with external links, by contrast, that are marginal topics due to their highly specialized nature. The topics in the lower left quadrant, representing emerging issues, are marginal and underdeveloped given their low centrality and density. Finally, the themes in the lower right quadrant, although significant, remain underdeveloped and therefore basic, general or transversal.

Fig. 2 illustrates the strategic diagram of the documents combining the themes of COVID-19 and the environment with the volume of each sphere being proportional to the number of articles containing each keyword. The driving force themes (COVID-19, nitrogen dioxide, environmental impact and meteorological factors) are reflected in the upper right quadrant. The graph thus corroborates that a great proportion of COVID-19-related environmental research is linked to the relationship between its outbreak and air quality and explores the interaction of the virus with meteorological factors (i.e., wind, temperature, humidity). The lower right quadrant, on the other hand, frames the fundamental and cross-cutting issues that are the base of environmental research. Public health is the most representative topic in this quadrant as most of the research linking COVID-19 and environmental studies explores strategies to improve public health such as through waste-water-based epidemiology. Emerging themes and sub-themes such as water pollution and smart tourism are gathered in the lower left quadrant. They corroborate the interest in exploring the role smart cities (based on technology, sustainability, accessibility and geolocation) play in preventing the spread of the virus, in restoring ecosystems and in reducing climate change subsequent to the crisis. The last upper left quadrant frames the issue of ecosystem conservation which, despite its high degree of specialization, has gained interest among the scientific community after the pandemic due to its relevance in monitoring waste management, food waste and energy consumption (Fig. 2).

3.3.2. *Main themes and subthemes*

The current study then focused on the development of the most relevant thematic networks so as to clarify the relationship between the keywords and the most frequent topics in articles focusing on the effect

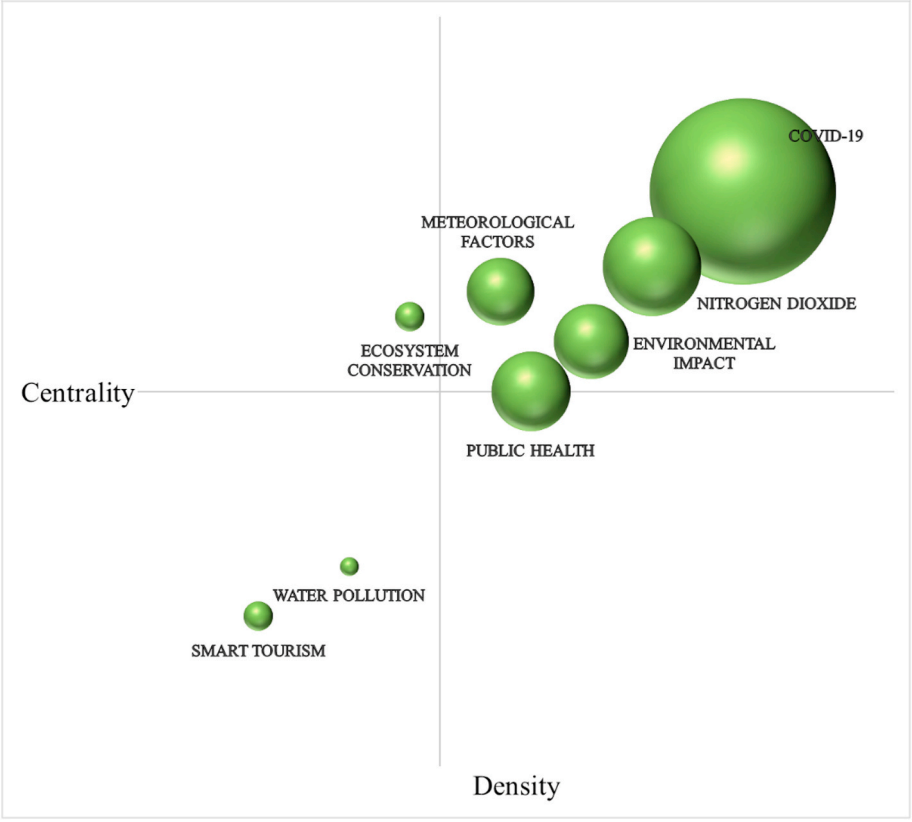

Fig. 2. Strategic diagram depicting the number of documents combining the themes of COVID-19 and the environment published between 1 December 2020 to 6 September 2020.

of COVID-19 on the environment. The size of the spheres for the thematic networks is proportional to the number of articles corresponding to each keyword, whereas the width of the link between two spheres i and j is proportional to the e_{ij} equivalence index (see Cobo et al., 2011 for more information). Through the citation-map analysis, we were able to identify six main themes: (1) COVID-19 and water and air pollution, (2) COVID-19 and meteorological factors, (3) effects of COVID-19 on wildlife and agricultural conservation, (4) COVID-19 and epidemiology, (5) COVID-19 and smart cities, and (6) lessons learnt from COVID-19 applicable to climate action.

3.3.2.1. COVID-19, air quality and water pollution. One of the motor themes of environmental study literature linked to the COVID-19 pandemic is the role of the virus in air and water quality. A number of studies have explored the reduction of air pollutants (e.g., nitrogen dioxide, NO_2; carbon dioxide, CO_2; Particulate Matters, PM) and the decrease in fossil fuel emissions stemming from the daily lockdown. Srivastava et al. (2020) and Karuppasamy et al. (2020), for example, assessed the lockdown effects in India on the levels of air pollutants and confirmed a decrease of about 46% of PM and 54% of other gaseous pollutants. Adams (2020), focusing on Ontario during the five-week Canadian lockdown, pinpointed a reduction of nitrogen dioxide and nitrogen oxides when compared to the previous 5-week control period. Along the same lines, Zangari et al. (2020) noted a decrease of $PM_{2.5}$ (36%) and NO_2 (51%) concentrations in New York shortly after the lockdown. The study by Tobías et al. (2020) describes the changes in air pollution levels stemming from the measures of containment in Barcelona. Their results reveal that levels of polluting gases fell by about 45% after two weeks. Similar findings are reported in Thailand (Stratoulias and Nuthammachot, 2020), China and Japan (Ma and Kang, 2020; Zhang et al., 2020), Ecuador (Zalakeviciute et al., 2020), Iran (Broomandi et al., 2020), Milan, Italy (Collivignarelli et al., 2020) and Morocco (Otmani et al., 2020). Siciliano et al. (2020) and Zhao et al. (2020), in turn, identified noteworthy increases in ozone concentrations (O_3) during the measures of social distancing adopted respectively by Brazil and China.

Other studies have explored the effects of city air pollution on the number of infections and COVID-19 deaths. Gupta et al. (2020), for example, suggest a correlation between a region's level of air pollution (indexed through PM with the aerodynamic diameters $\leq$ 10 μm and $\leq$2.5 μm) and lethal COVID-19 levels suggesting that air pollution aggravates the global death rate. Cole et al. (2020) go further by offering evidence that certain municipalities in the Netherlands with 1 μg/m3 more PM 2.5 concentrations suffered 9.4 more COVID-19 cases, 3.0 more hospital admissions, and 2.3 more deaths. In the same vein, Chakraborty et al. (2020) concluded that exposure to vehicle NO_2 emissions increased COVID-19 fatality in India. The authors argue that homeless, poverty-stricken Indian hawkers and roadside vendors, as well as individuals suffering regular exposure to the exhaust of vehicles, may be at a higher risk. Similar findings are reported by Comunian et al. (2020) and Conticini et al. (2020). Indeed, Ogen (2020) concluded that nearly 80% of the COVID-19 deaths take place in highly contaminated scenarios.

Environmental study researchers have likewise analyzed the effect of the lockdown on water quality. Dutta et al. (2020), for instance, confirmed that during the lockdown most of the districts falling under the Ganges Basin experienced a 60% excess of rainfall which led to an increase of the discharge of the river and a dilution of the pollutants. These authors also identified the storage during the outset of the third phase of the lockdown almost doubled that during the same period the previous year. Along a same line, Yunus et al. (2020) identified changes in surface water quality, notably a 15.9% decrease of suspended particulate matter (SPM) during the lockdown in the Vembanad, India's largest freshwater lake. Selvam et al. (2020) further studied the lockdown effects on subsurface water quality in southern India's coastal industrial city of Tuticorin and singled out a reduction in arsenic, selenium, lead and iron due to a marked decrease in wastewater discharges from metal-based industries Fig. 3.

3.3.2.2. COVID-19 and meteorological factors. Another thematic area that stands out among the main analyses of COVID-19 and the environment is the effect of meteorological factors (i.e., temperature, humidity, wind speed and ultraviolet radiation) on the rate of COVID-19 infection.

Xie and Zhu (2020) enquired into the relationship between COVID-19 cases and temperature in 122 cities in China. Their findings suggest that a 1 °C mean increase of temperature below 3 °C can be linked to a 5% increase in daily confirmed COVID-19 cases. Prata et al. (2020), in an analogous analysis, evaluated how temperature changes affected COVID-19 transmission in tropical cities of Brazil. Their results suggest that areas with average temperatures below 25.8 °C, each increase of 1 °C can be linked with a −4.8951% decrease in the number of daily cumulative COVID-19 confirmed cases. Shi et al. (2020), by contrast, noted that temperatures over 8°–10 °C decreased the daily incidence of COVID-19 cases. Other specialists, on the other hand, namely Iqbal et al. (2020) and Briz-Redón and Serrano-Aroca (2020), found no evidence of a link between rates of COVID-19 cases and temperature in either China or Spain.

Ma et al. (2020) explored the effects of variations of humidity on the rate of COVID-19 deaths. Their findings confirm a negative association between absolute humidity and the daily COVID-19 death count. Wu et al. (2020) likewise report that a 1% increase in relative humidity can be linked with a 0.85% decrease in new daily cases and a 0.51% increase with a reduction of new daily deaths. Lin et al. (2020) further assessed the interaction of temperature and relative humidity and their effects on the spread of the virus. Their findings indicate that high relative humidity promotes COVID-19 transmission when temperatures are low, but tends to reduce transmission when the temperatures are high. Auler et al. (2020) came to similar conclusions, demonstrating that the COVID-19 transmission rate in Brazil was boosted by higher mean temperatures (27.5 °C) combined with intermediate relative humidity (near 80%).

Other research has focused on the relationship between wind, ultraviolet radiation and COVID-19 rates. Rendana (2020) specifically concluded that low wind speed correlates with a rise in COVID-19 cases ($r = -0.314$). The study also reveals that low temperatures and the number of sunshine hours match with a higher number of COVID-19 cases. Şahin (2020) also assessed the impact of weather on the COVID-19 pandemic in Turkey pointing out that that wind speed 14 days prior to and the temperature of the day of the study yielded higher numbers of cases. Similarly, Lin et al. (2020) identified that meteorological parameters influence COVID-19 as daily maximal temperature, wind speed and air pressure are inversely correlated with reproductive ratios. Furthermore, Tang et al. (2020) explored the correlation between the average percent of positive COVID-19 in the USA and dosages of sunlight ultraviolet radiation. Their findings indicate that the monthly average percent of positive COVID-19 cases bears a negative correlation with the greater levels of sunlight ultraviolet radiation Fig. 4.

3.3.2.3. COVID-19 and its effects on agriculture and ecosystem conservation. Environmental studies are now paying particular attention to the effects of COVID-19 on wildlife and ecosystem conservation. Certain initial enquiries, such as that by Yuan et al. (2020), explored the link of the COVID-19 outbreak with the diet of wildlife in China and offered suggestions for regulating wildlife conservation and food security to prevent exposure of the virus to humans. As certain studies corroborate that bats are a natural reservoirs of COVID-19 (Banerjee et al., 2020), articles in the field of environmental science offer concrete guidelines on how to monitor forest and environmental areas where humans and bats closely interact (Nabi et al., 2020; Li et al., 2020).

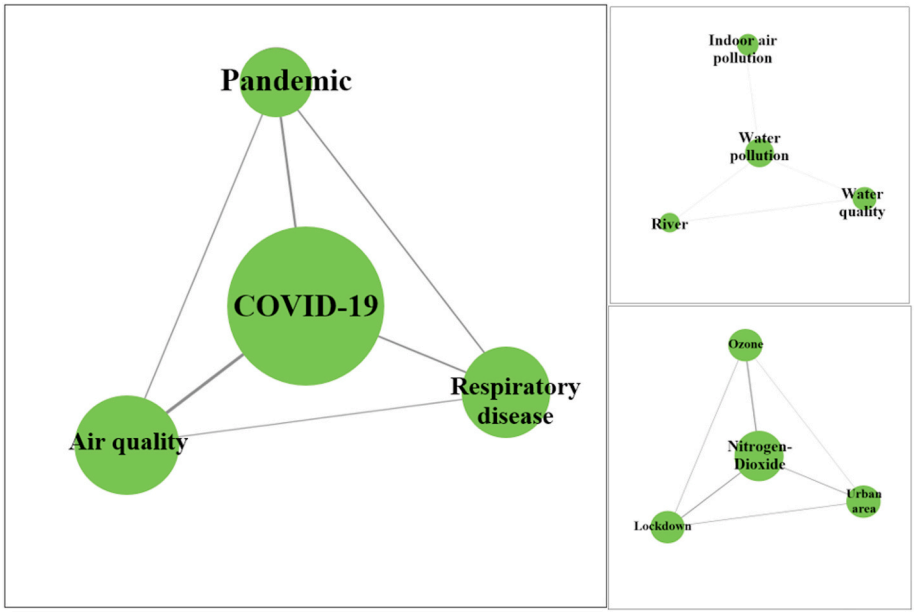

Fig. 3. The main thematic networks serving to investigate the interaction between COVID-19, air quality and water pollution.

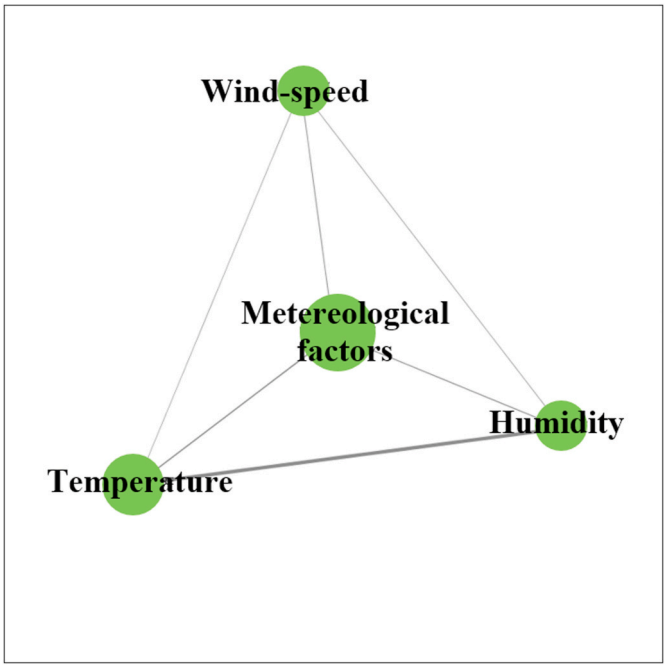

Fig. 4. The main thematic networks serving to explore the interaction between COVID-19 and meteorological factors.

Environmental specialists have more recently attempted to evaluate the effects of COVID-19 on food supply chain efficiency and security, i.e., the availability and delivery of food and its accessibility. This is an important issue in environmental research as after the COVID-19 crisis rose to the top of policy agendas, several decision makers warned of the problem of food supply and spikes of food prices (Keulertz et al., 2020). Deaton and Deaton (2020), for instance, in their appraisal of Canada's food security and agricultural systems during the pandemic, noted that despite surges in demand and supply chain disruptions, there was no broad, rapid hike in food prices suggesting an adequate short-term supply of food. Kerr (2020), commenting on the short and long term implications of the pandemic for international trade relations, suggested the need in the future to strengthen international cooperation to guarantee food supply chains in times of crisis. Gray (2020) further explored how virus-related disruptions in transportation services could impact Canadian agricultural supply chains. The analysis evinces that agricultural access to bulk ocean freight, rail, and trucking generally improved during the pandemic, bolstered by a reduction in demand for transportation services by other sectors of the economy. Other specific environmental studies have also examined the effects of COVID-19 on the supply chains of beef (Rude, 2020), fruit and vegetables (Richards and Rickard, 2020) and farmland markets (Lawley, 2020).

Environmental researchers have likewise focused on the lockdown impact on changes of energy consumption, waste management and daily habits among citizens. Jribi et al. (2020), for example, assessed the effect of the lockdown on Tunisian consumer awareness, attitudes and behaviors related to food wastage. Their findings indicate that the COVID-19 lockdown improved food shopping performance and pushed toward a positive behavioral change with regard to food wastage: 85% of the respondents declared that none of their purchases were discarded. Moreover, most of the respondents established a strategy of saving, storing and consuming leftovers. Sofo and Sofo (2020) further evaluated the benefits of plants during the period of isolation and explained how they can provide a small-scale approach to the sustainable use of natural resources, leading towards self-sufficiency, self-regulation, sustainability, and environmental protection. Aruga et al. (2020) investigated how COVID-19 cases affected Indian household energy consumption during the crisis and found a positive relationship between the cases and the consumption of energy.

Other investigations have specifically evaluated the impact of COVID-19 on biodiversity conservation. Lindsey et al. (2020), for example, contend that although restricting human movement has reduced economic activity and, consequently, improved nature conservation, the net conservation impact of the virus in Africa will be highly negative. The authors insist that the pandemic favors a perfect storm, reduced funding and restrictions on the operations of conservation agencies while elevating the human threat to nature. Jumba et al. (2020) offer a critical reflection and argue the need of alternative food systems in Uganda (e.g., agroecology) that are deemed more resilient in times of pandemics Fig. 5.

3.3.2.4. COVID-19 and epidemiology. Environmental study academics also have explored how the monitoring of environmental settings can

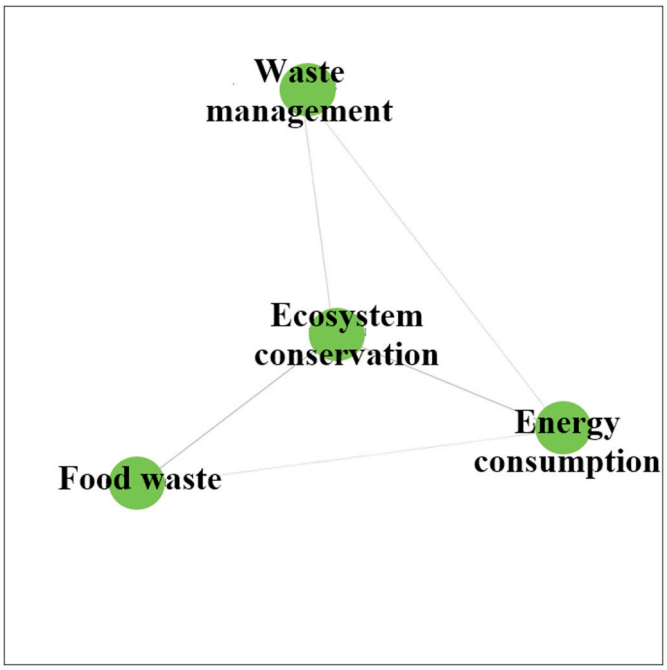

Fig. 5. The main thematic networks serving to evaluate the interaction between COVID-19 and ecosystem conservation.

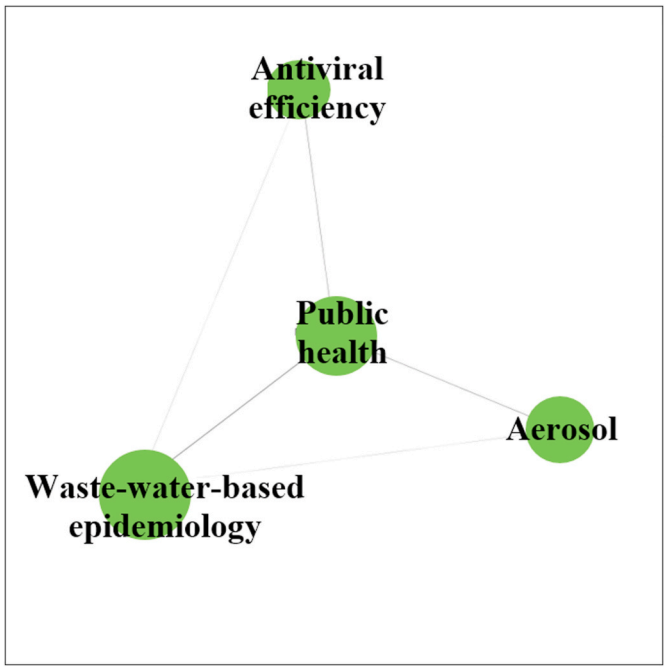

Fig. 6. The main thematic networks serving to evaluate the interaction between COVID-19 and public health.

serve to prevent and predict such outbreaks and, consequently, improve public health. Sims and Kasprzyk-Hordern (2020) concluded that the emergence of new infectious diseases (e.g., COVID-19) can be monitored comprehensively and in real time by analyzing accumulated wastewater. This technique has served to survey markers in wastewater treatment to characterize chemicals, drug use patterns, and the spread of disease within communities. The authors go as far as to state that this method could be more effective than those currently serving to test massive populations. González et al. (2020) carried out a pioneering COVID-19 surveillance in southeastern Virginia (USA) based on epidemiological studies of wastewater. Their conclusion is that this technique could act as a pre-screening tool to improve target clinical testing needs in communities with limited resources. Ahmed et al. (2020) likewise initiated a pioneering study to detect COVID-19 in wastewater in Australia. Their results suggest the great potential of wastewater monitoring to offer early warning signs on the extension of COVID-19 circulation in a community, especially among those marked by mild or no symptoms. Similar findings were reported by La Rosa et al. (2020) in Italy, Kumar et al. (2020) in India, and Mlejnkova et al. (2020) in the Czech Republic.

In order to implement strategies to prevent the spread of COVID-19, environmental researchers have also evaluated aerosol transmission. Morawska and Cao (2020), for example, recommend that the authorities take into account the airborne spread of COVID-19 in their regulations to prevent transmission in indoor spaces. Tang et al. (2020) review the evidence of aerosol transmission and concluded its plausibility and scored, based on the weight of the combined evidence, at 8 out of 9 Fig. 6.

3.3.2.5. COVID-19 and smart cities. Smart cities are urban centers that have profited from the boom of information and communication technologies to develop accessible, sustainable, connected and geolocated spaces (Inversini et al. 2016). According to recent studies (Xu et al., 2020; Pirouz et al., 2020), smart city connectivity and geolocation render it possible to determine the location of each citizen and accurately monitor outgoing individuals to manage and control population flow more orderly and avoid COVID-19 outbreaks. Current environmental research is thus evaluating how technology, geolocation and smart devices serve in monitoring the movements of positive COVID-19 cases.

Choi et al. (2020), for example, explain in detail how a smart city, Seoul, rapidly "flattened the curve" during the pandemic without shutting down its economy or its country's borders by implementing strong measures assisted by smart technologies and rapid innovations. According to the authors, proactive information-sharing enabled citizens to develop a shared understanding of the situation, comply with the newly adopted rules and safety measures, and build confidence in their government's abilities to manage the crisis. Rary et al. (2020) go further in their reflexive thematic analysis on the usefulness of biosensors in sanitation infrastructures (i.e., lavatories, sewage pipes and septic tanks) to assess individual and population health. Their findings demonstrate the potential of this emerging technology and the concept of *Smart Sanitation* to enhance health monitoring at both the individual (for diagnostics) as well as at the community level (for disease surveillance). Along a same line, Sarwar et al. (2020) evaluated how Geographic Information Systems (GIS) techniques, resources, and methods can serve in Pakistan to more effectively investigate the disease. The authors concluded that GIS approaches facilitate the comparison of algorithms for early detection within a spatially relevant context and thus make it possible to trace and treat the patients timely, as well to implant preemptive measures in that particular area to halt the COVID-19 spread.

Applying the concept of smart cities to tourism is known as Smart tourism, that is, the creation of innovative spaces and improve services founded on a state-of-the-art technological infrastructure taking advantage of the surge of Information and Communication Technologies. Its objective is to guarantee a sustainable development of a territory, accessible to all, and facilitate the interaction and integration of the visitor with the environment. In the framework of the current pandemic, tourism companies and institutions are increasingly boosting these intelligent environments as a way to monitor and guarantee tourist security. Jamal and Budke (2020), for example, explain the importance of smart destinations and offer directions for tourism research and practice subsequent to the pandemic. Specifically, the authors state that there is a need of a greater responsibility among residents and tourists to seek correct scientific facts about the virus and take sensible precautions, as well as exercise care to those suffering its adverse impact. They also

advise of the need of a greater global coordination and attention to vulnerable destinations and an increase in the use of smart devices. Chang et al. (2020) likewise advance the need of development of a more sustainable tourism as a way to balance tourism, travel, and the hospitality industry. Among other measures, the authors highlight the urgency of personal protection equipment during travel, the need to implement comprehensive and frequent monitoring to control diseases and pandemics, as well as the necessity to impose updated rules to monitor medical facilities and highly trained on-board healthcare workers. Gallego and Font (2020) also advanced a method of the early detection of the reactivation of tourist markets to help mitigate the effects of the COVID-19 crisis resorting to analyzing Skyscanner data as to flight searches between November 2018 and December 2020. Their results reveal how Big Data can offer timely information crucial to identify highly volatile situations and that destination firms must improve their Big Data analytical competence.

Environmental studies are also evaluating the effects of artificial intelligence (a field of science and technology investigating the combination of algorithms designed to create machines emulating human capabilities) on how to control COVID-19. Ghazaly et al. (2020), for example, conclude that artificial intelligence can be applied to deploy intelligent diagnostic and treatment devices. In addition, they surmise that it can serve for teleworking, distance education and intelligent production to ensure a minimal disruption of daily life. Along a same vein, Nadikattuan et al. (2020) propose an innovative localization method to track through sensors the position of individuals in an outdoor environment. Specifically, the authors suggest a novel smart device resorting to artificial intelligence to maintain social distancing as well as to detect COVID-19 symptoms. Similarly, Simsek and Kantarci (2020) recommend an artificial intelligence-driven strategy for mobile assessment agents during epidemics/pandemics. By means of simulations of real street map mobile crowd-sensing simulator, the authors signal "… that on the 15th day following the first confirmed case in the city under the risk of community spread, AI-enabled mobilization of assessment centers can reduce the unassessed population size down to one fourth of the unassessed population under the case when assessment agents are randomly deployed over the entire city" (Simsek and Kantarci, 2020, p. 1) Fig. 7.

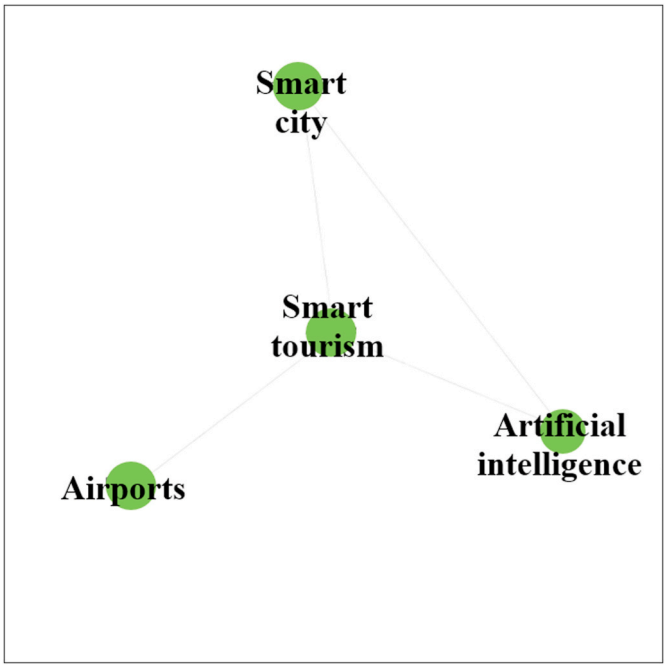

Fig. 7. Main thematic networks serving to evaluate the interaction between COVID-19 and smart cities.

3.3.2.6. Lessons from COVID-19 for climate action. A last research theme among the 440 documents identified by the searches of the databases focuses on the future tasks that we, as a society, and environmental researchers, must develop to mitigate climate change. Howarth et al. (2020), for example, posit that COVID-19 has raised our awareness of how vulnerable we are in the face of climate change. According to these authors, mitigating climate change requires a more carefully planned, inclusive, less disruptive and greater sustained response through deliberative engagement mechanisms aiming to build a social mandate for post-COVID climate action. In an effort to clarify the measures of sustainability that we must assume in the future help mitigate climate change, Meles et al. (2020) examined the impact of the COVID-19 pandemic on the 2030 EU CO_2 emissions target. The authors claim that although existing climate policy measures in the wake of the pandemic will reduce emissions more than 40% by 2030, this will not be enough to meet the guidelines of the Paris agreement. Hence a need for more strict and sustainable measures. Klenert et al. (2020) summarized the main lessons of COVID-19 applicable to reduce climate change: (i) delayed action increases mitigation costs; therefore, institutions and long-term incentives should be drawn up; (ii) there is a need to involve citizens in the reasons of climate change, thereby policies should be more appealing; (iii) actions in the future should address distributive concerns as well as measures of mitigation; (iv) individuals, governments and organizations must work together to encourage multilevel collaboration, tying in large emitters; and (iv) citizens must be inoculated against misinformation.

Environmental researchers have likewise highlighted that COVID-19 should serve as a starting point to promote social sustainable habits. Kleinschroth and Kowarik (2020) resorted to Google Trends to estimate changes in online searches for basic activities typically carried out in urban green areas (e.g., walking) before and after the onset of the pandemic. Their results indicate that searches for outdoor walks and parks during the pandemic increased exponentially. The authors therefore suggest that the crisis underscores the value of preserving and further developing urban green infrastructure. Along the same line, Mukanjari and Sterner (2020) propose that efforts to revitalize the economy after COVID-19 should resort to green and renewable resources as more polluting means and materials (e.g., airports, fossil fuel, carbon) experienced the largest decreases in stock value during the crisis. Furthermore, Goffman (2020) states that the best way to simultaneously alleviate the rapidly moving pandemic crisis and the slower moving environmental crisis is through *glocalization*, that is, a world in which people live far more local lives than in recent decades but foster a greater global awareness through a connective world. The author adds that these measures should be accompanied by a reduction of air and automobile travel and an increase in local production and smart growth Fig. 8.

4. Discussion and final conclusions

The global spread of the severe acute respiratory coronavirus 2 syndrome (COVID-19) and the response to the pandemic by national authorities is unprecedented in its speed and scope. The current crisis has likewise placed information professionals in the centre of an information pandemic (Torres-Salinas, 2020) as they are required to turn to scientific texts as sources to offer the public simple, instructive and accessible information. Moreover, academics are turning to bibliometric surveys to facilitate navigating through the scientific databases to synthesize and simplify access to the findings of research on COVID-19. Despite the fact that COVID-19 bibliometric studies have been carried out in the fields of biology and medicine (Bonilla-Aldana et al., 2020), socioeconomics (Verma and Gustafsson, 2020) and tourism (Sigala, 2020), no study of this ilk has explored the growing number of COVID-19-related scientific publications in the field of environmental research. The current article therefore is the first bibliometric analysis making use of SciMAT software to evaluate the publications on

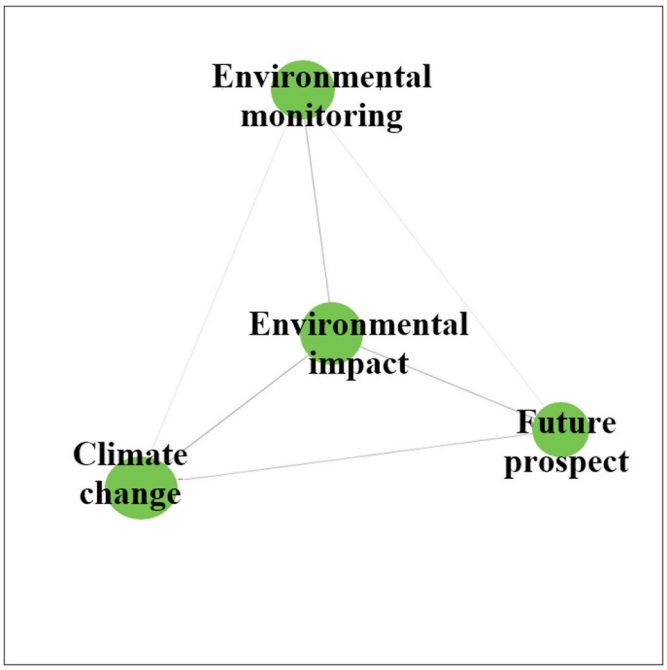

Fig. 8. Main thematic networks serving to evaluate the interaction between COVID-19 and future environmental impact.

COVID-19 linked to environmental studies between 1 December 2019 and 6 September 2020. It is our specific goal to quantify this scientific production, identify its main authors and scientific journals, describe and visually display its most relevant research lines and sublines, and offer a research agenda to environmental specialists. Consequently, this paper represents a contribution to the existing literature on COVID-19 and the environment as it amounts to a critical examination of the extant research and points out the research gaps that must be filled by future studies.

The results of the survey led to the assemblage of a corpus of 440 articles issued between 1 December 2019 to 6 September 2020 combining the subject of COVID-19 and the environment and published in peer-reviewed scientific journals identified through the Web of Science and Scopus databases. The articles leaning more to the environment were issued in journals such as *Science of the Total Environment, Public Health, Sustainability* or *Environmental Research*, whereas as those with closer ties to economics and environment in *Environmental and Resource Economics* and the *Canadian Journal of Agricultural Economics*. In line with the conclusions of Torres-Salinas (2020), the results reveal that four out of five articles on the subjects combining COVID-19 and environment are of open access.

The outcome of the citation-map analysis has led to the creation of descriptive and visual thematic networks and sub-themes of great interest to academics investigating the interaction between COVID-19 and the environment. These results specifically highlight the following six main lines of research Fig. 9:

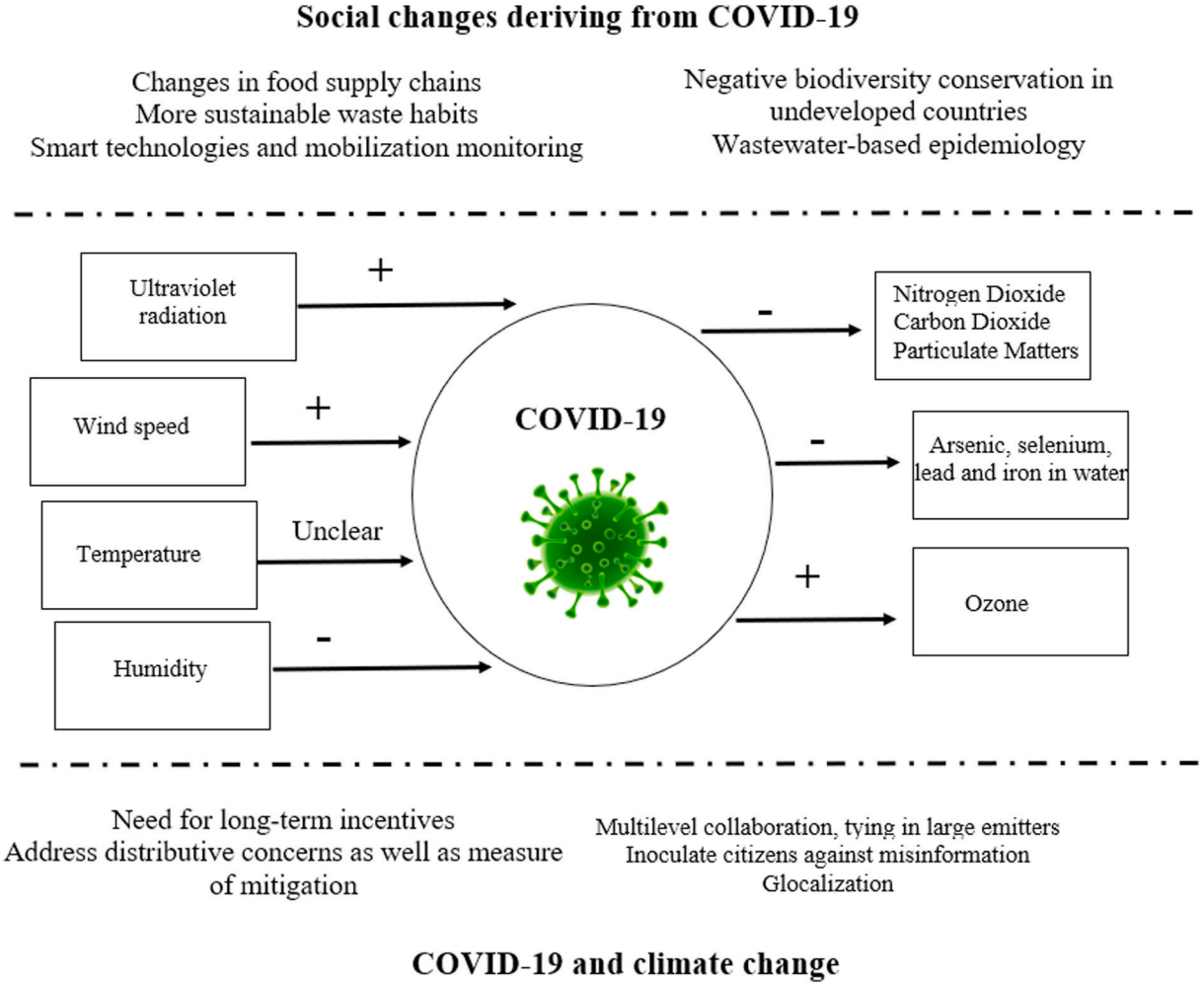

Fig. 9. The consequences of COVID-19 on the environment according to the bibliometric analysis.

(i) COVID-19 and water and air pollution. Environmental studies highlight a sharp decrease of air pollutants (NO_2, CO_2 and PM) and an increase of O_3 during the COVID-19 lockdown. This also suggests that populations suffering from poorer air quality suffer more COVID-19 infections, hospital admissions and deaths. Water pollution improved during the COVID-19 lockdown as evidenced by decreases in SPM and metal concentrations in lakes and rivers.

(ii) COVID-19 and meteorological factors. Environmental studies indicate significant correlations between wind speed, air pressure, humidity, ultraviolet radiation and COVID-19 rates. Despite certain findings suggesting an opposite effect between temperature and virus cases, little research corroborates such a link.

(iii) effects of COVID-19 on wildlife and agricultural conservation. Environmental study specialists exploring the changes provoked of COVID-19 on food supply chains and changes in waste habits during the pandemic offer arguments as to its impact on the conservation of biodiversity.

(iv) COVID-19 and epidemiology. Environmental researchers claim that monitoring wastewater has a great potential to offer early warning signs on the degree of distribution of COVID-19 in a community, especially among individuals bearing mild symptoms or no symptoms at all.

(v) COVID-19 and smart cities. Environmental and urban researchers coincide that the use of artificial intelligence, SIG and smart devices can serve in monitoring the mobilization of citizens in urban and tourism destinations, and thus play a vital role in preventing an advance of the pandemic.

(vi) lessons learnt from COVID-19 for climate action. Environmental researchers claim that the pandemic clearly demonstrates the dependence on natural and environmentally sustainable resources to reduce the effects of climate change. Collaboration by all spheres of society based on decisions gleaned from scientific results and the creation of sustainable incentives could lead to attaining the goals of Paris (2020).

Although positive strides are being made in the study of the interrelation between COVID-19 and the environment, the findings of the current analysis offer thematic networks that offer a direction for future lines of research. Firstly, future work should delve into the impact of water quality on the spread and control of COVID-19. Secondly, despite clear evidence of the impact of meteorological factors on COVID-19 mortality and transmission, environmental literature is not unanimous as to the temperature ranges that favor COVID-19 propagation. Hence prospective studies are now in a good position to evaluate this relationship in different tropical zones. Thirdly, future studies exploring social changes in energy consumption, real environmental purchases, waste behavior and leisure activities is required to advance in the understanding of the effects of pandemics on social daily routines. Fourthly, although studies have identified airborne transmission of COVID-19, no analysis to date has specifically enquired into what extent meteorological factors or urban contexts affect this type of transmission. Lastly, more environmental studies are required to assess the manner in which smart devices and monitoring platforms can assist prevention and avoidance of COVID-19 propagation.

Finally, the current study only isolated documents indexed in the Web of Science and Scopus and has not identified all published materials. This study likewise did not take into account preprints, early versions of scientific articles, which also represent a rapid means of dissemination of information (Torres-Salinas, 2020). However, despite the fact that preprints enable a rapid dissemination of findings, commentaries and critical reviews through open access platforms, we contend that they increase the risk of spreading false information as they are posted devoid of independent quality control. Considering the daily coverage that COVID-19 receives from the international media, erroneous conclusions could be quickly replicated beyond the scientific sources leading to misinformation. Finally, the current study did not account for the different methods applied by environmental researchers. Future research should discuss these diverse methods applied to each of the above-mentioned thematic networks.

Hence the findings of this article offer information professionals with a true and objective framework of the main current scientific research combining COVID-19 and the environment. Journalists as well as information and documentation professionals, by incorporating these findings into their news stories and narratives, would bolster and guarantee their credibility in a time marked by an unprecedented information explosion.

Author statement

Luis-Alberto Casado-Aranda, Conceptualization, Methodology, Software, Writing and Data Curation. Juan Sánchez-Fernández, Data curation, Reviewing and Editing. María-Isabel Viedma-del-Jesús, Visualization, Investigation, Supervision.

Declaration of competing interest

We have no conflict of interest to disclose.

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