A systematic review of the impacts of the coronavirus crisis on urban transport: Key lessons learned and prospects for future cities

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A B S T R A C T

The COVID-19 pandemic continues to have a significant impact on the transport sector worldwide. Lockdown and physical distancing requirements continue to be enforced in many cities leading to severe travel restrictions and travel demand reduction to limit the spread of the disease. This article provides bibliometric evidence-based insights into how the pandemic has exposed the vulnerability of established public transport systems and shared mobility solutions. It shows how some transport interventions can accelerate the shift to sustainable urban mobility practices such as micro-mobility and active transport. To accomplish this, the article examines recent studies (244 publications) from the Scopus database using a rigorous systematic literature review approach covering the period from January 2020 to February 2021. Importantly, the mapping of bibliographic coupling and co-citation analysis showed four heterogeneous clusters representing research efforts into "environment", "travel behavior and mode choice", "public transport", and "interventions". Inductive reasoning is used to analyze the disruptions that cities have encountered worldwide, the rapid interventions that were put in place, the aftershocks and the short and long-term impacts. Finally, the paper summarizes the lessons learned and opportunities ahead, and the challenges that must be overcome. The article also outlines pathways to build on the momentum of sustainable practices as part of a holistic approach for enabling resilient transport solutions for the new urban world.

1. Introduction

The COVID-19 crisis spread fast at the end of 2019 and was declared a global pandemic on 11 March 2020 (WHO, 2021). The crisis continues to present unprecedented challenges to various industries such as healthcare, economy and transport worldwide (Shen et al., 2020; Shen, Fu, Pan, Yu, & Chen, 2020). To date, more than 114 million people have been infected, over 89 million individuals have recovered, and over 2 million have died (Worldometers, 2020). Governments worldwide have enforced lockdowns, physical distancing and border closures to avoid the virus spread. It was estimated that one-third of the world's inhabitants were under travel restrictions in 2020 when governments urged people to stay home and limit their travel to only necessary trips within specific zones and boundaries (Buchholz, 2020). People also refrained from travelling to avoid the risk of contamination and exposure to other people, particularly in crowded spaces such as public transport vehicles (Tirachini & Cats, 2020).

These changes significantly impacted people's travel behavior and mode choices, including the use of private cars, public transport, active travel and micro-mobility nationally and internationally. Even when restrictions were relaxed for a limited time in 2020, people were still anxious about travel and exposure to the virus, which resulted in a significant reduction in travel demand. Also, government agencies and transport authorities had to limit public transport patronage to observe physical distancing. These issues introduced enormous challenges to the transport sector globally, which were reflected in large numbers of recent studies that evaluated the negative impacts on transport (Borkowski, Jażdżewska-Gutta, & Szmelter-Jarosz, 2021; de Haas, Faber, & Hamersma, 2020; Eisenmann, Nobis, Kolarova, Lenz, & Winkler, 2021; Zenker, Braun, & Gyimóthy, 2021). Other research during that period also examined the effects of these restrictions, such as the decrease in air pollution (Le Quéré et al., 2020; Muhammad, Long, & Salman, 2020; Sharma, Zhang, Gao, Zhang, & Kota, 2020), increase in active travel, and the use of micro-mobility solutions for short-distance travel (Aloi et al., 2020; Campisi et al., 2020; Li, Zhao, He, & Axhausen, 2020).

Remarkably, the pandemic had disproportionate geographic, environmental, socio-economic and equity impacts. Different countries and regions implemented travel limitations and restrictions at different

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times, and they faced and addressed the challenges in mobility behaviors and emerging travel habits in their own different ways. For example, in Sapporo, Japan, the central business district population density reduced by up to 90% (Arimura, Ha, Okumura, & Asada, 2020) as a result of travel restrictions and as a result of employers asking their staff to work from home rather than travel to their offices in the city. The measures and responses adopted were based on each country's local governance, socio-economic and cultural contexts (Shaw, Kim, & Hua, 2020). Inadvertently and without planned interventions, people reverted to some good sustainable practices such as more local shopping, reduced car usage, and telecommuting or working from home for those who could do it. Going forward, it is important that cities build on the momentum towards sustainable practices to enable resilient urban mobility by investigating and determining ways to improve health and safety and attracting travelers to public transport again (Jallow, Renukappa, & Suresh, 2020). In addition, service operators should be encouraged to maintain the service frequency with a safe capacity, and operators should be supported financially to keep transport services moving (Betkier, 2020). The recent literature also consistently reports a need for immediate attention to transforming urban environments through innovative sustainable transport models (Batty, 2020; Bucsky, 2020).

Although the literature on this topic is rapidly growing, there are currently few systematically analyzed articles that present a cohesive body of work on the myriad of interventions and their impacts. An example SLR publication related to the impacts of COVID-19 in the transport sector was provided by (Benita, 2021). The author identified four main themes based on co-occurrence of keywords and analysis on air transport, human behavior, operations and the environment. The author also provided insights on each theme that would enrich research knowledge of human mobility. This paper extends Benita's previous work and we note here few differences between the two papers. The work by Benita (2021) identified the common themes related to the topic based on occurrence of keywords and evidence mapping. Choosing a theme based only on this method can exclude a large number of papers that discussed similar research topics but used different terms or keywords. In our paper, we overcome this limitation and provide additional insights on policies and interventions and focus on impacts. We also track pairs of publications that are cited together in the source article (co-citation analysis) and also publications that cite the same source article (bibliographic coupling) which were missing in the literature on the topic and provide a boarder coverage and analysis of the literature. Furthermore, Benita's paper addressed two main research questions that were focused on the central research themes and research responses to COVID-19 emergency. This paper extends Benita's work by focusing on the impacts of the pandemic on urban mobility, particularly research that addresses the resilience of urban mobility systems in the face of acute shocks, and addresses the main challenges to transport introduced by COVID-19 and the potential interventions as well as the short and long-term future research directions needed to make transport systems more resilient in the face of future pandemics or disruptions.

Other studies also focused on one particular aspect of the interventions such as public transport e.g. (Almlöf, Rubensson, Cebecauer, & Jenelius, 2020; Dia, 2020) or travel behavior e.g. (Abdullah, Dias, Muley, & Shahin, 2020), or focused on the pandemics impacts on transport in a particular city or region e.g. (Aloi et al., 2020). This special issue of the journal therefore provides an opportunity to have a key paper that takes a holistic view of these issues and serve as a single point of reference to provide both the research and professional communities including transportation planners and operators, government stakeholders at all levels, and urban and transport practitioners with easy access to a rigorous and robust evaluation of the main interventions, trends and impacts of the Coronavirus crisis and how to build on some of the sustainable transport practices that have emerged during the pandemic to continue rather than hamper the transition to sustainable urban mobility. Identifying and observing the response

patterns during and amid the global pandemic is a valuable undertaking and is important for gaining a deeper understanding of how the transport and urban planning professions can respond to such situations effectively to help authorities in responding to similar outbreaks in the future.

This paper offers a thorough scan and comprehensive analysis of the literature on how COVID-19 impacted the transport sector by using a systematic literature review (SLR) approach. The Scopus database is used to uncover research for the period 2020–2021. The paper analyzes 244 publications to identify relevant research and visualize its bibliometric networks. The analysis includes co-occurrence of keywords, most research productive and influential countries on the topic, journal articles and bibliometric analysis of bibliographic coupling and co-citation analysis of relevant articles. This study also identified the knowledge gaps by answering a number of key research questions that explore the central research themes in this field and the key interventions and policy measures that have highest impacts particularly those targeting resilience of urban mobility systems in the face of acute shocks. This article also identified the key challenges to widescale implementation of these interventions, and how the barriers can be removed. Another contribution of this work is identifying short-term and long-term future research directions that are needed to make transport more resilient in the face of future acute shocks, pandemics or disruptions.

This paper is organized as follows. Section 2 presents the SLR method used in this research. Sections 3 and 4 present the bibliometric analysis undertaken in this study, which resulted in identifying main themes and clusters of research relevant to the objectives and research questions posed in this research. Section 5 summarizes the findings, and Section 6 identifies the major knowledge gaps and future research directions. Sections 7 and 8 present the contributions and limitations of this work. Finally, Section 9 presents a summary and conclusions.

1.1. Study objectives and research questions

The inspiration for developing this manuscript came from the critical role that systematic reviews play in scholarly communication and the need to have a key reference in the literature that provides a holistic overview of research evidence on this topic. It was also motivated by the need to have a single publication that can serve as a key reference for continued research in the still evolving COVID-19 crisis which has affected all forms of urban transport and how we should plan cities post-pandemic. The value of this work in providing a practical connection between COVID-19 and transport-related studies from local and global perspectives, synthesizing the findings from original research, identifying research gaps, challenges and barriers as well as future opportunities for innovative responses will inspire other scholars in the field to build on the findings and identify solutions to shape the future directions and responses to help develop sustainable transport systems for cities that are resilient in the face of acute shocks such as pandemics.

The main objectives of this study include:

1. Develop deeper knowledge of how COVID-19 impacted the transport sector, particularly how it shook up established sustainable transport solutions such as public transport, as well as the opportunities to accelerate the adoption of other sustainable urban mobility practices such as active travel and micro-mobility
2. Determine the most important research in the area (e.g. authors, articles, countries and journals)
3. Conduct article, country, and author citation analysis by identifying key research and frequently cited work
4. Conduct a bibliographic coupling and co-citation analysis to identify topics under investigation during the pandemic, proposed interventions and identify gaps in knowledge to bridge current challenges and implement lasting resilient solutions

This paper aims to address a number of research questions in order to

achieve the research goals and objectives:

RQ1. What are the central research themes, and how did they change between 2020 and 2021?

RQ2. Which authors, articles and nations had the most influence on the evolution of the literature?

RQ3. What is the latest research into the impacts of the pandemic on the urban mobility sector, particularly research that addresses the resilience of urban mobility systems in the face of acute shocks?

RQ4. What are the main challenges to transport introduced by COVID-19, the potential interventions, and the gaps in knowledge that must be overcome?

RQ5. What are the short and long-term future research directions needed to make transport systems more resilient in the face of future pandemics or disruptions?

2. The systematic review approach

A systematic review includes defining, analyzing, interpreting, and assessing the literature about a specific research field such as "COVD-19 and Transport*". This methodology employs a pre-determined search strategy to locate detailed and complete information on the subject. The SLR differs from traditional literature reviews in that it includes a rigorous research methodology that reduces bias in the findings and offers a thorough overview of literature related to research objectives (Abduljabbar, Liyanage, & Dia, 2021; Alawadhi, Almazrouie, Kamil, & Khalil, 2020; Wimbadi, Djalante, & Mori, 2021). Systematic literature reviews include several types and approaches (Xiao & Watson, 2019). The most common types are critical reviews (Bala and Verma, 2018), Meta-analysis (Gurevitch, Koricheva, Nakagawa, & Stewart, 2018) and mixed systematic reviews (Cerigo & Quesnel-Vallée, 2020). In this paper, we adopt a mixed systematic review approach that addresses the impacts of COVID-19 on transport by combining both quantitative and qualitative analysis as will be shown in later sections of the paper.

The SLR methodology begins with a review protocol that identifies research objectives and questions. The methodology relies on a transparent search approach to sort and classify relevant studies. The process of conducting SLR can be summarized into the three essential stages (Abduljabbar et al., 2021; Okoli, 2015; Abduljabbar and Dia, 2021) shown in Fig. 1. The first stage includes confirmation of the research study purpose and specifying key research questions. The second stage searches established scientific databases and select primary studies related to the topic. This stage also specifies inclusion and exclusion criteria based on title, abstract and full content of articles. The third and final stage includes undertaking critical evaluations of the literature and

Fig. 1. Systematic literature review process (Abduljabbar et al., 2021).

synthesizing the bibliometric data extracted from the studies by using appropriate techniques. Finally, findings are established and reported with future recommendations, as summarized in Fig. 1.

2.1. Literature search in scientific databases

The authors considered a number of different databases for the literature search. The Scopus database was selected because it retrieved a larger and more comprehensive number of publications compared to other databases. It also offered additional search criteria functionality including keywords, title and abstract which improved the search functionality using three identifying elements simultaneously compared to other databases which only covered one keyword or criteria at a time.

The literature search was conducted in Scopus, which was completed using the "titles, keywords, or abstracts" criteria. Before undertaking the systematic literature review, the authors conducted a preliminary literature assessment to decide on the most suitable search strings. The aim was to identify existing literature related to the topic and assess the volume of relevant literatures for each search string. After many trials using various combinations of keywords derived from the study focus, the following string was selected: "COVID-19 and Transport*" as the key search criteria. This search was selected over other options because it retrieved a more comprehensive set of publications related to the scope of this paper. In the search stage, all articles were specified, including journal articles, conference papers, books and book chapters, and technical reports. The timeframes of publications were restricted to articles published between January 2020 and February 2021, and all languages were included.

This search provided a total of 2288 articles. However, many subject areas then had to be excluded, such as "Medicine", "Biochemistry, Genetics and Molecular Biology", "Pharmacology, Toxicology and Pharmaceutics" which included mainly medically-related articles that are outside the scope of this study. The subject areas that were kept and included in this analysis were specific to engineering, social studies, and environmental science, with 445 articles included that covered all related studies specific to the transport industry.

2.2. Inclusion and exclusion criteria

The next step was to fine-tune the search results by using more specific inclusion and exclusion criteria (Fig. 2). To select articles that are specific to the aims of the paper, three exclusion criteria were identified. These were exclusions based on paper title, abstract and full content where papers were excluded if they did not cover the impacts of the Coronavirus on urban transport. Each criterion (title, abstract and full content) was read independently by two researchers, and in the case of uncertainty by a third researcher, until an agreement was reached. The excluded articles can be verified using the link provided to the data at the end of the paper.

First, a total of 110 publications were excluded by the authors based on the titles. Second, a total of 72 publications were also excluded based on abstract reviews, and 19 publications were excluded after a full article content review. This resulted in a total of 201 documents being excluded from the analysis and a total of 244 articles (203 of which were journal papers) that were identified as relevant for further detailed analysis. It should be mentioned that due to the short time frame being considered (2020−2021), all article types that appeared in the specified search engines were considered, including conference articles. All articles used in the analysis can be found via the link provided in the data availability section of the paper. To select articles that are specific to the aims of the paper, three exclusion criteria were identified. These were exclusions based on paper title, abstract and full content where papers were excluded if they did not cover the impacts of the Coronavirus on urban transport. Each criterion (title, abstract and full content) was read independently by two researchers, and in the case of uncertainty by a third researcher, until an agreement was reached. The excluded articles
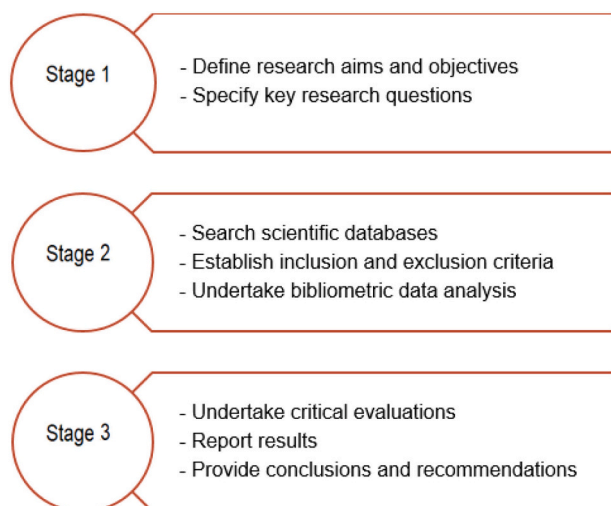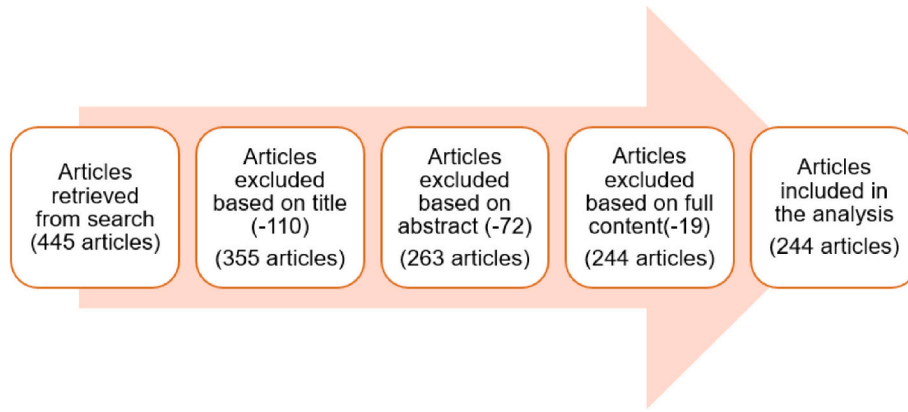
Fig. 2. Inclusion and exclusion criteria.

can be verified using the link provided to the data at the end of the paper. The data extraction process was planned based on the research questions to be addressed in this paper. After a careful screening process of titles, abstracts and keywords, a total of 244 articles were selected for detailed discussion in the literature review. While it is unavoidable that certain papers would be missed by the search criteria, the authors consulted more than one database and believe that these papers represent key peer-reviewed research of sufficient quality and size to provide a rigorous basis for the analysis.

The SLR analysis started by retrieving the relevant articles for the period 2020–2021. A total of 209 publications were retrieved for 2020, and 35 articles were retrieved for January and February 2021. The first part of the analysis then looked at the co-occurrence of author keywords per year, as shown in Fig. 3 (thus answering RQ1).

A web of keywords or co-occurrences was created using the VOSviewer software based on the 244 publications. VOSviewer is a software tool that is used to analyze bibliometric networks of research authors, keywords, journals and organizations. The tool provides clustering of individual items of different domains based on similarities and connections, which are referred to as nodes and links between items in the bibliometric networks. This analysis was useful in visualizing the content of the chosen publications. Nodes in the network represent specific keywords that distinguish the core elements in each article. A total of 1902 keywords were initially identified from the selected publications. Filtering was then used to select only keywords that appeared at least three times, yielding only 219 keywords that met this criterion. The keyword visualization analysis (Fig. 3) revealed that (as expected) the most commonly used keywords for the first half of 2020 were COVID-19, coronavirus, social distancing, and transport. For papers published after mid-2020, data collection, human mobility, wellness, and public transport were prioritized. Bike-sharing, data mining, and fuel consumption were the most used keywords in 2021.

3. Country of publication analysis

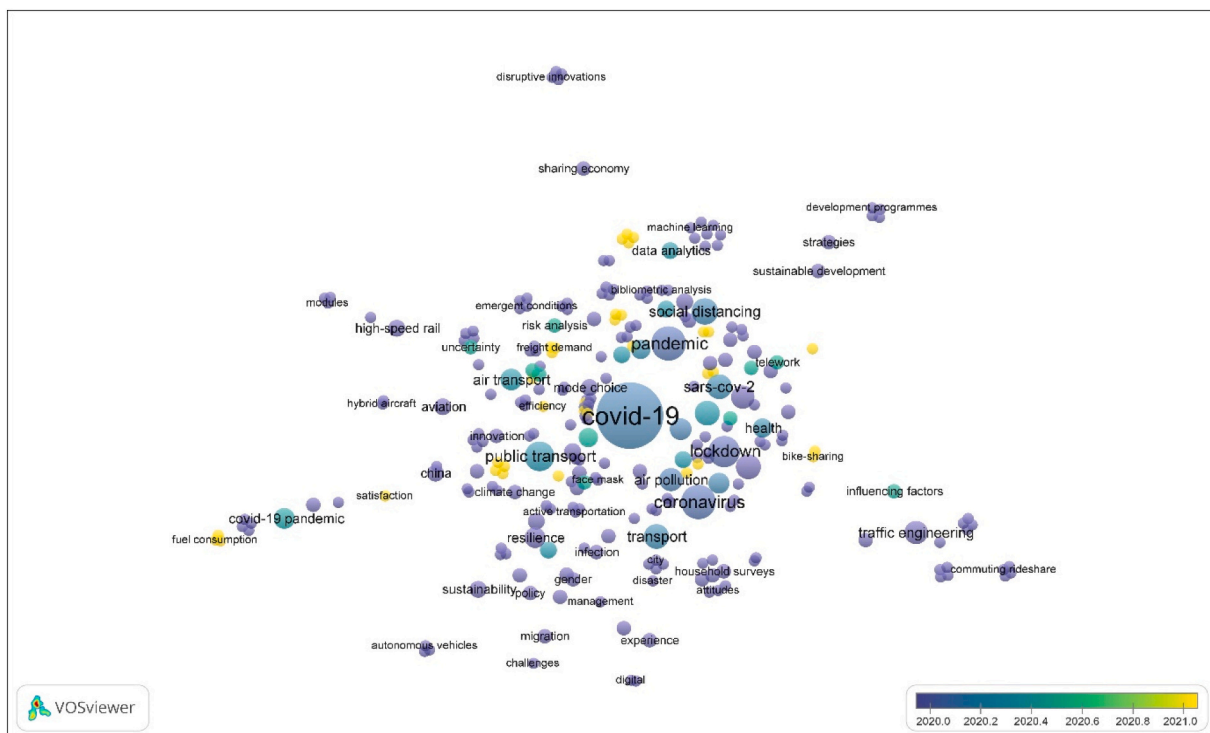A country citation analysis resulted in identifying nations that had

Fig. 3. Overlay visualization analysis for keywords for 2020 and 2021.

produced substantial research output related to the impacts of the pandemic. A minimum of two publications was used as a criterion, resulting in a total of 46 countries included in the analysis. The highly cited countries are shown in Table 1 and Fig. 4. These include China with (832 citations), the US (551 citations), India (469 citations), France (330 citations), the UK (317 citations) and the Netherlands, Australia, Germany, Italy and Norway with (239, 227, 225, 215 and 213 citations, respectively) (thus answering RQ2). Table 1 also shows that China and the US had the largest number of publications (50 and 45, respectively). This was followed by the UK (22 publications), India (21 publications), Australia (17 publications), and Canada (15 publications). Italy, Spain, France and Russia also had 14, 12, 11 and 10 publications, respectively. Fig. 4 presents the density visualization of top-cited countries. Each cluster in the density visualization has a color, ranging from red to blue, which indicates the density of the cited country. The red color represents the higher number of citations followed by orange, yellow, green and blue.

4. Co-citation analysis and bibliographic coupling

The assessments in this paper include a co-citation analysis that is used to count the number of times two papers are cited together in a publication (Abduljabbar et al., 2021). Such papers are more likely to be in the same cluster when they are frequently cited together. In this article, clusters with a minimum of 25 papers are identified to ensure meaningful clustering and classification of topics. From the 244 publications, only 168 were connected to each other and selected for the analysis. Four clusters are identified with a total of 2992 co-cited papers (Fig. 5), where each cluster comprises a series of articles that are strongly linked to one another (Pournader, Shi, Seuring, & Koh, 2020). For each cluster, the most common theme of research was chosen for the cluster's title. The four clusters identified in the co-citation analysis included "environment", "travel behavior and mode choice", "public transport", and "interventions". Bibliographic coupling was also investigated to measure the frequency with which two publications each cite one or more publications in common. The coupling uses citation analysis to find the relationship between articles through clustering the articles that share similar references. When two papers cite the same document, they will most likely belong to the same cluster. Three clusters were discovered, each containing a series of articles with clear links to one another as well as some connections to papers in other clusters (Mas-Tur et al., 2021; Patrício & Ferreira, 2020). An additional cluster was found in the bibliographic coupling, which referred to "air transport", but that was excluded from our analysis because it was outside the urban mobility scope, which was the focus of this study. This analysis is directly related to answering RQ3, RQ4 and RQ5, as will be shown next.

4.1. Cluster 1: interventions

To avoid COVID-19 transmission, many countries have taken measures such as physical distancing and city-wide lockdown as effective interventions to mitigate the spread of the disease (Acuna-Zegarra,

Table 1
The number of citations and publications per country (Top 10).

Country	Number of citations	Country	Number of articles
China	832	China	50
United States	551	United States	45
India	469	United Kingdom	22
France	330	India	21
United Kingdom	317	Australia	17
Netherlands	239	Canada	15
Australia	227	Italy	14
Germany	225	Spain	12
Italy	215	France	11
Norway	213	Russia	10

Comas-Garcia, Hernandez-Vargas, Santana-Cibrian, & Velasco-Hernandez, 2020; Jarvis et al., 2020). In this cluster, the authors focus on the intervention strategies that were aimed at reducing the virus spread. The impacts of these measures are discussed in Clusters 2, 3 and 4 in the following sections. These interventions varied among countries based on the time of the initial wave, which in return led to different infection and death rates for each country. According to (Askitas, Tatsiramos, & Verheyden, 2021; Desvars-Larrive et al., 2020; Haug et al., 2020), there are multiple non-pharmaceutical Interventions (NPIs) that were followed by countries around the globe. These interventions included school and office shutdowns, mass gathering limits, national and international border closures, public transport restrictions and closures, individual movement restrictions, face masks wearing, government assistance to vulnerable populations so that they don't need to work, quarantine, and police interventions. The most effective interventions were reported to be early lockdowns, gathering restrictions, travel restrictions, and school closures (Haug et al., 2020). Those results were found to be heterogeneous among 79 counties in the USA, which considered more than 6000 NPI measures (Haug et al., 2020). The same study found that these were far more effective than public space disinfecting measures which were found to have a lower impact in stopping the spread of the disease. Moreover, the results from this study indicated that a combination of NPI measures was necessary to control the virus spread and that timing and speed of intervention was a critical factor with the earlier interventions producing better outcomes. A model provided by (Acuna-Zegarra et al., 2020) indicated that delaying isolation by one or two weeks would lead to an outbreak escalation in Mexico. A study in China also showed that if the lockdown was applied two days earlier, it would have resulted in 1420 fewer infections (Ai et al., 2020). In addition, a study that traced infections from real-time mobility data from Wuhan showed how control measures impacted the spread (Kraemer et al., 2020). According to the study, travel restrictions were effective because they were enforced in the early stages of the outbreak and would have been less effective as the outbreak became more widespread.

Transport agencies and governments also played a major part in the preparations and development of intervention schemes. Various policy measures have been implemented by all governments and transport authorities to address the effect of COVID-19 worldwide. Before the pandemic, transport policies were mostly focused on transport demand management, 'smart' technology solutions and affordable/sustainable urban mobility. However, the policies that followed during the pandemic have been more focused on ensuring individual and public health and wellbeing by avoiding further spread during the pandemic. Since this disease is highly infectious in confined spaces, public transport needed particular attention and interventions (Shen, Duan, et al., 2020; Shen, Fu, et al., 2020). Examples of effective measures implemented for both workers and passengers included disinfections, personal protection including face masks, running more public transport services to avoid crowding, health promotion and in some cases, automated temperature measurements and apps for service crowd measurement or to book a seat on a service before departure (Dia, 2020). In the UK, restrictions and government policies resulted in reducing driving, public transport, and active transport by 60%, 80%, and 60%, respectively, compared to pre-pandemic levels (Hadjidemetriou, Sasidharan, Kouyialis, & Parlikad, 2020).

Global supply chains were also impacted by the travel restrictions imposed by governments amid the crisis. Travel restrictions on individual and cargo transport have led to ports and borders closures, which weakened the global supply chain. The main policy, which highly disrupted the supply chain was border closure. According to (Barua, 2020), 150 countries imposed border closures worldwide. A total of 91 countries completely closed their borders, and 59 countries forced a partial lockdown by April 2020, as shown in Fig. 6 below. Europe had the largest number of countries in lockdown, followed by South America.

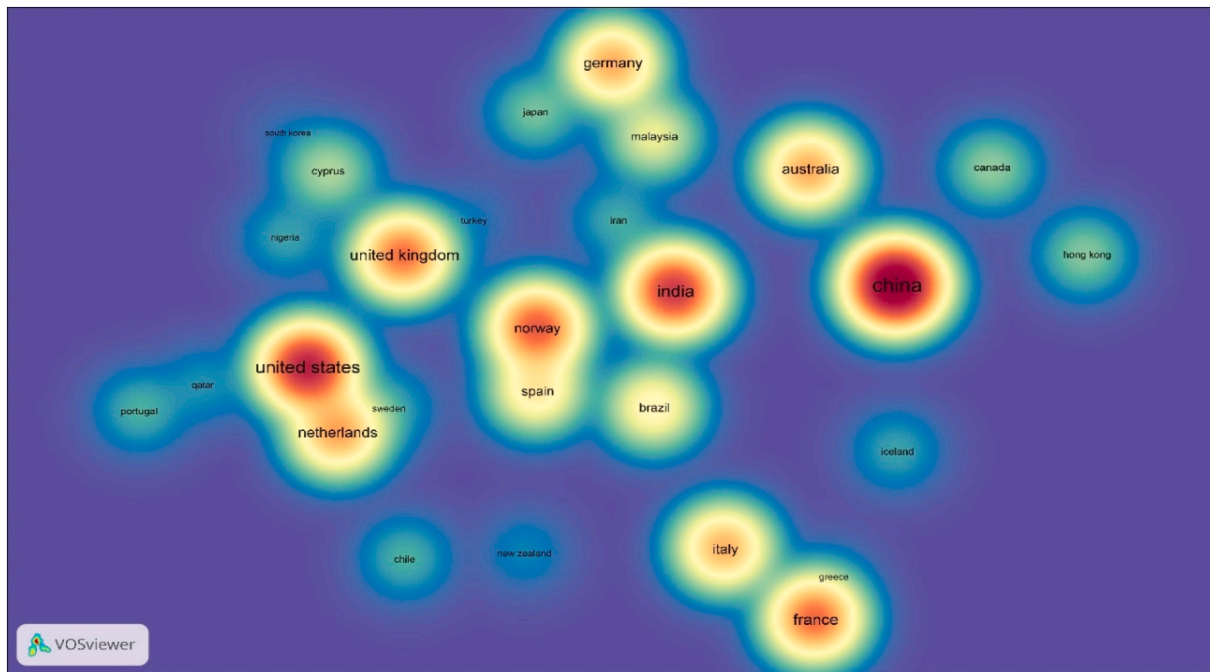Social distancing interventions forced multiple sectors to shut down,

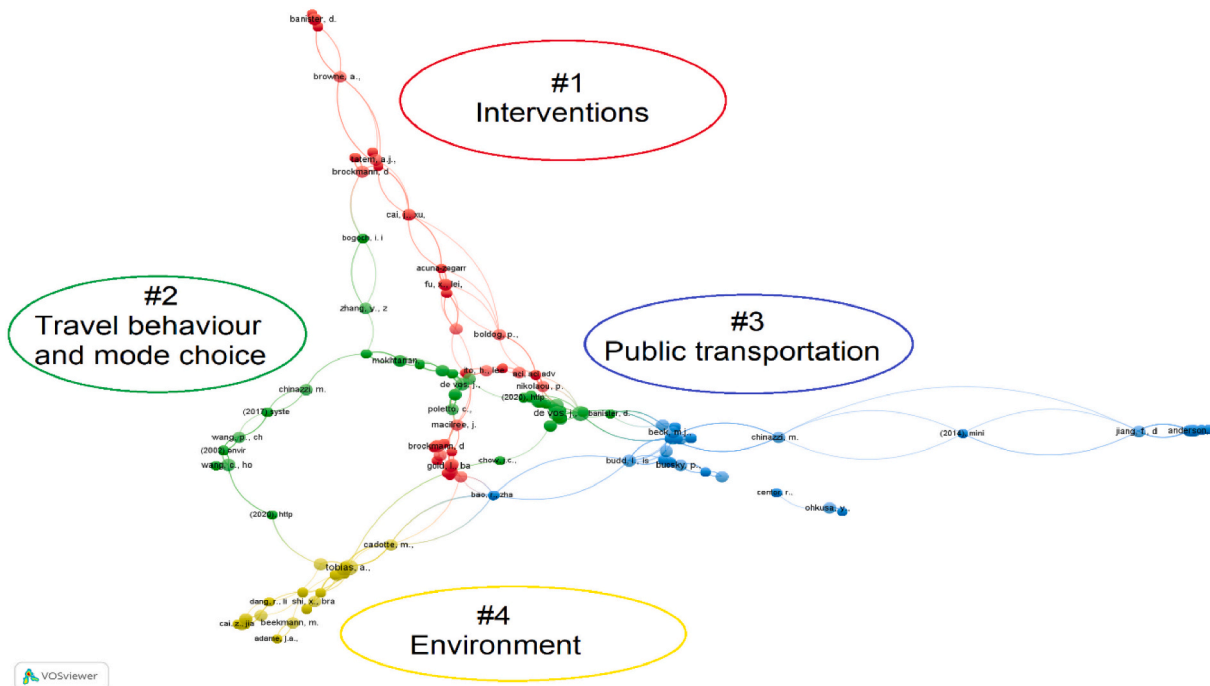**Fig. 4.** Density visualization of top-cited countries.

Fig. 5. Network visualization of co-citation analysis.

resulting in large numbers of workers becoming unemployed (Brinca, Duarte, & Faria-e-Castro, 2020). In addition, due to the lockdown, many consumers reduced their use of these services, which led to a supply and demand shock. Supply chain implications manifested themselves in three stages (Notteboom, Pallis, & Rodrigue, 2020). In stage one, a supply shock represented a lack of material or goods, with workers forced to stop working due to the lockdown. In stage two, constraints such as trade restrictions, reduced labor, and the closure of main distribution facilities such as airports and ports reduced the distribution capabilities. The final stage was the demand shocks which represented a

surge in demand for goods resulting in commodity shortages.

The transport-related public health considerations were explored in multiple studies (Budd et al., 2020; Cartaud, Quesque, & Coello, 2020; Gupta, Maurya, Mehra, & Kapil, 2021; Kamga & Eickemeyer, 2021; Tirachini & Cats, 2020; Vickerman, 2021). Other interventions that aimed to protect public health and reduce crowding in public spaces are outlined below.

1. Impose travel bans, border closures, wearing of face masks and restrict mass gatherings to reduce people flow and disease spread
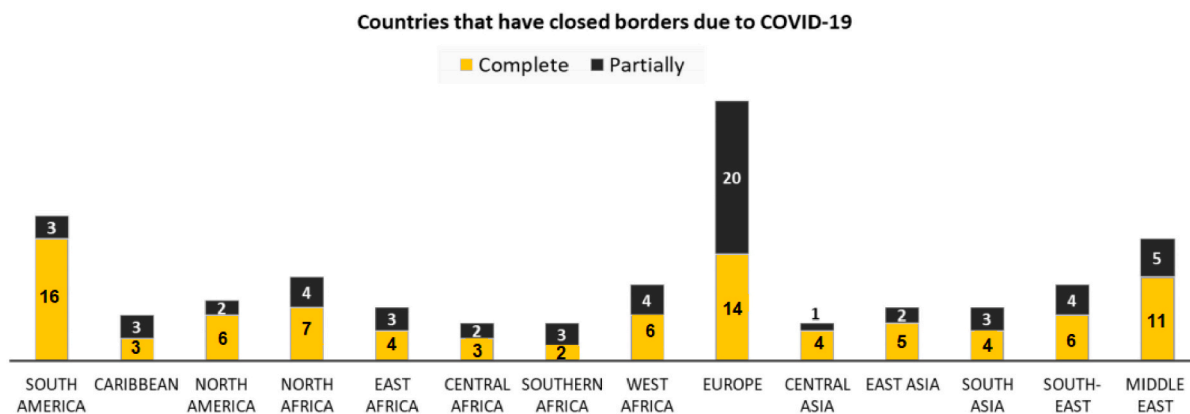
Countries that have closed borders due to COVID-19

Legend: ■ Complete ■ Partially

Bar chart data (Complete / Partially):
- SOUTH AMERICA: 16 / 3
- CARIBBEAN: 3 / 3
- NORTH AMERICA: 6 / 2
- NORTH AFRICA: 7 / 4
- EAST AFRICA: 4 / 3
- CENTRAL AFRICA: 3 / 2
- SOUTHERN AFRICA: 2 / 3
- WEST AFRICA: 6 / 4
- EUROPE: 14 / 20
- CENTRAL ASIA: 4 / 1
- EAST ASIA: 5 / 2
- SOUTH ASIA: 4 / 3
- SOUTH-EAST: 6 / 4
- MIDDLE EAST: 11 / 5

Fig. 6. Countries that closed borders per geographic area due to COVID-19 (Barua, 2020).

2. Offer public transport with lower fares or free and subsidize private operators to run more services and minimize crowding on public transport

3. Redesigning transport operations and services to accommodate changing demand patterns and capacity constraints as a result of COVID-19

4. Avoid interactions between travelers and public transport drivers by providing cashless payments and smartcards to pay for transit

5. Implement more automation such as automatic doors on public transport vehicles, train stations and platforms to reduce the need for contact between passengers and infrastructure

6. Sanitize all transport modes, stations and seating regularly and provide hand sanitizers to all users

7. Provide efficient travel information on measures to mitigate crowding and educate the public about the control measures

8. Implementation of digital technologies such as smartphone apps, drones, visualization tools and machine learning intelligent tools to aid in faster case identification and contact tracing to reduce virus spread on public transport

9. Using thermal temperature scanner and thermal cameras to detect fever in control points such as airports, bus stops, and metro platforms; and

10. Applying risk assessments for different transport modes, lines, and operations and adjust the plans according to the levels of restrictions

In summary, the articles in this cluster focused on intervention strategies and evaluated their impacts on reducing the spread of the virus. A few common limitations and challenges were identified in the methodological approaches used in the literature. Among them, limited availability of datasets on country-based responses and lack of commitment to data sharing are considered critical barriers that must be overcome. Most articles were not based on similar data sets which weakened the comparability between studies. Therefore, issues related to dataset availability and reliability of data limits the opportunity to capture deeper insights and restricts the assessment of less costly and more effective measures. In particular, these studies suffered from either a limited geographical cross-section or a more extensive cross-section but with only a one-dimensional measure of social distancing that cannot identify the impacts of independent effects of different policy types.

Other limitations also include difficulties in collecting data to evaluate child-child contacts. Some studies assumed that every age group contributes equally to transmission, which may not be realistic. Some intervention measures, such as measuring body temperature of public transport passengers suffered from accuracy limitations making them unreliable in the field. When evaluating the effectiveness of intervention strategies on virus spread, considering a number of simultaneous intervention measures would be valuable in removing biases and inaccuracies. This consideration is more challenging when multiple events, such as different pandemic situations, exist simultaneously, overlapping the whole event window compared to single events.

4.2. Cluster 2: travel behavior and mode choice

The countermeasures applied in response to the pandemic had an enormous influence on travel demand and urban mobility trends (Brezina et al., 2020; De Vos, 2020). Significant modal shifts from public transport and from carpool ride-sharing to single-occupancy vehicles were particularly prominent (and concerning), and continue to be a major challenge for cities (Griffiths, Del Rio, & Sovacool, 2021; Hu, Barbour, Samaranayake, & Work, 2020a, 2020b; Cui et al., 2020; Matiza, 2020). According to (Honey-Rosés et al., 2020), COVID-19 had spread from one to nine people on the same long-distance bus trip in China. Hence, people preferred using private vehicles due to the fear of virus spread. Similarly, around 88% of people surveyed in the Netherlands also stated that they preferred to use private transport rather than public or shared modes of transport (de Haas et al., 2020). Transport statistics for Australian households also showed a 7% shift from public transport to active travel modes such as walking or cycling, while the share for private vehicle modes remained unchanged (Beck & Hensher, 2020). Other studies showed that despite increased interest in telecommuting, public transport remained a key mode of urban transport, especially for users with low income who could not work from home (Wołek et al., 2021).

The impact of confinement measures and quarantine rules reduced daily mobility changed modal distribution and people's out-of-home trips, and also changed in-home activities (Abdullah et al., 2020). Even without restrictions, a number of studies showed a high tendency towards virtual activities (Bhaduri, Manoj, Wadud, Goswami, & Choudhury, 2020). In the Netherlands, a study showed that approximately 80% of people had outdoor activities such as grocery shopping (de Haas et al., 2020), while a survey conducted in Spain showed walking time for adults reduced by 16.8%, and other activities were also reduced by 58.2% (Shamshiripour, Rahimi, Shabanpour, & Mohammadian, 2020). Another study discussed the change in frequencies of trips by purpose and showed more trips for eating out and leisure activities rather than shopping or commuting trips (Parady, Taniguchi, & Takami, 2020).

With lockdown measures, the impacts were much more pronounced. The major impacts included replacement of work-related trips with telecommuting (Beck & Hensher, 2020; Hotle, Murray-Tuite, & Singh,

2020; Kamenidou, Stavrianea, & Liava, 2020; Parady et al., 2020; Shamshiripour et al., 2020; Wang & Ozbilen, 2020) and an increase in usage of sustainable modes of transport such as walking and cycling included e-bikes and e-scooters (Bruzzone, Scorrano, & Nocera, 2020; Button, Frye, & Reaves, 2020; Choi, 2020). In addition, work-related, shopping-related and study-related trips were reduced substantially (Ceder, 2020). In some studies, the share of workers who telecommuted in major cities around the world increased from 6% to 39% (de Haas et al., 2020). The reduction in physical travel, as a result of working or shopping online either by choice or by compulsion, led to a major change in peoples' activity-travel patterns. The amount of time spent at home increased substantially while the time spent at workplace and transit hubs experienced a dramatic fall (Beck & Hensher, 2020; Parady et al., 2020). A number of studies showed how working from home affected travel behavior and how people have performed a range of tele-activities without physically travelling (de Haas et al., 2020; Shamshiripour et al., 2020; Wang & Ozbilen, 2020). Governments, educational institutions and businesses are already rethinking the role of the office and providing their employees with opportunities for more flexible working arrangements which can have a positive impact on work-life balance for individuals and also promote sustainable transport solutions by reducing the need for travel particularly for automobile-dependent travelers and employees who can work from home even for few days a week (Beck & Hensher, 2020; Benita, 2021; Fatmi, 2020). The drastic measures adopted by governments during COVID-19 restrictions prompted consumers to shift to online shopping. In Australia, online shopping transactions increased by around 41% in 2020 (eCommerce, 2020). This resulted in increased freight and parcel delivery traffic to meet the increased demand for urban deliveries (Munawar, Khan, Qadir, Kouzani, & Mahmud, 2021). Even though online shopping reduced passenger vehicle kilometres of shopping-related travel, the purchased products still required to be transported and delivered to consumers in vans and freight vehicles (Villa & Monzón, 2021). According to HERE's traffic data, the number of heavy vehicles on roads increased by an average of 8.6% from March to May 2020 (Abu-Rayash & Dincer, 2020; Australian Government, 2020; Jia, Li, Wu, & He, 2021; The Fan Team, 2020). However, the literature on the net impacts (reduction in passenger vehicle travel that is offset by an increase in heavy vehicle delivery travel) is still not conclusive and it is not clear whether there has been a net benefit in terms of reductions vehicle-kilometres of travel and emissions.

When observing the global statistics, by the end of March 2020, there was approximately a 50% reduction in road transport activity compared to 2019. Passenger air travel was reduced by approximately 75% compared to 2019 (Sung & Monschauer, 2020), and that also impacted travel patterns to airports and reduced congestion. A survey conducted in Kelowna, Canada, between the middle of March and the end of April 2020 showed that individual out-of-home travel activities dropped from 3.33 trips per day per person to 1.62 trips per day per person (almost 50% drop) compared to the pre-pandemic period (Fatmi, 2020). In Budapest, urban mobility levels dropped between 51% and 64% in March 2020 (Bucsky, 2020). Similarly, slightly over half of the total trips in Australia disappeared (Barbieri et al., 2020; Beck & Hensher, 2020). A similar finding was reported in Germany where COVID-19 had a major impact on mobility behavior (Schmidt, Sieverding, Wallis, & Matthies, 2021). The authors found an overall reduction in travel on all transport modes compared to pre-pandemic periods, with each transport mode impacted differently.

This momentum, including sustainable mobility measures such as active transport and micro-mobility for short-distance travel, may contribute to long-term effects related to telecommuting and more hyper-local trips (Daher et al., 2021; Kanda & Kivimaa, 2020).

4.2.1. The rise of active travel and micro-mobility as travel mode choices during the pandemic

Analysis of the literature showed a marked increase in the adoption of non-motorized modes of transport such as biking and walking during the pandemic (Nikitas, Tsigdinos, Karolemeas, Kourmpa, & Bako-giannis, 2021; Paydar & Kamani Fard, 2021). In many cases, travelers shifted to walking and cycling to minimize the risk of infection (Niki-foriadis, Ayfantopoulou, & Stamelou, 2020). Cycling showed a significant increase in most cities around Europe, North America and Australia during 2020 (Buehler & Pucher, 2021). It was also noted in the literature that during the course of the pandemic, walking and biking trails were perceived among the very few low-risk spaces that individuals could use and easily access near their residential areas (Doubleday, Choe, Busch Isaksen, Miles, & Errett, 2021).

The emergence of micro-mobility services has attracted substantial attention in recent times (Abduljabbar et al., 2021). Cities around the world are continually embracing "bike-sharing" and "e-scooter" programs in collaboration with commercial partners. These modes of transport provide a socially distant mode of transport which is an appealing aspect for travelers who are concerned about crowding on public transport (Li et al., 2020). In Italy, a study showed bike-sharing systems substituted public transport and were more frequently used than e-scooter sharing systems during the pandemic (Campisi et al., 2020). The study also showed that commuters were inclined to use these services for longer duration trips during the pandemic, with more people shifting to micro-mobility services as a commuting mode choice. Another study which showed that the number of bicycle and scooter trips decreased during quarantine in Spain, also showed that the reduction in these modes was lower than public transport and walking (Aloi et al., 2020). A similar study in New York City showed that bike-sharing was more resilient and had a less significant ridership reduction compared to the subway system (Teixeira & Lopes, 2020). Another study in Budapest, Hungary, showed a reduction of 23% in bike ridership and 2% reduction in bike-sharing ridership compared to an 80% reduction in public transport ridership (Bucsky, 2020) which shows bike-sharing to be more resilient than other modes in terms of sensitivity to reduction in ridership. China, on the other hand, experienced a drastic decrease of 64.8% in bike-sharing ridership due to the COVID-19 crisis (Chai, Guo, Xiao, & Jiang, 2020). Another study that focused on Swedish residents showed that electric bikes were a promising substitute for public transport post the pandemic (Kazemzadeh & Koglin, 2021). In Greece, people who travelled in private cars before the pandemic were found to be more likely to use bike-sharing (Nikiforiadis et al., 2020) during and after the pandemic. Their responses were conditional on providing major steps to enhance operations such as eliminating contact between bike users and staff by developing enhanced technology (mobile apps, for example) to automate the process of hiring/returning a bicycle; ensuring hygiene in the docked/dock-less biking stations by using ultraviolet disinfection, and providing more bike lanes to ensure social distancing between cyclists. Others argued for the health benefits and recommended cycling and active travel should be encouraged to cope with the problems of social separation and limited physical activity (De Vos, 2020) as well as promotion of active transport modes such as biking and walking to school children of all ages (Benita, 2021).

Governments worldwide also implemented other measures, mainly financial assistance and incentives, to accommodate and encourage the increased use of active modes during pandemics (Buehler & Pucher, 2021). The lockdown has driven temporary worldwide strategies, including expansions of cycling and walking infrastructure. Examples included transitioning 35 km of road space to walking and cycling post lockdown in Milan. Many cities had similar strategies and repurposed public areas to add more space for pedestrians and cyclists, such as Vienna, Boston, Oakland, Philadelphia and Minneapolis (Honey-Rosés et al., 2020; Laker, 2020). Over 40 km of car lanes were dedicated to cycle paths from May to November 2020 in Brussels, which led to 44% increase in bike usage (Angiello, 2020). In Australia, Melbourne removed car parking spots and added 12 km of temporary bike lanes (Dunning & Nurse, 2020). More than 50 km of car lanes were shifted to bicycle lanes in Paris. It is also estimated that investments of more than

$325 million were dedicated to updating bicycle networks. Seattle also closed 20 miles of streets for walking and cycling after the lockdown as part of the "Stay Healthy Streets" plan (Bereitschaft & Scheller, 2020). Bogotá installed 76 km of temporary bike lanes and widened its current biking infrastructure (Herman & Drozda, 2021). An installation of more than 320 km has been declared to new pedestrian and bicycle lanes around the city of Montreal. Other cities that adopted bike lane infrastructure changes during the pandemic were Berlin, Oakland, Philadelphia, Denver, Minneapolis, Bogotá, Vancouver and Calgary (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). These infrastructure expansions and improvements that were aimed at building up protected cycling infrastructure, combined with concerns of riding as passengers in crowded public transport services, led to an increase in cycling during the pandemic. Such measures can help increase public confidence in adopting cycling as a legitimate mode of travel post-pandemic (Bera, Bhattacharjee, Shit, Sengupta, & Saha, 2020; Buehler & Pucher, 2021).

Some of the challenges for widespread use of shared micro-mobility, however, included hygiene issues and concerns the virus may be transmitted to users through surface materials of the devices. The timeline where the virus remained active on a material surface varied depending on material type, temperature, humidity and ventilation (Chin et al., 2020; Goldman, 2020; Riddell, Goldie, Hill, Eagles, & Drew, 2020; Watson, 2020).

In summary, this cluster included articles that aimed to understand the impacts of COVID on travel behavior and mode choice. Most of the literature was based on survey data which also had some critical limitations that were mainly associated with data collection methods. When asking questions related to recent events, the respondents would have a recall bias compared to answering questions related to comparatively distant events. The literature also showed that individuals who adhered to physical distancing measures were more likely to be a part of the survey, resulting in selection bias as they may respond in a way that overestimated the measures' impacts. If the survey is spread globally, the scatter and variation due to a geographical location was found to be high as individual counties had different measures and also variable numbers of infected people. Gathering unbiased data that are a true representation of their actual travel behaviors prior to and amid the pandemic was reported to be a real challenge. Another limitation related to survey data included challenges in comparing results of different studies based on paper-based surveys and web-based surveys, as they may have resulted in different categories of respondent groups.

4.3. Cluster 3: public transport

Although the pandemic resulted in a reduction in urban travel, the effects were not uniform across all modes, with public transport being affected the most (Astroza et al., 2020; Molloy et al., 2020). Crowding in enclosed environments such as public transport vehicles and stations can be a hot spot for spreading the virus (Browne, St-Onge Ahmad, Beck, & Nguyen-Van-Tam, 2016; Castilla et al., 2013; Goscé & Johansson, 2018; Zhu, Srebric, Spengler, & Demokritou, 2012). Concern factors that made public transport risky include (Tirachini & Cats, 2020):

- Passengers of public transport vehicles are confined in a limited space
- Asymptomatic passengers pose high risks to other passengers (Ferretti et al., 2020; Javid, Weekes, & Matheson, 2020).
- Even without crowding, public transport stations and vehicles pose other risks in terms of cleanliness of surfaces, vehicle seats, doors, handrails, station benches, ticket machines, all of which can be a source of contamination and risk.

These concerns and also lockdowns have discouraged the use of public transport, including trams, buses, trains and metros. According to (UITP, 2020), the main factors contributing to ridership reduction worldwide were government rules, public perception, working from home and increased usage of private and personal travel modes. Others linked the drop in public transport demand to socio-economic backgrounds and found that senior citizens and those with higher levels of education and higher income reduced their public transport use the most (Almlöf et al., 2020).

Research also showed a 90% drop in the ridership of New York City subway systems as early as April 2020, with daily trip averages of 500,000 trips compared to 5.5 million trips at the beginning of March before the pandemic (Teixeira & Lopes, 2020). Similar studies conducted by New York University showed an 80% reduction in subway and rail ridership as well as a 50% drop in bus ridership in July 2020 compared to 2019. However, the average daily bus ridership was 9% higher than subway ridership in June. Peak ridership reduction for subways was 94% in late March in New York City and Seattle amid stay at home rules (Bernardes et al., 2020; Gao et al., 2020; Gao, Bernardes, Bian, Ozbay, & Iyer, 2020; Wang et al., 2020; Wang, Chen, Zhu, Wang, & Zhang, 2020). Another study showed a decrease in public transport ridership in Sweden (Jenelius & Cebecauer, 2020). Analysis of data collected from smart cards showed a 60% fall in train ridership in both Stockholm and Västra Götaland regions. The decrease in tram ridership was 60% in Stockholm compared to 50% in Västra Götaland. A decrease of around 30% occurred on buses in Västra Götaland compared to a 60% decrease in ridership in Stockholm. Another study in the USA showed that the fixed-line bus ridership dropped at its peak by 66.9% in 2020 compared to 2019 baselines in Nashville before stabilizing at around a 48.4% drop (Wilbur et al., 2020). In Chattanooga, fixed-line bus ridership dropped by 65.1% and then stabilized at around 42.8%. The study also showed that the morning and evening travel times witnessed the highest peak decline, with the reduction varying between socio-economic groups. Ridership drop in highest-income areas was 77% compared to 58% drop in lowest-income areas (Wilbur et al., 2020).

In Metro Boston, ridership dropped to 85% within a week of the pandemic's announcement, and is currently 75% lower compared to pre-pandemic periods (Basu & Ferreira, 2021). In Santander, Spain, a 93% drop was observed in bus commuters and ridership (Aloi et al., 2020). Similarly, Coruña in Spain also witnessed a ridership drop during the pandemic (Orro, Novales, Monteagudo, Pérez-López, & Bugarín, 2020). In Australia, Melbourne witnessed the highest reduction in public transport usage (83.4%) in August 2020 compared to Sydney, where the highest drop (75.4%) was in April 2020. Other cities that experienced a sharp drop in public transport ridership despite strong ridership before the pandemic included Singapore and Budapest (80% reduction in train ridership (Bucsky, 2020; Chong, 2020)); 90% reduction in the Netherlands as the government and transport authorities advised people to use public transport only for essential activities and only if highly necessary (de Haas et al., 2020); 40.6% drop in Seoul, South Korea (Park, 2020); and Colombia (Arellana, Márquez, & Cantillo, 2020).

In Australia, and even with the easing of restrictions, people were found to still be concerned about using public transport, with 58% of commuters still concerned about the cleanliness of public transport (Beck & Hensher, 2020). The authors reported that 33% and 42% of people were not comfortable with using train/light rail and buses, respectively. In China, the virus was found to have spread from one to nine people on the same long-distance bus trip in China (Honey-Rosés et al., 2020). In the Netherland, 88% of people still preferred to use private transport rather than public or shared transport (de Haas et al., 2020).

A recent survey conducted in the United States, Canada, United Kingdom, Spain, France, Germany, Italy, China, and Australia found around 50% of people were uncomfortable using public transport modes post COVID-19 (Wyman, 2020). A similar study conducted in Gdańsk, Poland, investigated people's willingness to use public transport post-pandemic (Przybylowski, Stelmak, & Suchanek, 2021). The results showed that 90% of respondents abandoned or reduced their use of public transport during the pandemic. In addition, around 75% of respondents were willing to use public transport post-pandemic, with the

remaining 25% believing that public transport will not be as safe again (Przybylowski et al., 2021).

The future of public transport, as well as passengers' willingness to accept public transport modes after the pandemic, will be determined primarily by their perceived safety. Targeted transport interventions and policies should aim to improve these perceptions and the positive image of public transport in order to avoid a shift from public transport towards more energy-intensive modes such as private cars. If such a reverse shift happens, it will undo years of progress in building up public transport in cities around the world. These targeted policies can be part of a holistic effort to encourage awareness and rethink urban mobility and urban spaces in the world's cities (Barbarossa, 2020). Fig. 7 shows, for example, how some cities around the world with strong public transport patronage before the pandemic have struggled to attract people to use them during the health crisis. The red lines represent the changes in driving compared to a baseline of January 2020; the purple lines represent the changes in public transport usage, and the yellow lines represent the changes in walking. The diagram shows a consistent trend for avoiding public transport and an increase in private vehicle trips. It is also striking to note that as these cities started to recover from the impacts of the pandemic, the rate of recovery in public transport trips has lagged behind the recovery of private vehicle trips (sometimes by as much as ten times), which is concerning and problematic if this momentum continues, driving becomes the new norm. These impacts are not unique to cities in the developed world, with many cities in developing economies also experiencing a surge in driving.

In summary, the most common method used in the above-mentioned studies is based on surveys and interviews. Most surveys that discussed

the pandemic's effects on public transport excluded some important dimensions. For example, some surveys did not consider the responses for different public transport modes and focused on certain groups of travelers and excluded school children, youths and seniors. Most studies on public transport assumed the journeys were homogenous and ignored the potential effects of individuals' actions during travel such as switching between modes which was observed to be common during the pandemic. Other studies collected information on transport usage, hand washing and sanitizing by personal interviews, a methods that suffers from memory and other reporting biases. The authors also noted a lack of focus on the relationship between micro-mobility and other public transport modes (particularly bus systems) as previous research found evidence of competitiveness between these modes. Important insights were missed in these studies that could have assessed if this competitive relationship persisted or changed during the pandemic. This would have been an important learning for consideration in future emergencies and disruptions.

4.4. Cluster 4: the environment

Starting the first quarter of 2020, governments around the world implemented lockdowns which resulted in a decrease of average road transport activity to about half of 2019 levels. Petrol demand fell by 57%, and in March alone, the oil demand dropped by a record 10.8 mb/d compared to 2019 due to the reduction in air travel, road mobility and marine (International Energy Agency, 2020). According to (Oil and Energy Trends, 2020), the second wave of COVID-19 has hit the United States and Europe the hardest, where mobility reduced to its lowest level
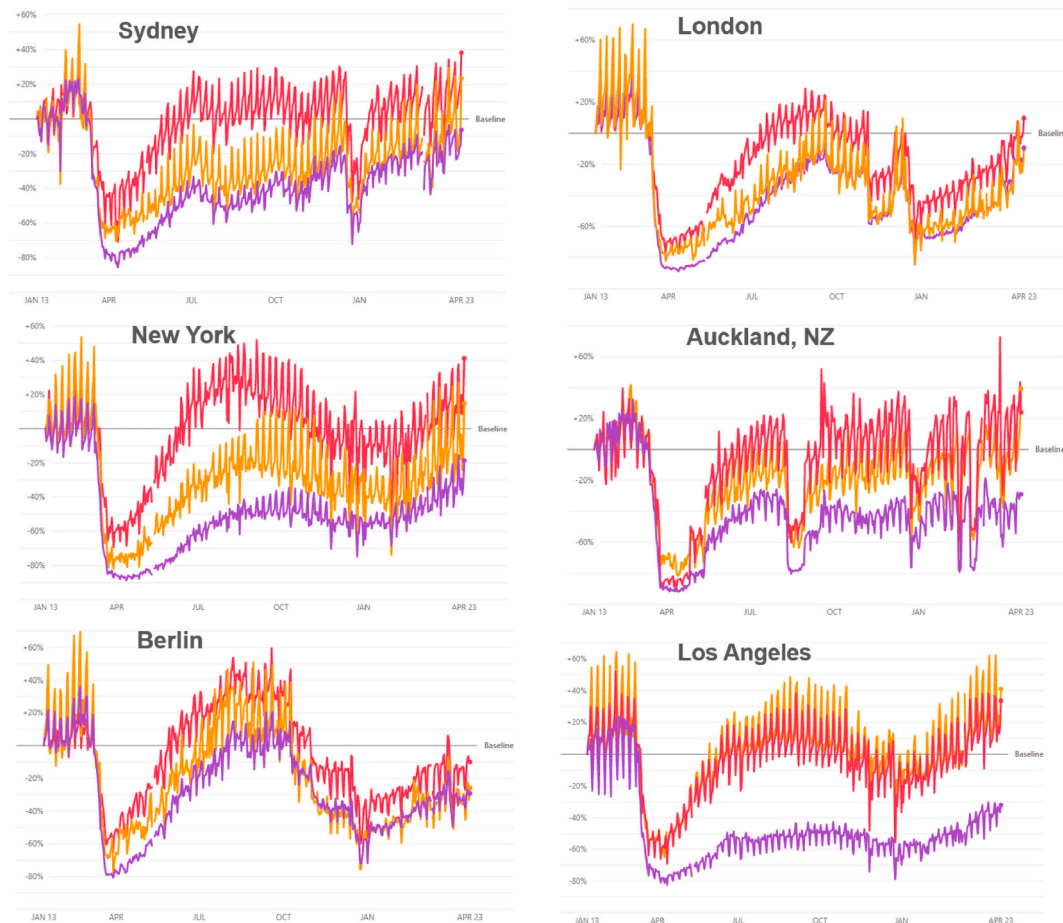

Fig. 7. Percent change in travel compared to January 2020 (red: driving; yellow: walking; purple: public transport).
Source: Apple Maps COVID-19 Mobility Trends (Apple Maps, 2021). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

since the pandemic, which highly impacted the demand for petrol and diesel in some cases by as much as 70% reduction hitting both France and the UK during the lockdown. Out of all countries surveyed, Canada witnessed the least drop in demand compared to other developed countries.

The reduction in travel demands and restrictions that were imposed by many countries resulted in significant traffic volume reductions, which in return reduced air pollution (Anjum, 2020; Chen, Chien, Li, & Lin, 2020; Mahato, Pal, & Ghosh, 2020; Menut et al., 2020; Saadat, Rawtani, & Hussain, 2020) and health-related incidents. There are six key pollutants that affect air quality such as fine particulate matter (PM2.5), coarse particulate matter (PM10), Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2), ground-level Ozone (O3), and Carbon Monoxide (CO). The reductions in these pollutants, which have been linked to serious health issues, including heart and lung problems, resulted in air quality and health improvements (Fann et al., 2012; Khaniabadi et al., 2017).

The literature points to a number of studies specific to some countries and regions, which showed that a reduction in mobility produced a significant drop in emissions. An example of how NO2 emissions, which are primarily emitted from motorized transport activities, have reduced in major cities in Europe, Asia, Africa, Oceania, North and South America, is shown in Fig. 8 (Fu et al., 2020).

A before-and-after study that examined the relationship between traffic volumes and air pollution was recently conducted in eight cities in Canada (Tian, An, Chen, & Tian, 2021). The results showed the demand for transport fuels had decreased during the lockdown period (February–July 2020). The results also showed that CO2 emissions from urban vehicles in Canada had continuously decreased during the lockdown but rebounded after the easing of restrictions. However, the second wave in Canada was expected to cause another reduction in CO2 emissions. Another example is a study in Spain (Aloi et al., 2020) which showed a 60% reduction in NO2 emissions (and interestingly also a 67% reduction in traffic crashes). Another study that examined the air quality

Fig. 8. Percent NO2 reduction in 20 cities worldwide (Fu, Purvis-Roberts, & Williams, 2020).

improvements due to lower traffic volumes in Almaty, Kazakhstan (Kerimray et al., 2020) showed substantial reductions in CO concentrations (49%) and NO2 concentrations (35%). Similar results were noted in a Kolkata, India, study which showed reductions in CO, NO2 and SO2 due to industrial closures and limited transport activities (Bera et al., 2020). The authors also noticed that the level of PM10 and PM2.5 were reduced to a mean average of 17.5% in comparison to pre-pandemic periods. Moreover, Sharma et al. (2020) analyzed the improvements in air quality in 22 cities in India. The results showed an overall reduction of 43% in PM2.5, 31% in PM10, 10% in CO, and 18% in NO2 during the lockdown period with no significant changes in SO2. Likewise, the reduced traffic volumes have contributed to lowering PM10, PM2.5, black carbon (BC), benzene, CO, and NOx in the city of Milan (Collivignarelli et al., 2020). Similar findings were reported for Rio de Janeiro, Brazil, with CO and NO2 levels falling substantially during partial lockdowns (Dantas, Siciliano, França, da Silva, & Arbilla, 2020). Delhi and Wuhan had the highest reduction of NO2 due to strict lockdown rules, vehicular movement and public transport closures. In Fig. 8, cities in blue and green lines had lower reductions in NO2 emissions due to lesser restriction measures. Similar observations were noted in a study that compared the air quality between 2019 and 2020 in six cities that were in early lockdown, including Wuhan, Hong Kong, Kyoto, Milan, Seoul and Shanghai (Cadotte, 2020). The results showed a major reduction in CO, NO2, SO2, PM10 and PM2.5 pollutants. The significant improvements in air quality can lead to considerable health benefits and prevent premature death caused by air pollution. For example, the 25% reduction in air pollution in China can prevent 36,000 monthly premature deaths caused by air pollution, which is more than the monthly death resulting directly from COVID-19 (He, Pan, & Tanaka, 2020). Another study in China showed a reduction in PM2.5 of 9.23 μg/m3 in Beijing, 6.37 μg/m3 in Shanghai, 5.35 μg/m3 in Guangzhou, and 30.79 μg/m3 in Wuhan (Wang, Chen, et al., 2020; Wang, Zuo, et al., 2020). Another study showed that the daily global CO2 emission had been reduced by 26% by April 2020 and was expected to reduce by an additional 4–7% if restrictions were eased by June (Le Quéré et al., 2020). The authors stated that half the decrease in emissions came from limiting vehicle movements. In addition, data from NASA and ESA (European Space Agency) showed a 30% reduction in pollution in impacted cities in Northeast US (Fig. 9) (Muhammad et al., 2020).

Most of these studies also reported that O3 concentration increased during lockdown globally due to a reduction of nitrogen oxides which would usually have removed some of this ozone by reacting with it (Kerimray et al., 2020; Sicard et al., 2020). Even though these resulted in a temporary reprieve, government policies played a major role in enhancing air quality and provided valuable lessons that can be learned in terms of responses that can be applied to maintain future long term environmental benefits, which include limiting private vehicle use and encouraging the use of micro-mobility and active travel solutions (Abduljabbar et al., 2021).

It is noteworthy that the citation analysis also showed that the top-cited articles were all publications related to air quality changes and the global CO2 emissions' reduction during COVID-19, as seen in Table 2 (thus answering RQ1 and RQ2).

In summary, and despite their usefulness, most studies in this cluster relied on limited air quality data in terms of spatial and temporal spread. The main issues associated with environmental data included inadequate automatic air quality measurement stations, non-working manual stations and difficulty to interact with experts and maintenance crews during the outbreak. More investigations are still required on the changes in urban traffic volume and air pollutant concentrations before and after outbreaks. In addition, a better understanding should be drawn towards the consumption of urban transportation fuel and the corresponding CO2 emissions as it will benefit the government in assessing impacts more comprehensively and prepare intervention strategies for potential future outbreaks.
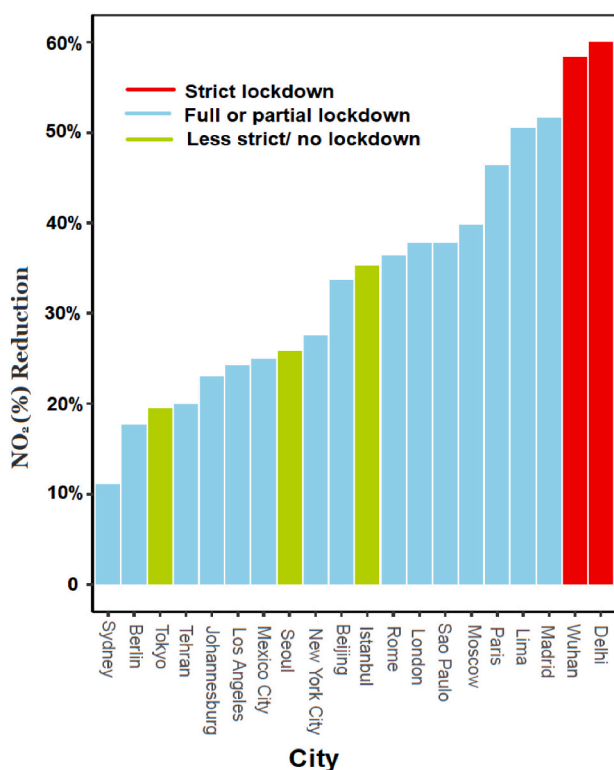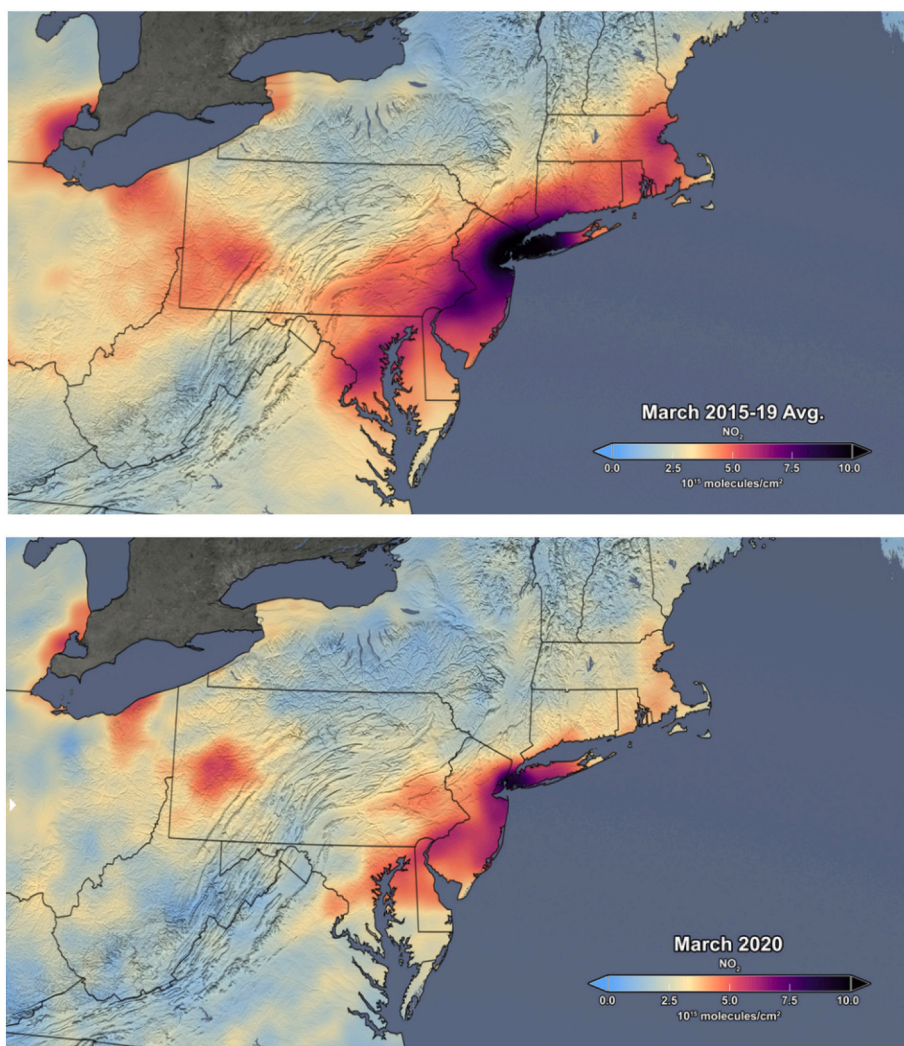
Fig. 9. Average concentrations in March 2020 compared to average concentrations measured between March 2015 and March 19 in Northeast US. Source: NASA.

5. Synthesis, discussion and lesson learned

Using a well-established systematic literature review approach, this paper provided a detailed scan of the literature on how COVID-19 impacted the transport sector. While the topic has attracted the interest of the research community over a relatively short period of time (2020-present), the findings of this study revealed a genuinely strong practical interest since the beginning of the pandemic, culminating in approximately 209 publications in 2020 and 35 publications in January and February 2021. The primary search identified a much larger corpus exceeding 2200 articles. However, many subject areas then had to be excluded to focus specifically on the engineering and urban planning areas, with a total of 445 articles identified as relevant to COVID-related studies in the transport industry.

First, the SLR results which were obtained from keyword co-occurrence showed that for the first half of 2020, the most used keywords included (as expected) the following transport-relevant keywords: "COVID-19", "Coronavirus", "social distancing" "data analysis", "human mobility", "health" and "public transport" particularly for the articles published after mid-2020. For 2021, the most used keywords to date were "bike-sharing", "data mining", "fuel consumption", and "air transport".

The country analysis showed that the top 5 highly cited countries for this topic were China with (832 citations), the US (551 citations), followed India (469 citations), France (330 citations), and the UK (317

citations). The results also showed that China and the US had the largest number of publications comprising of 50 and 45, respectively. This was followed by the UK (22 publications), India (21 publications) and Australia (17 publications). The analysis also identified that the top-cited articles were all publications related to air quality changes and the global CO2 emissions' reduction during COVID-19.

The co-citation analysis categorized the literature in four main transport-related themes: "interventions", "travel behavior and mode choice", "environment", and "public transport". In the "interventions" theme, the publication focused on control measures and policies adopted worldwide during the COVID-19 epidemic and how they impacted the transport sector. The "travel behavior and mode choice" theme included publications that discussed impacts on travel mode choice behavior and analyzed changes in transport behavior during the pandemic. The "environment" cluster focused on the worldwide interest in the impacts on urban transport and air quality and how early and quick interventions reduced pollution. Finally, the "public transport" theme discussed the global public transport planning adaption and the socio-economic factors explaining public transport usage under the COVID-19 pandemic crisis. The bibliographic results also showed strong research interest in air transport, but this was excluded from this article as it was outside the scope of this study in which we focused on urban transport only.

Table 2
Top cited articles.

Document title	Authors	Citations	Year
Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement	Corinne Le Quéré et al.	299	2020
Effect of restricted emissions during COVID-19 on air quality in India	Shubham Sharma et al.	229	2020
COVID-19 pandemic and environmental pollution: A blessing in disguise?	Sulaman Muhammad et al.	208	2020
Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India	Susanta Mahato et al.	182	2020
Severe air pollution events not avoided by reduced anthropogenic activities during the COVID-19 outbreak	Pengfei Wang et al.	159	2020
The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil	Guilherme Dantas et al.	130	2020
Lockdown for CoViD-2019 in Milan: What are the effects on air quality?	Maria Cristina Collivignarelli et al.	111	2020
The environmental perspective of COVID-19	Saeida Saadat et al.	113	2020
Amplified ozone pollution in cities during the COVID-19 lockdown	Pierre Sicard et al.	109	2020
Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan	Aiymgul Kerimray et al.	90	2020

5.1. Research methods

The literature shows that most used methodologies in exploring the impacts of COVID-19 are analytical methods. The literature analyzed and identified current intervention measures, and provided potential solutions that can be adopted by policy makers (e.g. Gkiotsalitis & Cats, 2021). Other methodologies included modelling-based scenarios. For example, agent based models such as MATSim-NYC were explored by Wang, Chen, et al. (2020), Wang, Zuo, et al. (2020), and Wang et al. (2021). These models were used to predict how the pandemic was changing travel behavior before and after lockdown. Also, Fazio et al. (2021) used agent-based models to simulate the spread of COVID-19 under different mobility restriction scenarios. Other publications used statistical methods to analyze ridership and traveler's behaviors such as linear and spatial regression to find factors affecting transit ridership during COVID-19 (Ahangari, Chavis, & Jeihani, 2020; de Souza & Mátrai, 2022; Fissinger, 2020). Descriptive statistics as well as Mann-Whitney *U* tests and Ordinary Least Square (OLS) regression analyses were also used in other studies to analyze the impacts of COVID-19 on bike sharing and subways (Teixeira & Lopes, 2020).

Machine learning techniques were also used to observe and predict the severity of COVID-19 impacts on transport systems. According to Wang, Chen, et al. (2020) and Wang, Zuo, et al. (2020), deep-learning based video-processing algorithms were used to observe and measure social distancing. The input data can be collected from CCTV cameras. Also, K-means clustering algorithms were used by Fissinger (2020) to capture complicated dynamics occurring in the world of urban mobility. Also, the rapid development of big data and complex computational intelligence has created AI models (i.e. deep learning models) that can capture future traffic patterns more accurately than statistical models (Abduljabbar et al., 2021a,b,c; Abduljabbar and Dia, 2019a,b). A study by Mehdizadeh Dastjerdi and Morency (2022) highlighted the importance of using deep learning methods for short term prediction of travel demands to understand the bike-sharing demand changes before and after lockdown.

The data sources used in these studies included:

- Surveys and interviews. Surveys were conducted in the context of a certain city or geography to understand passengers' psychological responses to the resumption of public transport operations after lockdowns (e.g. Dong, Ma, Jia, & Tian, 2021). Another study by Arellana et al. (2020) interviewed operators, managers and academics in the transport field to gather information about their perspectives on how the pandemic had impacted the transport systems and the findings were used to information policy and strategy interventions.
- Ticket validations, sales and passenger count data. These types of data were mainly used to understand the impacts of the pandemic to public transport ridership (Jenelius & Cebecauer, 2020).
- Publicly available data from reliable sources such as government online databases and smartphone apps. For example, Nižetić (2020) collected public data from relevant professional associations that are closely linked with the airline industry, such us the International Air Transport Association's (IATA), to analyze the impacts of COVID-19 on air transport mobility. In addition, Muhammad et al. (2020) analyzed data released by NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) to compare the pollution levels before and after the pandemic. Sung and Monschauer (2020) also studied passenger behavior and travel habits using smartphone apps and compared their total public transport ridership before and after the pandemic.

5.2. Global south versus global north transport interventions

Our analysis has shown some disparity in the impacts of COVID-19 on transport and that vulnerable groups, regions and countries were impacted differently. While the pandemic has affected all cities around the world, the geographic disparities in infections and deaths had an impact on the role of transport during the pandemic (Gaskin, Zare, & Delarmente, 2021). It is particularly noteworthy that the majority of cities in the global south (main cities in developing countries), which have relatively lower automobile ownership and reduced capacity to use private automobiles, have experienced higher use and dependency on public transport modes, resulting in over-utilized regular shared public transport and informal paratransit modes to accommodate the excess mobility demand which regular public transport modes couldn't accommodate. Therefore, during the pandemic, the steps needed to be considered to reduce passenger density in a service vehicle to ensure hygiene and reduce the risk of containment (European Commission, 2020). However, public transport has proved to be the most vulnerable and least resilient mode of transport, particularly in developing countries whose populations had a higher dependency on public transport modes (Babalık, 2020; Mogaji, 2020). Therefore, cities should consider investments in infrastructure that is focused on active travel modes, which opens up the possibility to sustain people's wellbeing and good health and enhance physical activities (Koehl, 2020). Immediately before the current pandemic, the World Health Organization (WHO) named the US and the UK at the top of the global health security index as being the 'best prepared' for the pandemic. However, opposite to this prediction, the global north region was found to have faced (and continue to face) the highest levels of COVID-19 infection and mortality (Carmody, McCann, Colleran, & O'Halloran, 2020). With this, the use of shared mobility and public transport dropped drastically, and people in this region preferred using cars, bicycles and walking (Lozzi et al., 2020). Measures have been taken to operate public transport during the lockdown considering the safety and health of the transport users and transport service staff while maintaining safe physical distance (Islam et al., 2020), proper personnel protective equipment and required training on how to use them properly. Fig. 10 (Hale & Webster, 2020) shows the range of public transport restrictions and measures taken by governments worldwide as of February 2021. The map shows that Russia, France and Germany had eased restrictions; Australia, the United States and Canada were still witnessing some closures and restrictions;
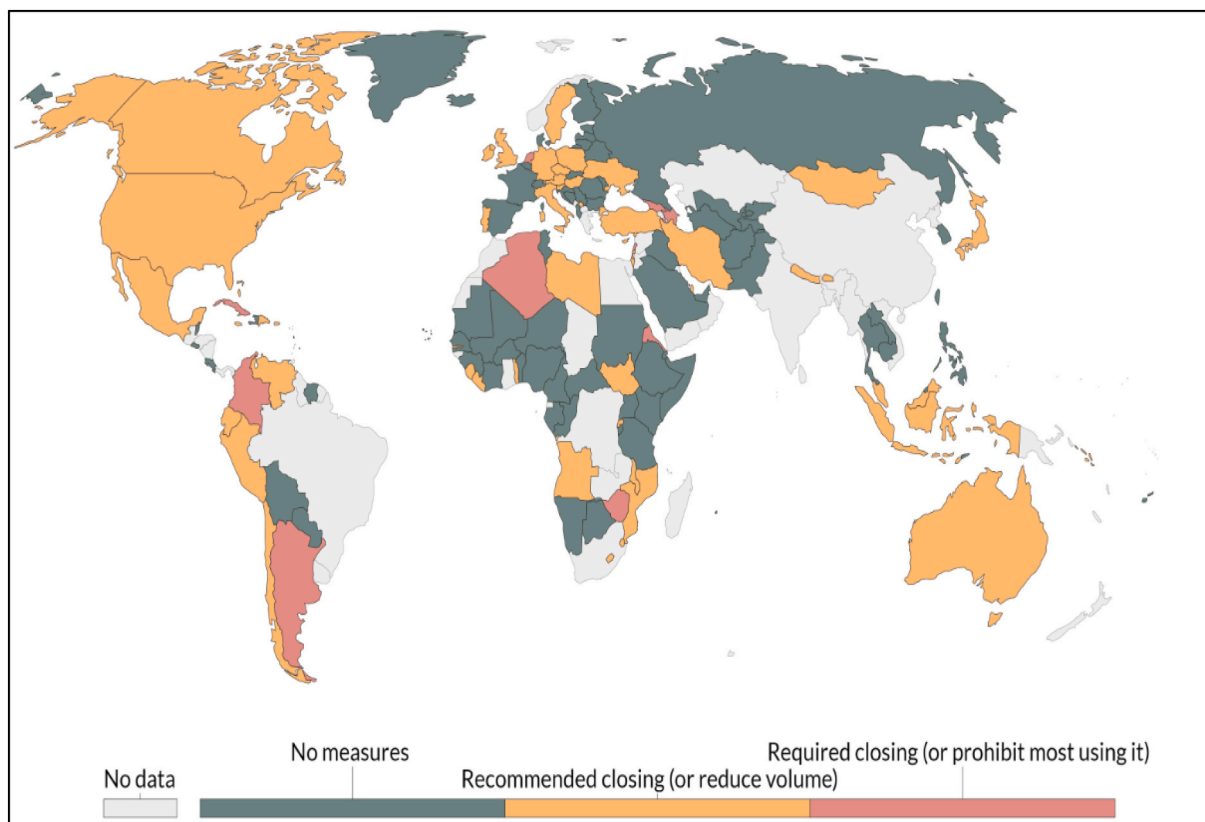
Fig. 10. Government policies on public transport closures (Hale & Webster, 2020).

whereas Colombia, Argentina and Nigeria were heading towards strict closures to control the crisis.

In order to guarantee safe mobility after lockdown, authorities and operators are focused on responding fast to find rapid and efficient solutions. These included proper measures to manage the safe crowding of shared transport vehicles and transport service stations (Bert et al., 2020). Example of such operations includes cities such as Beijing in China which started testing the operation of digital service bookings to control overcrowding and control passenger demand. Hamburg, Germany, adopted a flexible mobility-on-demand approach to provide the service frequently in the high demanded region and less frequently in low demanded areas (Liyanage, Dia, Abduljabbar, & Bagloee, 2019; Lozzi et al., 2020).

5.3. Transport management measures and interventions

Cities that established proper transport management measures during the pandemic were able to provide travelers and staff with much higher levels of safety and protection against the virus. Some of the key measures included running more services to reduce crowding, providing financial incentives to travelers who used public transport outside peak periods, and working with government agencies and other private sector and educational institutions to stagger working hours. More measures included trials of different technologies for automated passenger and staff temperature checks, apps for providing information on crowding and even booking seats in advance on a train, and increased focus on contactless services and more automation.

Other measures included optimizing passenger flow movement to avoid crowding, adequate supply of disinfectants, masks and other protection necessities for passengers and staff, and strengthening ventilation, disinfection and cleaning of passenger stations terminals and service vehicles. There was a generally strong focus on front-line workers who were equipped with gloves, face shields and masks,

disinfectants, and temperature checking equipment. Hand-washing facilities with hand sanitizers were almost always a common feature of a coordinated response and intervention and were made available most commonly at public places. Staff training and health education were also undertaken alongside work supervision and inspection to improve prevention and reduce risks (Shen, Duan, et al., 2020; Shen, Fu, et al., 2020). Also, some authors have also commented how the use of social media and online news information helped in spreading knowledge on prevention and control measures (Shen, Duan, et al., 2020; Shen, Fu, et al., 2020).

6. Research agenda and prospects for post-pandemic cities

The analysis reported in this paper show that urban transport systems have been exposed to key vulnerabilities and shortcomings as a result of the pandemic. Public transport and shared urban mobility solutions, in particular, have been shown to be the least resilient in the face of acute shocks such as the Coronavirus pandemic. Future research will need to consider gaps in knowledge and develop study areas that are aimed at improving the resilience of urban transport in the face of future short-term and long-term acute shocks that might cripple its performance. The analysis presented in this paper provides a transparent framework for appropriately positioning new research activities.

Future research should aim to address these challenges by undertaking important and urgent projects that target immediate, short-term and long-term resilience solutions with lasting positive impacts for global cities. These include the following recommendations and research directions.

6.1. How can public transport patronage be restored amid and post COVID-19?

Smart technologies that aim to manage passenger flows, reduce

waiting times, reduce crowding, and restore passenger confidence in public transport should be investigated in this theme. For example, video analytics can be used to estimate crowding and count the number of passengers waiting to board a service which can help to monitor passenger load restrictions. Apps can be created to determine service crowding to allow passengers to make decisions on which service to board or reserve a seat on a public transport service before departure. Thermal imaging can also be deployed on platforms to detect and isolate travelers with fever before they board public transport services.

6.2. How can working from home become an effective travel demand management strategy to ease congestion and reduce crowding?

Studies under this theme should undertake strategic transport modelling to determine the effectiveness of teleworking as a travel demand management strategy. Representative surveys should be conducted to understand people's travel behavior responses. The results can be used to update the population's travel choices in existing transport models. The models will then be used to test different teleworking scenarios to measure their impacts on reducing traffic congestion and crowding on public transport. The modelling can also be extended to future horizons (e.g. the year 2040) to evaluate the effectiveness of future infrastructure investments that target the transport network resilience and protect it against future threats.

6.3. How can on-demand public transport transform urban and suburban travel?

Studies under this research umbrella should develop and trial emerging modes of on-demand public transport. The project should first undertake extensive operational transport modelling to determine success factors for their deployment as a solution to reduce crowding and reliance on private vehicle trips. The trials should be informed by extensive research and modelling to identify the most suited study areas and the parameters which would lead to a successful outcome amid COVID-19, particularly for outer suburbs that don't have frequent bus services.

6.4. How can the transport infrastructure of the future be against acute shocks?

Studies under this research umbrella should undertake integrated land-use, transport, and environment modelling to evaluate how cities develop and manage their infrastructure to meet higher demands for active modes of travel, including walking and cycling (Dia & Cottman, 2006; Dia, Gondwe, & Panwai, 2008; Dia, Harney, & Boyle, 2001; Smit, Dia, & Morawska, 2009). Research under this category should model the interaction of four key factors: population, land use, transport and environment. Using these models, the influence of land-use patterns amid and post COVID-19 will be reflected in the repurposing or development of transport infrastructure that is commensurate with community values and future visions for metropolitan areas as sustainable cities. Similarly, the models can be used to evaluate how transport interventions will impact urban form and the way people engage in land-use activities amid and post COVID-19.

Research under this theme should also develop an understanding on how a city functions amidst acute shocks and how quickly it recovers from such shocks. The issue of resilience has come into more focus recently during the pandemic particularly around how public transport has been shown to be very fragile and vulnerable, and how it has impacted mobility in cities as people continue to avoid crowded spaces and use their vehicles instead, which is not sustainable. A transport modelling framework can be set up to develop data-driven approaches to evaluate the impacts of such shocks and what interventions would need to be in place to mitigate their impacts. The models would then be used to demonstrate the transformative nature and benefits of a number

of resilient and sustainable transport interventions (e.g. instead of relying on trains we use more tech-based or app-based shared transport that carries smaller numbers of passengers etc.). The models will then be used to test the effectiveness of different strategies and how travelers adapt to their use. Research under this theme should also include stakeholder consultations (members of the public, decision makers, city officials, government agencies) to seek their feedback on model outcomes and the potential strategies that can be put in place to mitigate the impacts of acute shocks. The feedback can also be used to inform the development of pathways and strategies for implementation which would be practical outcomes to help cities and governments use the model to overcome barriers to implementation. These initiatives will rely on advanced modelling tools that would need to be developed as part of research under this theme.

7. Contributions

This paper presented the findings of a bibliometric analysis conducted to support the identification of the most active research related to the impacts of COVID-19 on transport, as well as the range of interventions undertaken and their relative degrees of success. The paper consolidated knowledge on the topic over the period 2020 and early 2021, analyzed research developments and provided guidance for potential future research. The article identified a body of 244 articles that represented key research on COVID-19 and transport in urban environments and conducted a co-citation analysis that categorized the literature into four major research themes that addressed "interventions", "mode choice and travel behavior", "public transport", and the "environment". As a result, this paper serves as a key reference of research over the past 14–16 months (January 2020–February 2021) and consolidates evidence on the subject and a starting point for future research on urban resilience interventions that deal with system vulnerability in the face of acute short and long term shocks.

8. Limitations

Although the majority of authors might have used keywords that mirrored their COVID-related work, it is unavoidable that certain papers would be missed by the search criteria. This was addressed in this paper by also looking at grey literature such as conference papers and technical studies. Another limitation is "publication bias", where more "positive" results are generally published than "negative" results. This can result in a systematic bias which in this study was addressed by consulting the grey literature on the topic, including conference proceedings and technical reports.

9. Conclusions and implications for research and practice

The Coronavirus pandemic has had a significant impact on cities. People changed their habits by telecommuting, doing more local shopping, and travelling only when absolutely necessary. Urban transport will be a particular challenge with recovery efforts. While cities around the world start to open up, many current measures, such as physical separation and group size limits, will remain in place for some time. People will use public transport less as they try to avoid congested areas resulting in a shift to other modes. If public transport is abandoned in favor of private cars, congestion will worsen, and pollution will rise.

This paper provided a rigorous systematic review of empirical evidence on the transport-related impacts and interventions concerning COVID-19. Through bibliometric analysis, influential contributions that shaped the development of this topic are acknowledged and deliberated. The article classified the literature into four distinct categories and consolidated evidence on the COVID-related impacts and interventions. The evidence-based approach helped to undertake unbiased aggregation of empirical results through a review of academic contributions and identification of trends emerging in the field of urban resilience

research. The key benefits of this work also include summarizing the lessons learned to date and identifying the challenges and opportunities going forward. In particular, this review showed that transport systems resilience, specifically public transport longevity and sustainability, will increasingly become the focus of an ignited deliberation on the future of our cities during and in the aftermath of the pandemic.

This paper is an original contribution to the pandemic's transport-related impacts. The paper offers a thorough understanding of the literature and its evolution over the course of the pandemic and the key influencers who shaped the field's research direction. The paper also makes recommendations for future research directions to promote urban resilience as part of sustainable solutions for cities and urban centers. In this process, the article identified a number of gaps in the literature which provide a transparent framework for appropriately positioning future research directions. The pandemic also introduced some big challenges for cities as driving amid the pandemic has spiked. Research pathways that are needed going forward were identified to better understand the drivers of travel change and examine the role of road network pricing in ameliorating traffic congestion and emissions post-pandemic. In addition to the academic contributions of this work, this study provides transport operators, public stakeholders, and transport planners and practitioners' easy access to main topics, trends and ramifications of research sub-themes around the impact of coronavirus crisis on the transition to sustainable urban mobility. The thorough discussion provided in this paper, summarizing the responses during the Coronavirus global pandemic, is aimed at providing a deeper understanding of how to respond to such situations effectively.

Finally, there is a genuine opportunity now to capitalize on the ongoing momentum of positive habit changes. Many previous travel habits will have changed by the time the pandemic is over. The idea that people had to leave their homes every day to go to work has already been debunked. If these new habits are sustained, they have the ability to help us address long-standing problems like traffic congestion and pollution, which have long plagued our urban environments. One of the guiding principles that should underpin recovery efforts is for cities and their citizens to make decisions today that they intend to keep in the future. Cities that capture this momentum increase social infrastructure investment and commit to developing a recovery that rebuilds lives while fostering equity and sustainability will be stronger, more egalitarian, and more resilient in the post-coronavirus world.

CRediT authorship contribution statement

Hussein Dia, Rusul Abduljabbar: Planning and conceptualization. Rusul Abduljabbar: Methodology and generation of results. Rusul Abduljabbar, Sohani Liyanage: Drafting of paper content, editing and updating. Hussein Dia: Reviewing, editing, and structuring. Hussein Dia: Supervision and mentoring of the two research students.

Data availability statement

The following link includes the list of articles that were used in this study. https://bit.ly/2RXNm9k

Declaration of competing interest

The authors declare that there are no known conflicts of interest that can influence the work presented in this research.

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References

Abduljabbar, R. L., & Dia, H. (2019a). Predictive Intelligence: A neural network learning system for traffic condition prediction and monitoring on freeways. *Journal of the Eastern Asia Society for Transportation Studies, 13*, 1785–1800.

Abduljabbar, R. L., & Dia, H. (2019, October). A deep learning approach for freeway vehicle speed and flow prediction. In *Proceedings of the Australasian Transport Research Forum (ATRF), 41st*.

Abduljabbar, R. L., & Dia, H. (2021). A bibliometric overview of IEEE transactions on intelligent transportation systems (2000-2021). *IEEE Transactions on Intelligent Transportation Systems*.

Abduljabbar, R. L., Liyanage, S., & Dia, H. (2021). The role of micro-mobility in shaping sustainable cities: A systematic literature review. *Transportation Research Part D: Transport and Environment, 92*. https://doi.org/10.1016/j.trd.2021.102734

Abduljabbar, R. L., Dia, H., Tsai, P. W., & Liyanage, S. (2021a). Short-term traffic forecasting: An LSTM network for spatial-temporal speed prediction. *Future Transportation, 1*(1), 21–37.

Abduljabbar, R. L., Dia, H., & Tsai, P. W. (2021b). Development and evaluation of bidirectional LSTM freeway traffic forecasting models using simulation data. *Scientific Reports, 11*(1), 1–16.

Abduljabbar, R. L., Dia, H., & Tsai, P. W. (2021c). Unidirectional and bidirectional LSTM models for short-term traffic prediction. *Journal of Advanced Transportation, 2021*.

Abdullah, M., Dias, C., Muley, D., & Shahin, M. (2020). Exploring the impacts of COVID-19 on travel behavior and mode preferences. *Transportation Research Interdisciplinary Perspectives, 8*, Article 100255. https://doi.org/10.1016/j.trip.2020.100255

Abu-Rayash, A., & Dincer, I. (2020). Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities. *Energy Research and Social Science, 68*, Article 101693. https://doi.org/10.1016/j.erss.2020.101693

Acuna-Zegarra, M. A., Comas-Garcia, A., Hernandez-Vargas, E., Santana-Cibrian, M., & Velasco-Hernandez, J. X. (2020). *The SARS-CoV-2 epidemic outbreak: A review of plausible scenarios of containment and mitigation for Mexico*. medRxiv. https://doi.org/10.1101/2020.03.28.20046276

Ahangari, S., Chavis, C., & Jeihani, M. (2020). *Public transit ridership analysis during the COVID-19 pandemic*. Medrxiv.

Ai, S., Zhu, G., Tian, F., Li, H., Gao, Y., Wu, Y., Liu, Q., & Lin, H. (2020). *Population movement, city closure and spatial transmission of the 2019-nCoV infection in China*. MedRxiv. https://doi.org/10.1101/2020.02.04.20020339

Alawadhi, M., Almazrouie, J., Kamil, M., & Khalil, K. A. (2020). Review and analysis of the importance of autonomous vehicles liability: A systematic literature review. *International Journal of Systems Assurance Engineering and Management, 11*, 1227–1249. https://doi.org/10.1007/s13198-020-00978-9

Almlöf, E., Rubensson, I., Cebecauer, M., & Jenelius, E. (2020). *Who is still travelling by public transport during COVID-19? Socioeconomic Factors explaining travel behaviour in stockholm based on smart card data. Socioecon. Factors Explain. Travel Behav. Stock. Based smart card data (September 8, 2020)*. https://doi.org/10.2139/ssrn.3689091

Aloi, A., Alonso, B., Benavente, J., Cordera, R., Echániz, E., González, F., Ladisa, C., Lezama-Romanelli, R., López-Parra, Á., & Mazzei, V. (2020). Effects of the COVID-19 lockdown on urban mobility: empirical evidence from the city of Santander (Spain). *Sustainability, 12*, 3870. https://doi.org/10.3390/su12093870

Angiello, G. (2020). Toward greener and pandemic-proof cities: Italian cities policy responses to Covid-19 pandemic. *TEMA Journal of Land Use, Mobility and Environment, 13*, 271–280. https://doi.org/10.6092/1970-9870/7047

Anjum, N. A. (2020). *Good in the worst: COVID-19 restrictions and ease in global air pollution*. Prepr. 2020.

Arellana, J., Márquez, L., & Cantillo, V. (2020). COVID-19 outbreak in Colombia: An analysis of its impacts on transport systems. *Journal of Advanced Transportation, 2020*. https://doi.org/10.1155/2020/8867316

Arimura, M., Ha, T. V., Okumura, K., & Asada, T. (2020). Changes in urban mobility in Sapporo city, Japan due to the Covid-19 emergency declarations. *Transportation Research Interdisciplinary Perspectives, 7*, Article 100212. https://doi.org/10.1016/j.trip.2020.100212

Askitas, N., Tatsiramos, K., & Verheyden, B. (2021). Estimating worldwide effects of non-pharmaceutical interventions on COVID-19 incidence and population mobility patterns using a multiple-event study. *Scientific Reports, 11*, 1–13. https://doi.org/10.1038/s41598-021-81442-x

Astroza, S., Tirachini, A., Hurtubia, R., Carrasco, J. A., Guevara, A., Figueroa, M., & Torres, V. (2020). Mobility changes, teleworking, and remote communication during the COVID-19 pandemic in Chile. *Santiago (Greater Urban Area), 3*, 73.

Australian Government. (2020). *Australia's emissions projections 2020*.

Babalık, E. (2020). Urban mobility after COVID-19: A developing-country perspective. *The Town Planning Review*, 165–170. https://doi.org/10.3828/tpr.2020.33

Bala, M., & Verma, D. (2018). A critical review of digital marketing. *International Journal of Management, IT & Engineering, 8*(10), 321–339.

Barbarossa, L. (2020). The post pandemic city: Challenges and opportunities for a non-motorized urban environment. An overview of italian cases. *Sustainability, 12*, 7172. https://doi.org/10.3390/su12177172. preprint.

Barbieri, D. M., Lou, B., Passavanti, M., Hui, C., Lessa, D. A., Maharaj, B., Banerjee, A., Wang, F., Chang, K., & Naik, B. (2020). A survey dataset to evaluate the changes in mobility and transportation due to COVID-19 travel restrictions in Australia, Brazil, China, Ghana, India, Iran, Italy, Norway, South Africa, United States. *Data in Brief, 33*, Article 106459. https://doi.org/10.1016/j.dib.2020.106459

Barua, S. (2020). *COVID-19 pandemic and world trade: Some analytical notes*. https://doi.org/10.2139/ssrn.3577627. Available SSRN 3577627.

Basu, R., & Ferreira, J. (2021). Sustainable mobility in auto-dominated Metro Boston: Challenges and opportunities post-COVID-19. *Transport Policy, 103*, 197–210. https://doi.org/10.1016/j.tranpol.2021.01.006

Batty, M. (2020). The Coronavirus crisis: What will the post-pandemic city look like? *Environment and Planning B: Urban Analytics and City Science, 47*(4), 547–552. https://doi.org/10.1177/2399808320926912

Beck, M. J., & Hensher, D. A. (2020). Insights into the impact of COVID-19 on household travel and activities in Australia-The early days under restrictions. *Transport Policy, 96*, 76–93. https://doi.org/10.1016/j.tranpol.2020.07.001

Benita, F. (2021). Human mobility behavior in COVID-19: A systematic literature review and bibliometric analysis. *Sustainable Cities and Society, 70*, Article 102916. https://doi.org/10.1016/j.scs.2021.102916

Bera, B., Bhattacharjee, S., Shit, P. K., Sengupta, N., & Saha, S. (2020). Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. *Environment, Development and Sustainability, 1–28*. https://doi.org/10.1007/s10668-020-00898-5

Bereitschaft, B., & Scheller, D. (2020). How might the COVID-19 pandemic affect 21st century urban design, planning, and development? *Urban Science, 4*, 56. https://doi.org/10.3390/urbansci4040056

Bernardes, S. D., Bian, Z., Thambiran, S. S. M., Gao, J., Na, C., Zuo, F., Hudanich, N., Bhattacharyya, A., Ozbay, K., & Iyer, S. (2020). *NYC recovery at a glance: The rise of buses and micromobility*. preprint.

Bert, J., Schellong, D., Hagenmaier, M., Hornstein, D., Wegscheider, A. K., & Palme, T. (2020). How COVID-19 will shape urban mobility. *City, 25*, 21–28.

Betkier, I. (2020). Safety of urban transport users during the Covid-19 pandemic. *European Research Studies Journal, 99–115*. https://doi.org/10.35808/ersj/1856

Bhaduri, E., Manoj, B. S., Wadud, Z., Goswami, A. K., & Choudhury, C. F. (2020). Modelling the effects of COVID-19 on travel mode choice behaviour in India. *Transportation Research Interdisciplinary Perspectives, 8*, Article 100273. https://doi.org/10.1016/j.trip.2020.100273

Borkowski, P., Jażdżewska-Gutta, M., & Szmelter-Jarosz, A. (2021). Lockdowned: Everyday mobility changes in response to COVID-19. *Journal of Transport Geography, 90*, Article 102906. https://doi.org/10.1016/j.jtrangeo.2020.102906

Brezina, T., Shibayama, T., Leth, U., Fabian, S., Laa, B., Kapfenberger, M., … Emberger, G. (2020). *Dataset: International survey on covid-19 lockdowns and mobility behaviour*. https://doi.org/10.17632/hkb3923nj3.1

Brinca, P., Duarte, J. B., & Faria-e-Castro, M. (2020). *Is the COVID-19 pandemic a supply or a demand shock?*. https://doi.org/10.20955/es.2020.31. Available SSRN 3612307.

Browne, A., St-Onge Ahmad, S., Beck, C. R., & Nguyen-Van-Tam, J. S. (2016). The roles of transportation and transportation hubs in the propagation of influenza and coronaviruses: A systematic review. *Journal of Travel Medicine, 23*, Article tav002. https://doi.org/10.1093/jtm/tav002

Bruzzone, F., Scorrano, M., & Nocera, S. (2020). The combination of e-bike-sharing and demand-responsive transport systems in rural areas: A case study of Velenje. *Research in Transportation Business and Management, 100570*. https://doi.org/10.1016/j.rtbm.2020.100570

Buchholz, K. (2020). *What share of the world population is already on COVID-19 lockdown? [WWW Document]*. URL. Statista (accessed 4.11.20) https://www.statista.com/chart/21240/enforced-covid-19-lockdowns-by-people-affected-per-country/.

Bucsky, P. (2020). Modal share changes due to COVID-19: The case of Budapest. *Transportation Research Interdisciplinary Perspectives, 8*, Article 100141. https://doi.org/10.1016/j.trip.2020.100141

Budd, J., Miller, B. S., Manning, E. M., Lampos, V., Zhuang, M., Edelstein, M., Rees, G., Emery, V. C., Stevens, M. M., & Keegan, N. (2020). Digital technologies in the public-health response to COVID-19. *Nature Medicine, 26*, 1183–1192. doi:1. Budd, J., Miller, B.S., Manning, E.M., Lampos, V., Zhuang, M., Edelstein, M., Rees, G., Emery, V.C., Stevens, M.M., Keegan, N., 2020. Digital technologies in the public-health response to COVID-19. Nat. Med. 26, 1183–1192.

Buehler, R., & Pucher, J. (2021). COVID-19 impacts on cycling, 2019–2020. *Transport Reviews*. https://doi.org/10.1080/01441647.2021.1914900

Button, K., Frye, H., & Reaves, D. (2020). Economic regulation and E-scooter networks in the USA. *Research in Transportation Economics, 100973*. https://doi.org/10.1016/j.retrec.2020.100973

Cadotte, M. (2020). *Early evidence that COVID-19 government policies reduce urban air pollution*. Earth Arxiv. https://doi.org/10.31223/osf.io/nhgj3

Campisi, T., Basbas, S., Skoufas, A., Akgün, N., Ticali, D., & Tesoriere, G. (2020). The impact of COVID-19 pandemic on the resilience of sustainable mobility in sicily. *Sustainability, 12*, 8829. https://doi.org/10.3390/su12218829

Carmody, P., McCann, G., Colleran, C., & O'Halloran, C. (2020). *COVID-19 in the Global South: Impacts and responses*. Bristol University Press.

Cartaud, A., Quesque, F., & Coello, Y. (2020). *Beware of virus! Wearing a face mask against COVID-19 results in a reduction of social distancing*. PsyArXiv. https://doi.org/10.31234/osf.io/ubzea

Castilla, J., Godoy, P., Domínguez, Á., Martín, V., Delgado-Rodríguez, M., Martínez-Baz, I., Baricot, M., Soldevila, N., Mayoral, J. M., & Astray, J. (2013). Risk factors and effectiveness of preventive measures against influenza in the community. *Influenza and Other Respiratory Viruses, 7*, 177–183. https://doi.org/10.1111/j.1750-2659.2012.00361.x

Ceder, A. (2020). Urban mobility and public transport: Future perspectives and review. *International Journal of Urban Sciences, 1–25*. https://doi.org/10.1080/12265934.2020.1799846

Cerigo, H., & Quesnel-Vallée, A. (2020). Systematic mixed studies reviews: Leveraging the literature to answer complex questions through the integration of quantitative and qualitative evidence. *International Journal of Public Health, 65*, 699–703. https://doi.org/10.1007/s00038-020-01386-3

Chai, X., Guo, X., Xiao, J., & Jiang, J. (2020). *Analysis of spatial-temporal behavior pattern of the share bike usage during COVID-19 pandemic in Beijing*. e-prints.

Chen, L.-W. A., Chien, L.-C., Li, Y., & Lin, G. (2020). Nonuniform impacts of COVID-19 lockdown on air quality over the United States. *The Science of the Total Environment, 745*, Article 141105. https://doi.org/10.1016/j.scitotenv.2020.141105

Chin, A., Chu, J., Perera, M., Hui, K., Yen, H.-L., Chan, M., Peiris, M., & Poon, L. (2020). *Stability of SARS-CoV-2 in different environmental conditions*. MedRxiv. https://doi.org/10.1016/S2666-5247(20)30003-3

Choi, T.-M. (2020). Innovative "bring-service-near-your-home" operations under coronavirus (COVID-19/SARS-CoV-2) outbreak: Can logistics become the messiah? *Transportation Research Part E-Logistics & Transportation Review, 140*, Article 101961. https://doi.org/10.1016/j.tre.2020.101961

Chong, C. (2020). *Train ridership down by 80% since coronavirus outbreak started [WWW document]*. Transp. Minist. Khaw. Straitstimes. URL https://www.straitstimes.com/singapore/train-ridership-fell-80-since-coronavirus-outbreak-started-but-upside-was-good-safe. (accessed 5.30.20).

Collivignarelli, M. C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., & Miino, M. C. (2020). Lockdown for CoViD-2019 in Milan: What are the effects on air quality? *The Science of the Total Environment, 732*, Article 139280. https://doi.org/10.1016/j.scitotenv.2020.139280

Cui, Z., Zhu, M., Wang, S., Wang, P., Zhou, Y., Cao, Q., Kopca, C., & Wang, Y. (2020). *Traffic performance score for measuring the impact of COVID-19 on urban mobility*. preprint.

Daher, C., Koch, S., Ferri, M., Vich, G., Foraster, M., Carrasco, G., Khomenko, S., Baraibar, S., Hidalgo, L., & Nieuwenhuijsen, M. (2021). Mobility and COVID-19: Time for a mobility paradigm shift. Urban Heal. Wellbeing Program. *Policy Briefs, 2*, 29. https://doi.org/10.1007/978-981-33-6036-5_6

Dantas, G., Siciliano, B., França, B. B., da Silva, C. M., & Arbilla, G. (2020). The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *The Science of the Total Environment, 729*, Article 139085. https://doi.org/10.1016/j.scitotenv.2020.139085

de Haas, M., Faber, R., & Hamersma, M. (2020). How COVID-19 and the Dutch 'intelligent lockdown'change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands. *Transportation Research Interdisciplinary Perspectives, 6*, Article 100150. https://doi.org/10.1016/j.trip.2020.100150

de Souza, R. N., & Mátrai, T. (2022). Impacts of the COVID-19 pandemic in the demand for urban transportation in Budapest. *Transportation Research Procedia, 62*, 99–106.

De Vos, J. (2020). The effect of COVID-19 and subsequent social distancing on travel behavior. *Transportation Research Interdisciplinary Perspectives, 5*, Article 100121. https://doi.org/10.1016/j.trip.2020.100121

Desvars-Larrive, A., Dervic, E., Haug, N., Niederkrotenthaler, T., Chen, J., Di Natale, A., Lasser, J., Gliga, D. S., Roux, A., & Sorger, J. (2020). A structured open dataset of government interventions in response to COVID-19. *Scientific Data, 7*, 1–9. https://doi.org/10.1038/s41597-020-00609-9

Dia, H. (2020). *Coronavirus recovery: Public transport is key to avoid repeating old and unsustainable mistakes [WWW document]*. URL. Conversat https://theconversation.com/coronavirus-recovery-public-transport-is-key-to-avoid-repeating-old-and-un sustainable-mistakes-138415.

Dia, H., & Cottman, N. (2006). Evaluation of arterial incident management impacts using traffic simulation. In *IEE proceedings-intelligent transport systems* (pp. 242–252). IET. https://doi.org/10.1049/ip-its:20055005.

Dia, H., Gondwe, W., & Panwai, S. (2008). Traffic impact assessment of incident management strategies. In *2008 11th international IEEE conference on intelligent transportation systems* (pp. 441–446). https://doi.org/10.1109/ITSC.2008.4732621

Dia, H., Harney, D., & Boyle, A. (2001). Dynamics of drivers' route choice decisions under advanced traveller information systems. *Road Transport Research, 10*, 3.

Dong, H., Ma, S., Jia, N., & Tian, J. (2021). Understanding public transport satisfaction in post COVID-19 pandemic. *Transport Policy, 101*, 81–88.

Doubleday, A., Choe, Y., Busch Isaksen, T., Miles, S., & Errett, N. A. (2021). How did outdoor biking and walking change during COVID-19?: A case study of three US cities. *PLoS One, 16*, Article e0245514. https://doi.org/10.1371/journal.pone.0245514

Dunning, R., & Nurse, A. (2020). The surprising availability of cycling and walking infrastructure through COVID-19. *The Town Planning Review*. https://doi.org/10.3828/tpr.2020.35

eCommerce. (2020). *Inside Australian online shopping*.

Eisenmann, C., Nobis, C., Kolarova, V., Lenz, B., & Winkler, C. (2021). Transport mode use during the COVID-19 lockdown period in Germany: The car became more important, public transport lost ground. *Transport Policy, 103*, 60–67. https://doi.org/10.1016/j.tranpol.2021.01.012

European Commission. (2020). *Joint European Roadmap towards lifting COVID-19 containment measures [WWW document]*. URL. EU Comm (accessed 5.20.20) https://www.clustercollaboration.eu/news/joint-european-roadmap-towardslifting-covid-19-containment-measures.

Fann, N., Lamson, A. D., Anenberg, S. C., Wesson, K., Risley, D., & Hubbell, B. J. (2012). Estimating the national public health burden associated with exposure to ambient PM2. 5 and ozone. *Risk Analysis, 32*, 81–95. https://doi.org/10.1111/j.1539-6924.2011.01630.x

Fatmi, M. R. (2020). COVID-19 impact on urban mobility. *Journal of Urban Management, 9*, 270–275. https://doi.org/10.1016/j.jum.2020.08.002

Fazio, M., Pluchino, A., Inturri, G., Pira, M. L., Giuffrida, N., & Ignaccolo, M. (2021). *Exploring the impact of mobility restrictions on the COVID-19 spreading through an agent-based approach*. arXiv preprint arXiv:2102.08226.

Ferretti, L., Wymant, C., Kendall, M., Zhao, L., Nurtay, A., Abeler-Dörner, L., Parker, M., Bonsall, D., & Fraser, C. (2020). Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. *Science (80-.), 368*.

Fissinger, M. R. (2020). *Behavioral dynamics of public transit ridership in Chicago and impacts of COVID-19*. Massachusetts Institute of Technology. Doctoral dissertation.

Fu, F., Purvis-Roberts, K. L., & Williams, B. (2020). Impact of the covid-19 pandemic lockdown on air pollution in 20 major cities around the world. *Atmosphere (Basel), 11*, 1189. https://doi.org/10.3390/atmos11111189

Gao, J., Bernardes, S. D., Bian, Z., Ozbay, K., & Iyer, S. (2020). *Initial impacts of COVID-19 on transportation systems: A case study of the US Epicenter, the New York Metropolitan Area*. preprint.

Gao, J., Wang, J., Bian, Z., Bernardes, S. D., Chen, Y., Bhattacharyya, A., Thambiran, S. S. M., Ozbay, K., & Iyer, S. (2020). *The effects of the COVID-19 pandemic on transportation systems in New York City and Seattle, USA*. preprint.

Gaskin, D. J., Zare, H., & Delarmente, B. A. (2021). Geographic disparities in COVID-19 infections and deaths: The role of transportation. *Transport Policy, 102*, 35–46. https://doi.org/10.1016/j.tranpol.2020.12.001

Gkiotsalitis, K., & Cats, O. (2021). Public transport planning adaption under the COVID-19 pandemic crisis: literature review of research needs and directions. *Transport Reviews, 41*(3), 374–392.

Goldman, E. (2020). Exaggerated risk of transmission of COVID-19 by fomites. *The Lancet Infectious Diseases, 20*, 892–893. https://doi.org/10.1016/S1473-3099(20)30561-2

Goscé, L., & Johansson, A. (2018). Analysing the link between public transport use and airborne transmission: Mobility and contagion in the London underground. *Environmental Health, 17*, 1–11. https://doi.org/10.1186/s12940-018-0427-5

Griffiths, S., Del Rio, D. F., & Sovacool, B. (2021). Policy mixes to achieve sustainable mobility after the COVID-19 crisis. *Renewable and Sustainable Energy Reviews. , Article 110919.* https://doi.org/10.1016/j.rser.2021.110919

Gupta, A., Maurya, S., Mehra, N., & Kapil, D. (2021). COVID-19: Employee fever detection with thermal camera integrated with attendance management system. In *2021 11th international conference on cloud computing, data science & engineering (confluence)* (pp. 355–361). IEEE. https://doi.org/10.1109/Confluence51648.2021.9377079.

Gurevitch, J., Koricheva, J., Nakagawa, S., & Stewart, G. (2018). Meta-analysis and the science of research synthesis. *Nature, 555*, 175–182. https://doi.org/10.1038/nature25753

Hadjidemetriou, G. M., Sasidharan, M., Kouyialis, G., & Parlikad, A. K. (2020). The impact of government measures and human mobility trend on COVID-19 related deaths in the UK. *Transportation Research Interdisciplinary Perspectives, 6*, Article 100167. https://doi.org/10.1016/j.trip.2020.100167

Hale, T., & Webster, S. (2020). *Oxford COVID-19 government response tracker*. Blavatnik Sch. Gov.

Haug, N., Geyrhofer, L., Londei, A., Dervic, E., Desvars-Larrive, A., Loreto, V., Pinior, B., Thurner, S., & Klimek, P. (2020). Ranking the effectiveness of worldwide COVID-19 government interventions. *Nature Human Behaviour, 4*, 1303–1312. https://doi.org/10.1038/s41562-020-01009-0

He, G., Pan, Y., & Tanaka, T. (2020). *COVID-19, city lockdowns, and air pollution: Evidence from China*. medRxiv. https://doi.org/10.1101/2020.03.29.20046649

Herman, K., & Drozda, Ł. (2021). Green infrastructure in the time of social distancing: Urban policy and the tactical pandemic urbanism. *Sustainability, 13*, 1632. https://doi.org/10.3390/su13041632

Honey-Rosés, J., Anguelovski, I., Chireh, V. K., Daher, C., Konijnendijk van den Bosch, C., Litt, J. S., Mawani, V., McCall, M. K., Orellana, A., & Oscilowicz, E. (2020). The impact of COVID-19 on public space: An early review of the emerging questions–design, perceptions and inequities. *Cities & Health, 1–17.* https://doi.org/10.1080/23748834.2020.1780074

Hotle, S., Murray-Tuite, P., & Singh, K. (2020). Influenza risk perception and travel-related health protection behavior in the US: Insights for the aftermath of the COVID-19 outbreak. *Transportation Research Interdisciplinary Perspectives, 5*, Article 100127. https://doi.org/10.1016/j.trip.2020.100127

Hu, Y., Barbour, W., Samaranayake, S., & Work, D. (2020). *Impacts of Covid-19 mode shift on road traffic*. preprint.

Hu, Y., Barbour, W., Samaranayake, S., & Work, D. (2020). *The rebound - how Covid-19 could lead toworse traffic, a transportation cyber physical systems lab at the Institute for Software Integrated Systems Vanderbilt University*.

International Energy Agency. (2020). *Global energy review 2020: The impacts of the Covid-19 crisis on global energy demand and CO2 emissions*.

Islam, N., Sharp, S. J., Chowell, G., Shabnam, S., Kawachi, I., Lacey, B., Massaro, J. M., D'Agostino, R. B., & White, M. (2020). Physical distancing interventions and incidence of coronavirus disease 2019: Natural experiment in 149 countries. *BMJ, 370*. https://doi.org/10.1136/bmj.m2743

Jallow, H., Renukappa, S., & Suresh, S. (2020). The impact of COVID-19 outbreak on United Kingdom infrastructure sector. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-05-2020-0068

Jarvis, C. I., Van Zandvoort, K., Gimma, A., Prem, K., Klepac, P., Rubin, G. J., & Edmunds, W. J. (2020). Quantifying the impact of physical distance measures on the transmission of COVID-19 in the UK. *BMC Medicine, 18*, 1–10. https://doi.org/10.1186/s12916-020-01597-8

Javid, B., Weekes, M. P., & Matheson, N. J. (2020). Covid-19: should the public wear face masks? *British Medical Journal*. https://doi.org/10.1136/bmj.m1442

Jenelius, E., & Cebecauer, M. (2020). Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts. *Transportation Research Interdisciplinary Perspectives, 8*, Article 100242. https://doi.org/10.1016/j.trip.2020.100242

Jia, C., Li, W., Wu, T., & He, M. (2021). Road traffic and air pollution: Evidence from a nationwide traffic control during coronavirus disease 2019 outbreak. *The Science of the Total Environment, 781*, Article 146618. https://doi.org/10.1016/j.scitotenv.2021.146618

Kamenidou, I. E., Stavrianea, A., & Liava, C. (2020). Achieving a Covid-19 free country: Citizens preventive measures and communication pathways. *International Journal of Environmental Research and Public Health, 17*, 4633. https://doi.org/10.3390/ijerph17134633

Kamga, C., & Eickemeyer, P. (2021). Slowing the spread of COVID-19: Review of "social distancing" interventions deployed by public transit in the United States and Canada. *Transport Policy*. https://doi.org/10.1016/j.tranpol.2021.03.014

Kanda, W., & Kivimaa, P. (2020). What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? *Energy Research and Social Science, 68*, Article 101666. https://doi.org/10.1016/j.erss.2020.101666

Kazemzadeh, K., & Koglin, T. (2021). Electric bike (non) users' health and comfort concerns pre and peri a world pandemic (COVID-19): A qualitative study. *Journal of Transport and Health, 20*, Article 101014. https://doi.org/10.1016/j.jth.2021.101014

Kerimray, A., Baimatova, N., Ibragimova, O. P., Bukenov, B., Kenessov, B., Plotitsyn, P., & Karaca, F. (2020). Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. *The Science of the Total Environment, 730*, Article 139179. https://doi.org/10.1016/j.scitotenv.2020.139179

Khaniabadi, Y. O., Goudarzi, G., Daryanoosh, S. M., Borgini, A., Tittarelli, A., & De Marco, A. (2017). Exposure to PM 10, NO 2, and O 3 and impacts on human health. *Environmental Science and Pollution Research, 24*, 2781–2789. https://doi.org/10.1007/s11356-016-8038-6

Koehl, A. (2020). Urban transport and COVID-19: challenges and prospects in low-and middle-income countries. *Cities & Health, 1–6.* https://doi.org/10.1080/23748834.2020.1791410

Kraemer, M. U. G., Yang, C.-H., Gutierrez, B., Wu, C.-H., Klein, B., Pigott, D. M., Du Plessis, L., Faria, N. R., Li, R., & Hanage, W. P. (2020). The effect of human mobility and control measures on the COVID-19 epidemic in China. *Science (80-.), 368*, 493–497. https://doi.org/10.1126/science.abb4218

Laker, L. (2020). *World cities turn their streets over to walkers and cyclists. [WWW document]*. URL. Guard (accessed 4.11.20) https://www.theguardian.com/world/2020/apr/11/world-cities-turn-their-streets-over-to-walkers-and-cyclists.

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J. P., Abernethy, S., Andrew, R. M., De-Gol, A. J., Willis, D. R., Shan, Y., & Canadell, J. G. (2020). Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. *Nature Climate Change, 10*, 647–653. https://doi.org/10.1038/s41558-020-0797-x

Li, A., Zhao, P., He, H., & Axhausen, K. W. (2020). Understanding the variations of micro-mobility behavior before and during COVID-19 pandemic period. *Arbeitsberichte Verkehrs-und Raumplan, 1547*. https://doi.org/10.3929/ethz-b-000460847

Liyanage, S., Dia, H., Abduljabbar, R., & Bagloee, S. A. (2019). Flexible mobility on-demand: An environmental scan. *Sustainability, 11*. https://doi.org/10.3390/su11051262

Lozzi, G., Rodrigues, M., Marcucci, E., Teoh, T., Gatta, V., & Pacelli, V. (2020). *COVID-19 and urban mobility: Impacts and perspectives: Rapid-response briefing. TRID*. https://doi.org/10.2861/747305

Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *The Science of the Total Environment, 730*, Article 139086. https://doi.org/10.1016/j.scitotenv.2020.139086

Mas-Tur, A., Roig-Tierno, N., Sarin, S., Haon, C., Sego, T., Belkhouja, M., Porter, A., & Merigó, J. M. (2021). Co-citation, bibliographic coupling and leading authors, institutions and countries in the 50 years of Technological Forecasting and Social Change. *Technol. Forecast. Soc. Change, 165*, Article 120487. https://doi.org/10.1016/j.techfore.2020.120487

Matiza, T. (2020). Post-COVID-19 crisis travel behaviour: Towards mitigating the effects of perceived risk. *Journal of Tourism Futures*.

Mehdizadeh Dastjerdi, A., & Morency, C. (2022). Bike-sharing demand prediction at community level under COVID-19 using deep learning. *Sensors, 22*(3), 1060.

Menut, L., Bessagnet, B., Siour, G., Mailler, S., Pennel, R., & Cholakian, A. (2020). Impact of lockdown measures to combat Covid-19 on air quality over western Europe. *The Science of the Total Environment, 741*, Article 140426. https://doi.org/10.1016/j.scitotenv.2020.140426

Mogaji, E. (2020). Impact of COVID-19 on transportation in Lagos, Nigeria. *Transportation Research Interdisciplinary Perspectives, 6*, Article 100154. https://doi.org/10.1016/j.trip.2020.100154

Molloy, J., Schatzmann, T., Schoeman, B., Tchervenkov, C., Hintermann, B., & Axhausen, K. W. (2020). Observed impacts of COVID-19 on travel behaviour in Switzerland based on a large GPS panel. *Arbeitsberichte Verkehrs-und Raumplan, 1544*. https://doi.org/10.3929/ethz-b-000465060

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*, 93–111. https://doi.org/10.3390/smartcities4010006

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *The Science of the Total Environment, 728*, Article 138820. https://doi.org/10.1016/j.scitotenv.2020.138820

Munawar, H. S., Khan, S. I., Qadir, Z., Kouzani, A. Z., & Mahmud, M. A. (2021). Insight into the impact of COVID-19 on Australian transportation sector: An economic and community-based perspective. *Sustainability, 13*, 1276. https://doi.org/10.3390/su13031276

Nikiforiadis, A., Ayfantopoulou, G., & Stamelou, A. (2020). Assessing the impact of COVID-19 on bike-sharing usage: The case of Thessaloniki, Greece. *Sustainability, 12*, 8215. https://doi.org/10.3390/su12198215

Nikitas, A., Tsigdinos, S., Karolemeas, C., Kourmpa, E., & Bakogiannis, E. (2021). Cycling in the era of COVID-19: Lessons learnt and best practice policy recommendations for a more bike-centric future. *Sustainability, 13*(9), 4620. https://doi.org/10.3390/su13094620

Nižetić, S. (2020). Impact of coronavirus (COVID-19) pandemic on air transport mobility, energy, and environment: A case study. *International Journal of Energy Research, 44* (13), 10953–10961.

Notteboom, T., Pallis, T., & Rodrigue, J.-P. (2020). Disruptions and resilience in global container shipping and ports: The COVID-19 pandemic versus the 2008–2009 financial crisis. *Maritime Economics & Logistics, 1–32.* https://doi.org/10.1057/s41278-020-00180-5

Oil and Energy Trends. (2020). *2020. Second Covid-19 wave hits oil demand again, oil and energy trends [WWW document].* URL. Wiley (accessed 1.15.21) https://onlinelibrary.wiley.com/doi/10.1111/oet.12830.

Okoli, C. (2015). A guide to conducting a standalone systematic literature review. *Communications of the Association for Information Systems, 37*, 43. https://doi.org/10.17705/1CAIS.03743

Orro, A., Novales, M., Monteagudo, Á., Pérez-López, J.-B., & Bugarín, M. R. (2020). Impact on city bus transit services of the COVID–19 lockdown and return to the new normal: The case of A Coruña (Spain). *Sustainability, 12*, 7206. https://doi.org/10.3390/su12177206

Parady, G., Taniguchi, A., & Takami, K. (2020). Travel behavior changes during the COVID-19 pandemic in Japan: Analyzing the effects of risk perception and social influence on going-out self-restriction. *Transportation Research Interdisciplinary Perspectives, 7*, Article 100181. https://doi.org/10.1016/j.trip.2020.100181

Park, J. (2020). Changes in subway ridership in response to COVID-19 in Seoul, South Korea: Implications for social distancing. *Cureus, 12.* https://doi.org/10.7759/cureus.7668

Patrício, L. D., & Ferreira, J. J. (2020). Blockchain security research: Theorizing through bibliographic-coupling analysis. *Journal of Advances in Management Research.* https://doi.org/10.1108/JAMR-04-2020-0051

Paydar, M., & Kamani Fard, A. (2021). The hierarchy of walking needs and the COVID-19 pandemic. *International Journal of Environmental Research and Public Health, 18*(14), 7461. https://doi.org/10.3390/ijerph18147461

Pournader, M., Shi, Y., Seuring, S., & Koh, S. C. L. (2020). Blockchain applications in supply chains, transport and logistics: A systematic review of the literature. *International Journal of Production Research, 58*, 2063–2081. https://doi.org/10.1080/00207543.2019.1650976

Przybylowski, A., Stelmak, S., & Suchanek, M. (2021). Mobility behaviour in view of the impact of the COVID-19 pandemic—public transport users in Gdansk Case Study. *Sustainability, 13*, 364. https://doi.org/10.3390/su13010364

Riddell, S., Goldie, S., Hill, A., Eagles, D., & Drew, T. W. (2020). The effect of temperature on persistence of SARS-CoV-2 on common surfaces. *Virology Journal, 17*, 1–7. https://doi.org/10.1186/s12985-020-01418-7

Saadat, S., Rawtani, D., & Hussain, C. M. (2020). Environmental perspective of COVID-19. *The Science of the Total Environment, 138870.* https://doi.org/10.1016/j.scitotenv.2020.138870

Schmidt, K., Sieverding, T., Wallis, H., & Matthies, E. (2021). COVID-19–A window of opportunity for the transition toward sustainable mobility? *Transportation Research Interdisciplinary Perspectives, 10*, Article 100374. https://doi.org/10.1016/j.trip.2021.100374

Shamshiripour, A., Rahimi, E., Shabanpour, R., & Mohammadian, A. K. (2020). How is COVID-19 reshaping activity-travel behavior? Evidence from a comprehensive survey in Chicago. *Transportation Research Interdisciplinary Perspectives, 7*, Article 100216. https://doi.org/10.1016/j.trip.2020.100216

Sharma, S., Zhang, M., Gao, J., Zhang, H., & Kota, S. H. (2020). Effect of restricted emissions during COVID-19 on air quality in India. *The Science of the Total Environment, 728*, Article 138878. https://doi.org/10.1016/j.scitotenv.2020.138878

Shaw, R., Kim, Y., & Hua, J. (2020). Governance, technology and citizen behavior in pandemic: Lessons from COVID-19 in East Asia. *Progress in Disaster Science, 6*, Article 100090. https://doi.org/10.1016/j.pdisas.2020.100090

Shen, H., Fu, M., Pan, H., Yu, Z., & Chen, Y. (2020). The impact of the COVID-19 pandemic on firm performance. *Emerging Markets Finance and Trade, 56*, 2213–2230. https://doi.org/10.1080/1540496X.2020.1785863

Shen, J., Duan, H., Zhang, B., Wang, J., Ji, J. S., Wang, J., Pan, L., Wang, X., Zhao, K., & Ying, B. (2020). Prevention and control of COVID-19 in public transportation: Experience from China. *Environmental Pollution, 115291.* https://doi.org/10.1016/j.envpol.2020.115291

Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., Rodriguez, J. J. D., & Calatayud, V. (2020). Amplified ozone pollution in cities during the COVID-19 lockdown. *The Science of the Total Environment, 735*, Article 139542. https://doi.org/10.1016/j.scitotenv.2020.139542

Smit, R., Dia, H., & Morawska, L. (2009). Road traffic emission and fuel consumption modelling: Trends, new developments and future challenges. In *Traffic related air pollution and internal combustion engines.* USA: Nova Publishers.

Sung, J., & Monschauer, Y. (2020). In *Changes in transport behaviour during the Covid-19 crisis* (p. 2020). IEA.

Teixeira, J. F., & Lopes, M. (2020). The link between bike sharing and subway use during the COVID-19 pandemic: The case-study of New York's Citi Bike. *Transportation Research Interdisciplinary Perspectives, 6*, Article 100166. https://doi.org/10.1016/j.trip.2020.100166

The Fan Team. (2020). *Data shows truck movements increased by since COVID started [WWW document].* URL. Fleet Auto News (accessed 8.15.21) https://fleetautonews.com.au/data-shows-truck-movements-increased-by-since-covid-started/.

Tian, X., An, C., Chen, Z., & Tian, Z. (2021). Assessing the impact of COVID-19 pandemic on urban transportation and air quality in Canada. *The Science of the Total Environment, 765*, Article 144270. https://doi.org/10.1016/j.scitotenv.2020.144270

Tirachini, A., & Cats, O. (2020). COVID-19 and public transportation: Current assessment, prospects, and research needs. *Journal of Public Transportation, 22*, 1. https://doi.org/10.5038/2375-0901.22.1.1

UITP. (2020). *Public transport authorities and Covid-19 impact and response to a pandemic [WWW document].* URL. Int. Assoc. Public Transp (accessed 3.1.20) https://www.lek.com/sites/default/files/PDFs/COVID19-public-transport-impacts.pdf.

Vickerman, R. (2021). Will Covid-19 put the public back in public transport? A UK perspective. *Transport Policy, 103*, 95–102. https://doi.org/10.1016/j.tranpol.2021.01.005

Villa, R., & Monzón, A. (2021). Mobility restrictions and e-commerce: Holistic balance in Madrid Centre during COVID-19 lockdown. *Economies, 9*, 57. https://doi.org/10.3390/economies9020057

Wang, D., He, B. Y., Gao, J., Chow, J. Y., Ozbay, K., & Iyer, S. (2021). Impact of COVID-19 behavioral inertia on reopening strategies for New York City transit. *International Journal of Transportation Science and Technology, 10*(2), 197–211.

Wang, D., Zuo, F., Gao, J., He, Y., Bian, Z., Bernardes, S. D., … Chow, J. Y. (2020). *Agent-based simulation model and deep learning techniques to evaluate and predict transportation trends around COVID-19.* arXiv preprint arXiv:2010.09648.

Wang, K., & Ozbilen, B. (2020). Synergistic and threshold effects of telework and residential location choice on travel time allocation. *Sustainable Cities and Society, 63*, Article 102468. https://doi.org/10.1016/j.scs.2020.102468

Wang, P., Chen, K., Zhu, S., Wang, P., & Zhang, H. (2020). Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. *Resources, Conservation and Recycling, 158*, Article 104814.

Watson, S. (2020). *Coronavirus on surfaces: What's the real risk? [WWW document].* URL. WebMD (accessed 2.12.20) https://www.webmd.com/lung/news/20200903/coronavirus-on-surfaces-whats-the-real-risk.

WHO. (2021). *Rolling updates on coronavirus disease (COVID-19) [WWW Document].* URL. WHO https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen.

Wilbur, M., Ayman, A., Ouyang, A., Poon, V., Kabir, R., Vadali, A., Pugliese, P., Freudberg, D., Laszka, A., & Dubey, A. (2020). *Impact of COVID-19 on public transit accessibility and ridership.* preprint.

Wimbadi, R. W., Djalante, R., & Mori, A. (2021). Urban experiments with public transport for low carbon mobility transitions in cities: A systematic literature review (1990–2020). *Sustainable Cities and Society, 103023.* https://doi.org/10.1016/j.scs.2021.103023

Wołek, M., Wolański, M., Bartłomiejczyk, M., Wyszomirski, O., Grzelec, K., & Hebel, K. (2021). Ensuring sustainable development of urban public transport: A case study of the trolleybus system in Gdynia and Sopot (Poland). *Journal of Cleaner Production, 279*, Article 123807. https://doi.org/10.1016/j.jclepro.2020.123807

Worldometers. (2020). *COVID-19 Coronavirus pandemic. [WWW document].* URL. worldometers https://www.worldometers.info/coronavirus/.

Wyman. (2020). *Glimpse of recovery: Traveler sentiement survey [WWW document].* URL (1). Oliver Wyman: A Marsh McLennan Company (accessed 2.2.20). https://www.oliverwyman.com/our-expertise/insights/2020/jun/glimpses-of-recovery.html.

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research, 39*, 93–112. https://doi.org/10.1177/0739456X17723971

Zenker, S., Braun, E., & Gyimóthy, S. (2021). Too afraid to travel? Development of a pandemic (COVID-19) anxiety travel scale (PATS). *Tourism Management, 84*, Article 104286. https://doi.org/10.1016/j.tourman.2021.104286

Zhu, S., Srebric, J., Spengler, J. D., & Demokritou, P. (2012). An advanced numerical model for the assessment of airborne transmission of influenza in bus microenvironments. *Building and Environment, 47*, 67–75. https://doi.org/10.1016/j.buildenv.2011.05.003