Journal of Public Value and Administrative Insight
Journal Homepage: http://readersinsight.net/JPVAI

Research Article

# Transport emission models: A bibliometric and content analysis

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*Submitted: 29 April 2022* *Revised: 10 June 2022* *Accepted: 17 June 2022*

## ABSTRACT

Environment deterioration and subsequent climate change require the accountability of each contributor. Pollutants produced from fossil fuel in the transport sector is measured using emission models and this paper offers a Bibliometric analysis of these models from 1990-2020 of previous literature supported with the content analysis done in two tiers; review of the most cited research work of last ten years and the evolving research themes from recently published articles of last five years. From Bibliometric analysis, we identified top authors, institutions and journals, co-occurrence analysis of keywords, and co-authorship countries. Content analysis revealed that emission models have evolved globally with modifications and integrations of new techniques, multi disciplinary variables combining emission, transport, air quality, dispersion, and environment models. The technological adaptations in models have also been carried out locally by some countries bringing transport emissions to inventory counting for global warming potential. Research trends for future emission reduction suggest that besides the warming potential of fossil fuel from the transport sector, parallel reductions can be achieved through efficient traffic planning, road designs, driving patterns, stop and go cycles, traffic calming techniques impacting spatial and temporal goals through reduced clustering and hot spots.

**Keywords:** Bibliometric Analysis; Carbon Dioxide; Climate Change; Emission Models; Greenhouse Gases; Road Transport Models

## 1. INTRODUCTION

There is an increasing concern on the environment (U.S. Environmental Protection Agency, 2016) as global temperatures have risen mainly due to anthropogenic emissions (Henderson et al., 2016)(Dalby, 2013). All climate change indicators were static (NHTSA, 2016) for the last century but with the growing population, industrial activity, and an ever-increasing demand for energy (Ferreira Mercuri et al., 2016) temperatures are expected to rise further 2 $^{\circ}$C by the end of this century (IPCC, 2014a). 80% of the total energy demand globally is met by fossil fuel (Olivier et al., 2016) emitting carbon dioxide a long-range climate forcer (Fiore et al., 2015) that has exceeded beyond natural sink absorption capacity (IPCC, 2014b) of the planet. Transport sector shares major fossil fuel consumption releasing an estimated 23% of global CO2 emissions (Liu et al., 2015). There is an expected surge in

https://doi.org/10.31580/jpvai.v5i2.2530
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fossil fuel-based vehicle ownership to 2 billion in 2040 despite growing sales on electric vehicles reading 300 million by that time (2018 BP Energy Outlook, 2018). Emissions in real-life scenarios face a challenge as most remain underestimated due to errors resulting from extracting methods, tests, measures, and subsequent calculations (Thomas, 2017). Research on carbon emissions focuses on trends and drivers of emission, forecasting transportation models and subsequent emissions, and formulating strategies to counter and limit carbon emission through policies or mitigation measures (Tian et al., 2018).

Climate change impact on the global level falls in various spatial and temporal scales and traffic models are made to bring forward all the independent or inter-dependent components of a real-life system to analyze the impact of these on the overall system (Linton et al., 2015). Models from transport systems show an underlying epistemology that helps these distinguish from one another besides representing different elements of the transport system. Microsimulation models capture emissions from individual vehicles; the dynamics of behaviour, dynamic system, and impact of technology, economy, or multiple areas to the level of Integrated Assessment Model (IAM) reveal different time dependant impacts on regional & global levels as shown in Fig. 1.

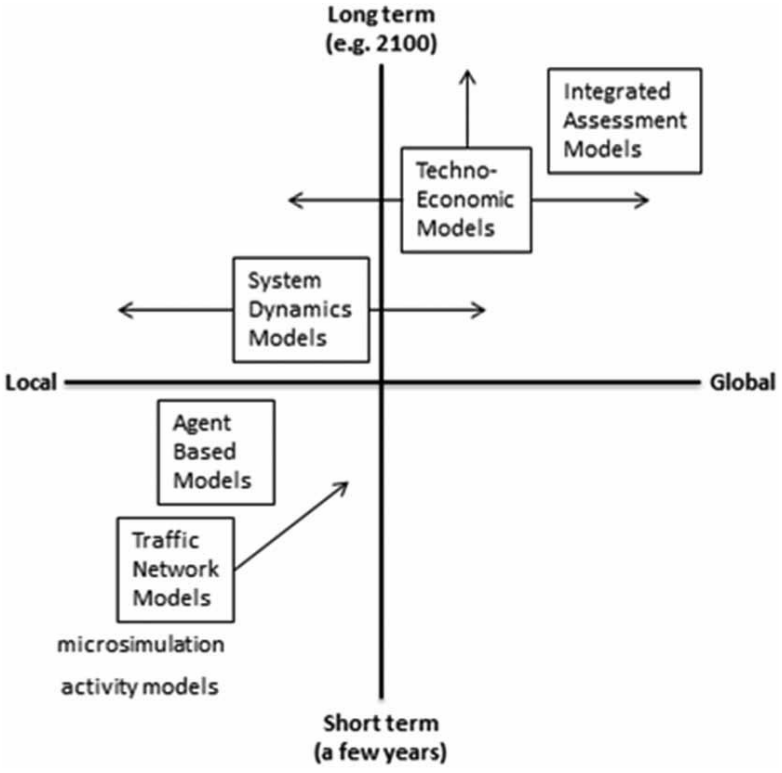



**Fig. 1.** Spatial and Temporal Spread of Transport Models

The microsimulation models are bottom-up while macroscopic models are top-down based on fuel consumption gauged by mass and volume of fuel consumed or heat or carbon content released. The emission released can be based on an activity basis as well measured from vehicle kilometre travelled and emission factor of fuel (U.S. Environmental Protection Agency, 2016) (Harris et al., 2011). Overall, the impact of climate change is generated through the integration of emission with transport and air quality, or climate change models as shown in Fig. 2.

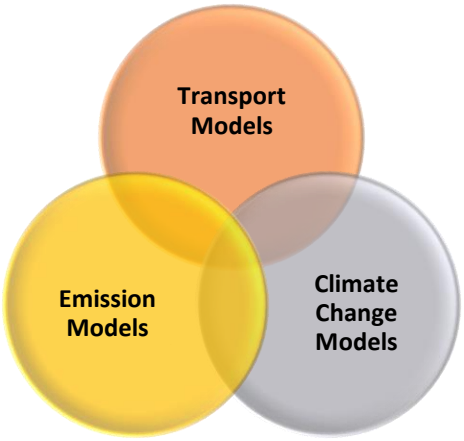



**Fig. 2.** Overlapping Models in the theme of study

The main research interest in conducting the bibliometric analysis along with content analysis of the past literature available on transport emission models is to answer questions like; a) How is the research evolving for road emission models and if the research trends are also integrated into the applied models calculating emissions around the globe? b) Which areas are the most explored areas of road emission models and which areas are yet to be explored? c) Are the same models in use in different parts of the world or are there local or interdisciplinary adaptations?

An extensive search on Bibliometric study is carried out on Scopus and Google Scholar for Road Transport Emission Models; however, there was no such work found. This led to a research gap which is being offered in this paper as a novice attempt to offer current research and future trends on transport emission models. Bibliometric analysis is done on emission models and then a content analysis is made on selected papers on two levels; top-cited papers of last ten years and areas of research in the last five years for a deeper understanding of the latest trends of research. Here both analyses were done on the same data extracted from Scopus.

The last thirty years are chosen as the period of study keeping given the global awareness towards environmental deterioration, the first steps started with restriction on Chlorofluorocarbons (CFC) and Halons in the 1985 Vienna Convention and subsequent Montreal Protocol in 1987. The work started with the identification of top-order ozone-depleting compounds and phasing out of the banned gasses by passing regulations in 1994 by the collaboration of initial 105 counties through the allocation of phasing-out targets to each. It was on the same pattern that further gasses were classified as causing GHG effects and bringing damage to the earth's atmosphere. $CO_2$, NOx, SOx, VOC and PM are these gasses identified by UNFCC and signed by counties under Koyoto protocol in 1997 and later in Copenhagen Accord in 2009 and Paris Agreement in 2015. Globally speaking 1990-2020 is the period when emissions related to transport and other sectors were studied at a national level and the need to measure and control was felt leading to emission models, mitigation policies, fabrication of devices, etc to study this area at a greater depth.

The need for this study is felt as the transport sector is included in the nationally determined target allocated by UNFCC for each country, however, clear path ways with

action plans are not provided by most countries. Out of 193 signatories, only 10% have chalked out their national targets for mitigation of emissions from this sector (International Transport Forum, 2018). Measures mentioned by most remain vague and questionable as most countries do not have established metrics of their own to understand the real dynamics of these sectors emissions. Academically, this research opens a quest for new variables that can account for road emissions, from the industrial point of view automobile industry can look into the future direction of vehicle designs with better aerodynamic and road movement, autonomous vehicles and smooth drive features while for governments they can incorporate this in better policy planning and transport management.

## 2. LITERATURE REVIEW:

Transport drives economies all around the world and is accounted for major emission shares for countries. In Europe alone, from 1990-2010, emissions increased by 23% and same is the state of affairs in other countries, as well. Vehicle Emission models help in estimating these emissions that are classified either in terms of consumption or its warming potential derived from fuel quantities, heating potential, traffic volumes, transport vehicle type, modal emissions, measurement models, traffic situations, etc (Esteves-Booth et al., 2002). It is learnt that modal models are better models compared to emission factor models and average speed models as they can predict well on a micro-scale and driving cycle conditions. However, research suggests that there is a need for improving transportation emission measurement techniques, developing new-generation transportation emission models utilizing better land use, system planning and legislative actions (Yu et al., 2009). Scholars employ Bibliometric analysis for various reasons, such as identifying developing trends of a topic, collaboration patterns, major journals in the field and their performance, research constituents. It also enables scholars to investigate the intellectual structure of a certain area in the existing literature (Donthu et al., 2021b; Verma and Gustafsson, 2020). It allows us to unravel the evolutionary nuances of a discipline while also shedding light on the field's emerging areas (Donthu et al., 2021a)

Analyzing Bibliometric studies, the closet work on transport emissions is based on generic trends and characters from 1997-2016 (Tian et al., 2018) covering general emissions only and not by applying emission models to its calculations. Similarly, Sun & Wu covered generalized analysis on emissions from 2004-2109 (Sun et al., 2020) related to the industrial sector and suggest that these models may be studied while integrating theories and methods from other disciplines in order to bring out conclusive results from industrial sector emissions. The latest studies covered low carbon alcohol fuels used in internal combustion engines (Jin et al., 2021), energy efficiency (Yu and He, 2020), green energy and environmental technologies leading to green logistics and supply chains (Tan et al., 2021). The improvement of traffic system and controls also enhance sustainability with reduced traffic emissions, less fuel consumption and a lesser number of accidents primarily studied in the context of speed regulations covered through Bibliometric analysis done for freeway network analysis (Sacone et al., 2020). Even Bibliometric studies are conducted on suitable business models for alternate electric vehicles (Secinaro et al., 2020) and sustainable technologies for enhanced environmental policy tools (Akbari et al., 2020). Significant

research is seen in Maditati's work from 1997-2016 urging on meta-analysis models that can correlate drivers, practices, and performance measures together (Maditati et al., 2018).The implication of such research findings leads future researchers to integrate performance measuring variables with energy, environment and climate change so as mitigation strategies and energy policies can develop in a better manner and this was analyzed in a Bibliometric study from 1990-2019 (Hou and Wang, 2021). With the advent of big data and streaming data, climate change models in today's multidisciplinary environmental management have also become more in depth and practical for applications in any areas of governance, technological innovation and low carbon transportation (Su et al., 2020).

Content analysis of last ten years show a gradual shift from the basic emission models like Computer Programme to Calculate Emissions from Road Transport (COPERT), Handbook Emission Factors of Road Transport (HBEFA), and Motor Vehicle Emission Simulator (MOVES) (Demir et al., 2011), etc to emission estimates derived from neural networks (Wang et al., 2018) and integrated overlapping models (Jamshidi Kalajahi et al., 2020). Leading research also studies emission in different contexts like congestion (Abdull et al., 2020), microscopic to macroscopic spatial domains and temporal to long term basis (Kan et al., 2020) besides freight and commuter vehicle categories operating in urban and rural domains. The urban environment is closely linked to urban transport and interest in environmental parameters relates to subjective areas like sustainability and autonomous vehicles (Maditati et al., 2018). Bibliometric analysis on Emission Models in the transport sector impacting climate change is searched extensively on Scopus and Google Scholar but studies made were mostly scattered in areas like industrial emissions (Sun et al., 2020), green supply chain management (Maditati et al., 2018), alternate fuels for Diesel Engine (Redel-Macías et al., 2021).

## 3. METHODOLOGY:

We aim to provide an extensive review of the evolution of transport emission models, identify their main themes and provide future directions. Some of the mainstream approaches to review the existing literature are Bibliometric analysis, content analysis, and meta-analysis. This research provides the Bibliometric analysis along with content analysis to present a comprehensive review of the available literature on the said topic.

The Scopus database is employed as a data source for the bibliometric study. Traditionally the two main widely used databases for bibliometric analysis are Web of Science (WoS) and Scopus (Pranckutė, 2021) (Singh et al., 2021) but we chose Scopus because it has 20% higher coverage than WoS and is nicely integrated with Mendeley data and references. Scopus is one of the databases with the most comprehensive global and regional coverage of journals, books, and conferences, as well as broad coverage of articles (Sikandar et al., 2021a, 2021b). On the other hand, WoS is very selective in its journal coverage and has therefore less coverage of articles than Scopus (Singh et al., 2021). Google Scholar launched in 2004 is another database used for bibliometric analysis and is comparatively larger than Scopus and WoS. It covers a wide range of articles and is generally considered a superset of both Scopus and WoS (Martín-Martín et al., 2018). To prevent duplication and limit our search to only journal articles, we excluded Google Scholar from the study and instead used the

Scopus database because Google Scholar includes non-journal publications such as books, book chapters, dissertations, pre-prints, working papers, and conference papers (Martín-Martín et al., 2018).

Initially, 843 documents were extracted from Scopus using the search string “TITLE-ABS-KEY ("emission models” AND “transport")” shown in Appendix. After limiting the search to the data of the past 30 years i.e., 1991 to 2020 we got 603 documents. To identify the publication trends, top authors, journals, and countries a descriptive analysis was performed. Co-occurrence analysis of keywords, co-authorship countries were also carried out in the Bibliometric analysis through VOS viewer software. We also performed a content analysis on the past ten years' most cited literature for the research themes, however, we understand that current emerging trends cannot be justified based on citations of the last ten years, therefore, we analyzed the evolving trends from past five years as well. A total of 111 highly cited documents were extracted based on 20+ citations for each paper. From these three categories were made.

1. Irrelevant papers that relate to open biomass burning, agriculture, sewer, landuse, aviation or by sea emission models.
2. Partially relevant that relates to air pollution but emissions from stationary sources, non-motorized vehicle and emissions like Ammonia ($NH_3$), Methane ($CH_4$), Plumes, Black Carbon, and other work domains like cost estimations, supply chain, dispersion patterns, etc
3. Relevant research papers relates to air pollution, emission models, transport models etc for road transport, air quality targeting Koyoto Protocol gasses like Carbon dioxide, nitrogen, sulphur, etc.

The relevant 31 papers are from the last 10 years based on 20+ citations. For the content analysis from 5 years publications irrelevant research like air flame, thermionic emissions, biomass burning, isoprene, NH3 and other pollutants, noise, radiations, etc were all removed to cover only the target emissions from road transport is studied. Overall, 49 papers were extracted and reviewed as shown below in Fig. 3.

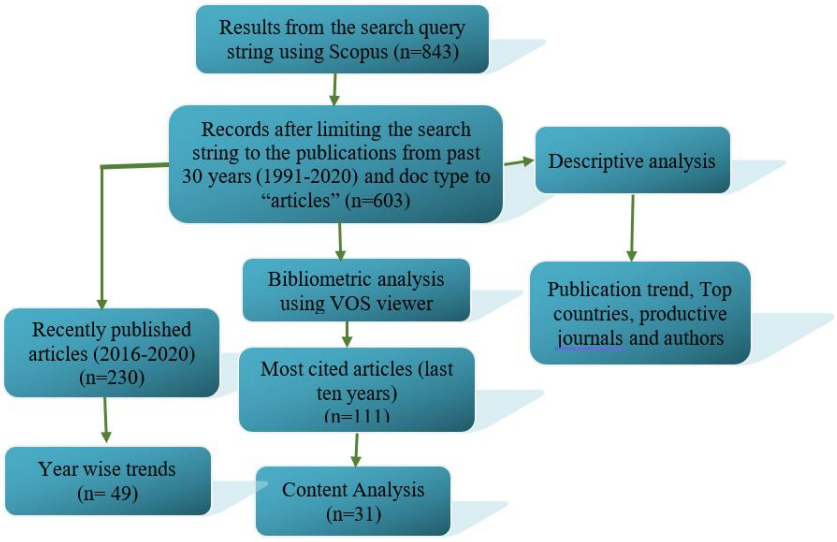



**Fig. 3.** Flowchart of the Bibliometric and Content analysis

# 4. DESCRIPTIVE ANALYSIS:

## 4.1. PUBLICATION TREND

Fig. 4 shows the evolution of the research in the field of transport emission models. The interests of researchers in transport emission models date back to 1991 and the number of publications increased over time from 2 publications per year to 60 publications in the year 2020. It is also noteworthy that the trend in publication increased after the year 2002 as it gradually started increasing at a greater pace and the current publication pattern shows that this trend will continue to grow.

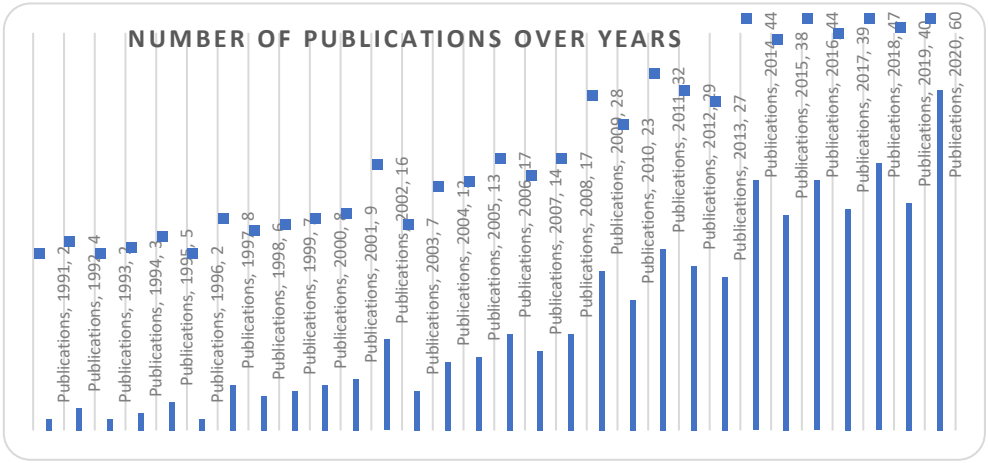



**Fig. 4.** Publications from 1991-2020

## 4.2. MOST PROLIFIC AUTHORS

Fig. 5 shows the top ten prolific authors in the area of transport emission models. Hatzopoulou, M.(Canada) is the top productive author with ten published documents followed by Baldasano, J.M. (Spain) with a total of eight publications. The top ten authors in the field are listed in Fig. 5 as below:

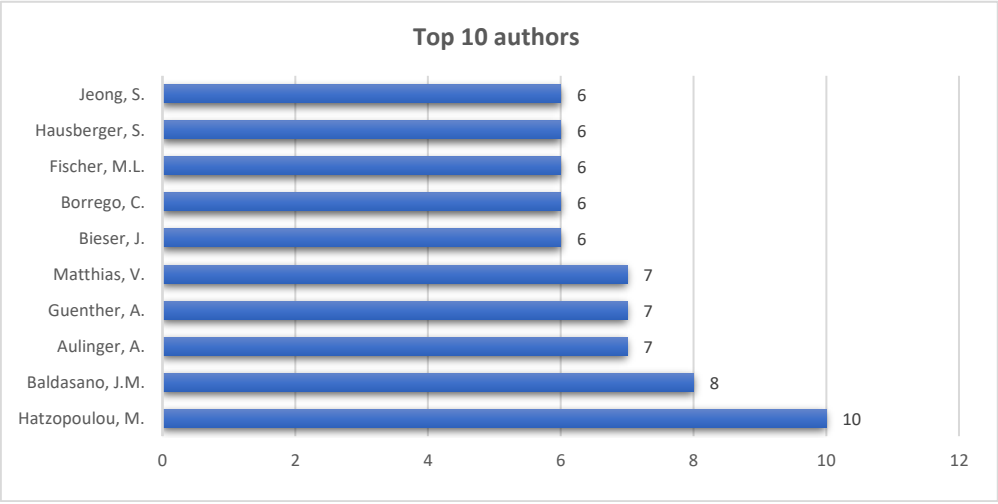



**Fig. 5.** Top Ten Authors

### 4.3. Institutions with Most Publications

The top 10 institutions are listed below in the figure. Université McGill (Canada), University of Colorado Boulder (Colorado), and Lawrence Berkeley National Laboratory (California) are the top three most productive institutions as shown in Fig. 6 below:

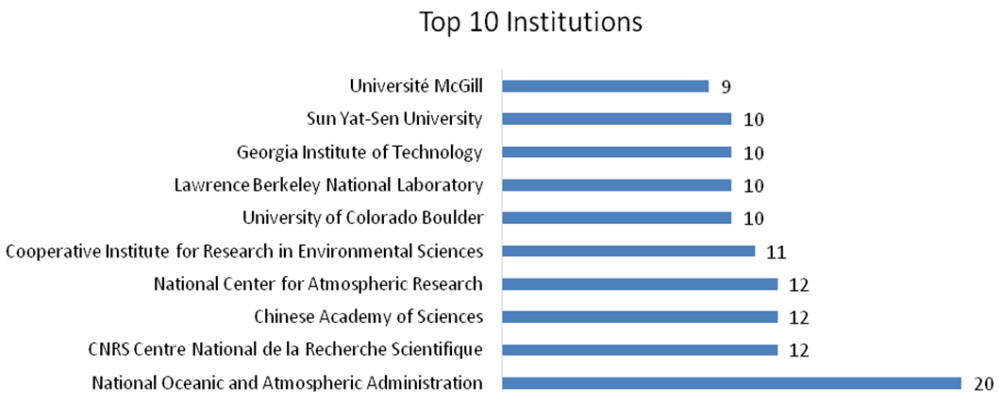



**Fig. 6.** Top Institutions with most publications

### 4.4 Most Productive Journals

Atmospheric Environment, Transportation Research Part D (Transport and Environment) & Atmospheric Chemistry and Physics are the top 3 journals in the field with the most publication on the transport emission models that is, 54, 40 and 25 publications respectively as shown in Fig. 7 below.

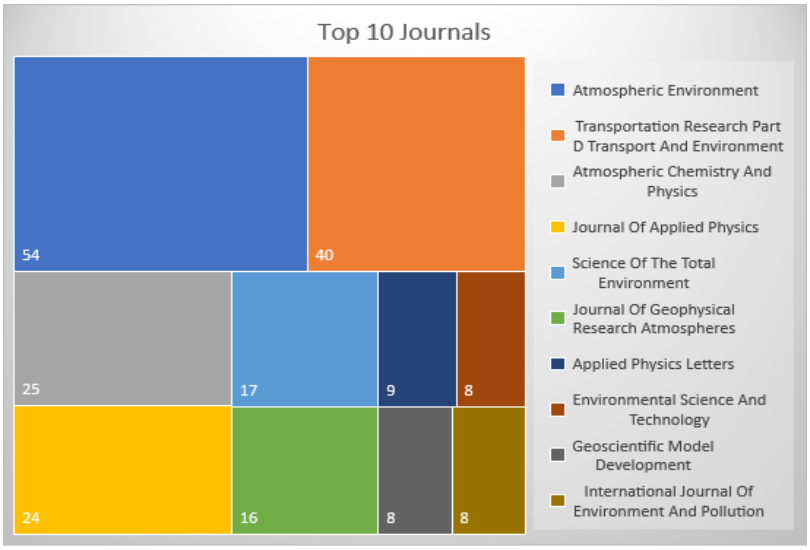



**Fig. 7.** Top Journals

## 5. BIBLIOMETRIC ANALYSIS:

### 5.1. Co-Occurrence of Keywords

The results of co-occurrence analysis revealed that 1574 keywords were used in 603 documents that were part of the analysis. The minimum number of occurrences per

keyword was set to 2. The issue of assigning co-authored publications to individual authors is a well-known problem in the field of bibliometrics. Many different approaches to this problem have been proposed in the context of bibliometric indicator calculation. The two most popular ways are the full counting method and the fractional counting method. A paper co-authored by five researchers is awarded to each researcher with a full weight of one under the full counting approach. In the fractional counting system, on the other hand, each researcher is assigned a fractional weight of 1/5 for each publication (Perianes-Rodriguez et al., 2016). For this analysis, the counting method was set to 'Full Counting'.

As a result, we got 211 keywords. In the next step, the map and network files were downloaded to clean the data on the map. The data was cleaned up by using the map file to create a thesaurus key. Similar keywords were merged, and irrelevant keywords were removed, resulting in a map that displays the important keywords (Fig. 8). For instance, emission inventories and emission inventory were merged into one keyword "emission inventory". Similarly, greenhouse gas, greenhouse gas (GHG) emissions, greenhouse gas emissions, and greenhouse gases were merged into a single keyword "greenhouse gas (GHG) emissions". Consequently, we found 111 keywords out of 1473 that met the threshold of two occurrences per keyword. We discovered that out of 111 keywords 107 were connected forming 366 links with total link strength (TLS) of 493. The keywords were initially divided into 14 clusters but in the next step, we re-clustered all the variables into 6 main clusters i.e. climate parameters, traffic emission models, traffic model parameters, air pollutants, non-traffic anthropogens and incoherent generic terms. The co-occurrence of author keywords map in network visualisation mode is shown in Fig. 8. The six clusters are represented in six different colours in Fig. 8 (figure can also be viewed online using the link in the caption).

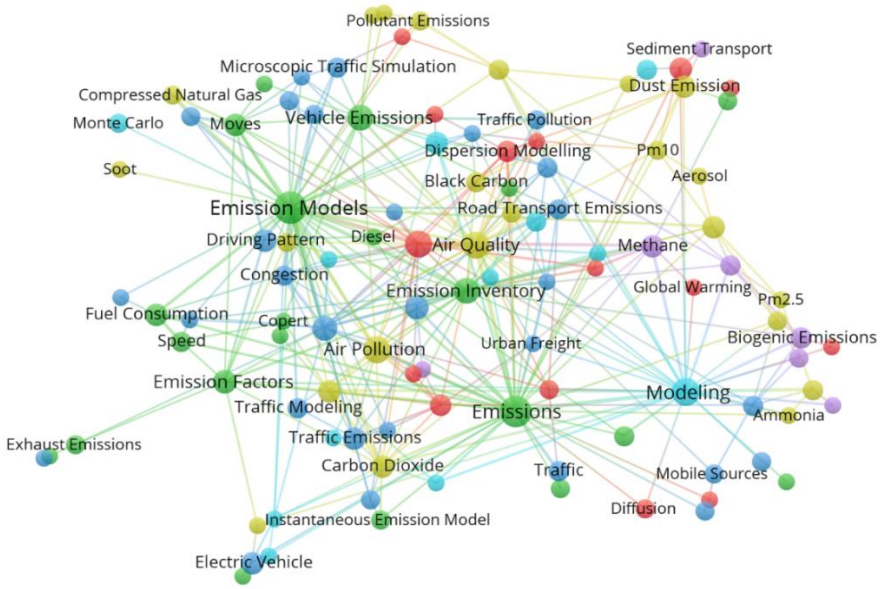



**Fig. 8.** Network Visualisation view of the co-occurrence of author keywords analysis, available online at https://bit.ly/3GZd0PR

In the figure, the bigger circle demonstrates the density of the keyword across different published articles. The distance between the two keywords reveals the relative strength

and similarity of the two topics (Guo et al., 2019). Circles of the same colour show the similarity of the topic among different published articles. The similarity of the topic among different published articles is shown by circles of the same colour. The most prominent keywords based on the total link strength were found to be Emission Models (n=77), Emissions (n=60), and Modelling (n=49). This suggests that Emission Models have 70 links with other keywords, Emissions have 37 and modelling has 31 links with other keywords. Similarly, some of the other top keywords discovered in the analysis are Air Quality, Emission Inventory, Greenhouse Gas (GHG) Emissions, Road Traffic Model, Air Pollution, Carbon Dioxide, MOVES, NOx Emissions, Vehicle Emissions, Emission Factors, Methane, Congestion, Traffic Emissions, Dust Emission, Climate Change, Fuel Consumption, and Dispersion Modelling (Table 1, Appendix B). This also suggests that these topics are well explored with transport emission models.

Similarly, we analysed the emerging topics in the said field based on the average publication year. For instance, the keyword published in the past 5 years is considered as emerging topics. The keywords that are the emerging hot topics in the selected field are autonomous vehicles, PM 2.5, bus stops, nitrogen dioxide, sediment transport, vehicle-specific power, COPERT, environment. The top 20 emerging keywords based on their average publication year are given in the are listed in table 2 Appendix B.

## 5.2. Co-authorship Analysis of Countries

The top 10 productive countries were determined that actively published research articles related to the transport emission model. These countries are the United States (180 publications), China (101 publications), United Kingdom (58 publications), Germany (40 publications), France (37 publications), Canada (34 publications), Japan (30 publications), Italy (27 publications), India (26 publications) and South Korea (26 publications) as shown in the map in Fig. 9.




**Fig. 9.** Top 10 productive countries with most publications

We also performed a co-authorship analysis of countries to determine the collaboration between different countries. To create a co-authorship map, we used the data from Scopus and opened it on the VOS viewer software and used the 'full counting' method while performing the co-authorship analysis of countries. The 603 documents extracted from Scopus belonged to 67 different countries. We set the criteria for the minimum number of publications per country to 2 to get a larger set of countries to analyse. As a result, we got 47 countries out of which 46 were connected with a total of 197 links and total link strength of 361 forming 8 clusters. To get a simplified and better visualization, we re-clustered the countries according to their respective continents that are Europe (1), Asia (2), America (3), Africa (4), and Oceania (5) so the network map visualises 5 main clusters. We found that from the complete dataset, 22 countries belonged to Europe, 14 countries were from Asia, 5 items were from America and 3 from Africa, and 2 from Oceania.

The results of our analysis revealed that the United States, China, the United Kingdom, Germany, France, Canada, Japan, Italy, India, and South Korea are the countries with the most publications (Fig. 10). Authors from the US published 181 documents with 30 different countries and has 30 links with other countries and total link strength (TLS) of 118. Similarly, China is the second-largest country with most publications having published 101 documents with 15 other countries and has total link strength of 38. China published 16 documents in collaboration with the United States. The United Kingdom is placed as the third most productive country and has published a total of 58 documents with 24 other countries having total link strength of 66. The top 20 countries with the most publications are listed in table 3, Appendix B along with their citations and total link Strength (TLS).

It is worth noting that in terms of collaboration the top 3 countries are the US, UK, and Germany. China has more publications than Germany, but their collaborative research is far less. In fact, in terms of collaborative research, the leading countries are the United States, United Kingdom, Germany, France, Italy, Japan, Switzerland, South Korea, China, and Canada in the same order. Algeria, Oman, Ukraine, Vietnam, New Zealand, Singapore, Malaysia, Argentina, Iran, Mexico, Pakistan, Slovenia, and Tunisia are among the countries with the least number of publications. Pakistan, Slovenia, Tunisia, and Egypt are among the countries that have a long way to go in terms of collaborative research, with each having only one publication with another country. This revelation opens doors for researchers to expand their work in future research because Scientific collaboration is considered to be a necessary component for improving the quality and impact of research (Kaya Ozbag et al., 2019) as seen in Fig. 10 below:

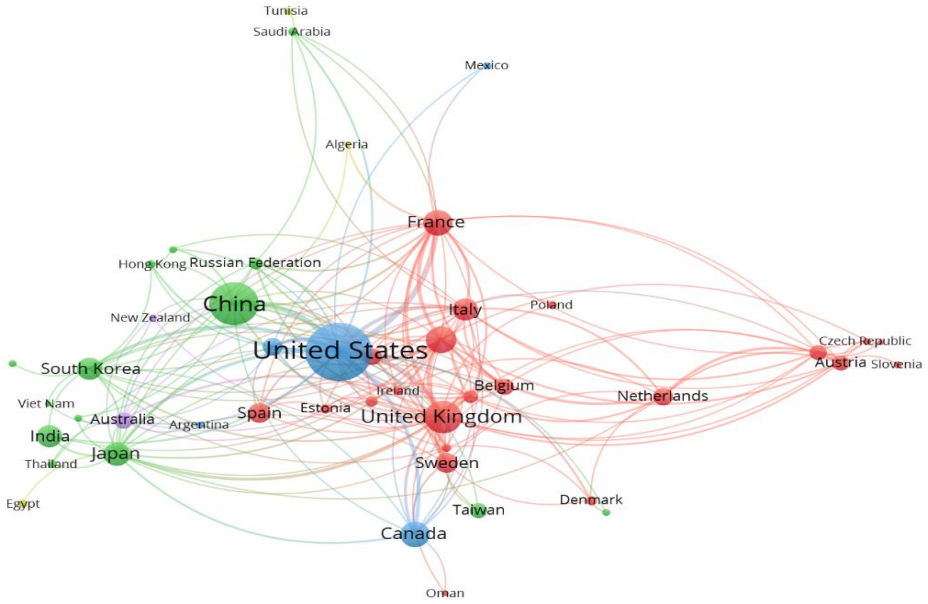



**Fig. 10.** Co-authorship analysis of countries in Network Visualisation mode of VOS Viewer, available online at https://bit.ly/3C3R4jG

## 6. DISCUSSION

Scopus database was reviewed for the past 10 years data and analysis are done on work with two types of approaches; the first one was to review and analyse the top-cited work during the last ten years and then the focus on work in this domain during the last five years:

### 6.1. PART A: ANALYSIS OF TOP-CITED WORK ON EMISSION MODELS (2010-2020)

Scopus search was aimed to find research done on Emission Models and the search revealed mostly micro simulation fuel consumption models. 607 publications from the year 2010 till the years 2020, further narrowed down to most cited papers, and all above 20 citations were listed out, 111 such papers are extracted and further categorized into relevant research topics, partially relevant and irrelevant areas of research.

Computer Programme to Calculate Emissions from Road Transport (COPERT), Handbook Emission Factors of Road Transport (HBEFA), and Motor Vehicle Emission Simulator (MOVES) are the most utilized models evaluating emissions, COPERT & HBEFA are used mostly in countries following European emission standards (Kholod et al., 2016), MOVES is a US EPA model but also used worldwide, while in underdeveloped countries that lack extensive data like India, a simplified Vehicular Air Pollution Emission Inventory (VAPI) model is suggested that utilizes EF and correction factors for emission calculations (Nagpure and Gurjar, 2012). Europe particularly Spain contributed significantly to novice Emission models like HERMES04 for NOx (Guevara et al., 2013) and a lot of research in environmental impacts from vehicle emissions. The most cited paper of this search is a review paper analyzing emission models in freight logistics focusing on fuel consumption-based models calculating $CO_2$ emissions for operational level planning using emission

factors, speed, and mode in instantaneous, elemental, and running speed fuel consumption models (Demir et al., 2011).

Research model modifications and refinements were suggested with time in the built-in models like In-use-fuel consumption values in both Diesel and Petrol vehicles show variation in EF to type-approval values (Ntziachristos et al., 2014), HBEFA and COPERT v.8.1 were found to overestimate EF values in a study conducted in Spain (Borge et al., 2012) and later on in multiple studies the same is endorsed (Krecl et al., 2017). This led researchers to pursue other predictability models like the real-life Portable Emission model (PEMS) integrating vehicle class, velocity, payload and driving behaviour, etc as input variables in emission calculations (Ligterink et al., 2012) (Ntziachristos et al., 2016). Emission factor calculation was also suggested to be made simple (Dente and Tavasszy, 2017) by taking derivatives of two models namely the EcoTransIT World model and Ligterink model, and then checking the effectiveness of the proposed framework. When analyzing emission results on geographic regions a non-linear trend of error is identified in microscopic scenarios that can be dealt with by Lagrangian and Eulerian approaches (Fontes et al., 2015) though each city has a unique vehicle mix, vehicle, and road types, and traffic conditions so Emission Factor (EF) values are city-specific as per their driving cycles (Amirjamshidi and Roorda, 2015). GHG emissions are also suggested to be calculated through a spreadsheet-based Fuel Emission Calculator using scaled tractive power and the Greenhouse Gases, Regulated *Emissions (*GREET) model to compare fuel emissions from diesel, hybrid and electric vehicles (Xu et al., 2015). Static speed modelling also evolved to dynamic fuel consumption data from the Internet of Vehicles, a novel approach that proved to be superior in predicting fuel consumption that Virginia Tech Microscopic Emission Model (VT-Micro), Vehicle Specific Power (VSP), and CMEM models (Xu et al., 2018).

Different multi-model integrations were also carried out on Emission models like MOVES became MOVES 2010a when combined with traffic simulation model VISSIM and generate precise emission values (Abou-Senna et al., 2013). Sparse Matrix Operator Kernel Emission (SMOKE) model developed by US-EPA in 2000 was revised and adopted as a comprehensive emission model for Europe termed SMOKE-EU using Chemical Transport Models for Ammonia (NH3), Nitrous Oxide ($NO_2$), Sulphur Dioxide ($SO_2$), etc (Bieser et al., 2010). Chemistry Transport Model (CTM) LOTUS-EUROS is a model evolved in Germany for calculating $NO_X$, $SO_2$, and Particulate Model (PM) that can also accommodate regional specific factors and metrological data for a refined real-time dynamic model (Mues et al., 2014). Metamodel simulation-based optimization (SO) combined traffic and emission models to generate an optimized solution for traffic signal optimization (Ghafghazi and Hatzopoulou, 2014). Urban segments are pollution hubs and buses are major contributors to city environmental deterioration, however, the potential emission impact per passenger-km is lowest by buses (Wang et al., 2015) besides being five times lesser emission releaser than taxis and passenger cars (Wang et al., 2015). An exclusive emission model for diesel-based bus fleet evolved in Spain (López-Martínez et al., 2017), and the impact of their speed variations, stop and go cycles, load capacity, etc was reviewed critically for different fuels using VSP & Artificial Neural Network (ANN) models to estimate pollutants precisely (Wang et al., 2018). These impacts of emission from mobile segment forms the basis for

environmental policy planning ensuring least human exposures and social cost factors (SCF) are monitored in different geographical locations like during port operations in California a multi-model study integrating spatial dispersion, emission, and health impact models revealed SCF of millions of dollars (Lee et al., 2012), similarly in a separate study of Paris emission, 6% freight logistics vehicle movement caused 36% share of environmental deterioration in the city (Coulombel et al., 2018). In another multi-mode integration study activity-based transport model, dispersion, land use regression, and vehicle emission models are carried out to reveal huge impacts on human health (Lefebvre et al., 2013).

It is learned with time that reduction in emissions is significantly achieved through good traffic planning and management; traffic calming through speed breakers is one way of reducing vehicle numbers but generates more emissions (Ghafghazi and Hatzopoulou, 2014), even the narrower it is, the more emission friendly it is (Lee et al., 2013). Freeway corridors are ideally suited for lesser emission provided there is no congestion that might be found on signalized corridors promoting stop and go, deceleration, idling, and acceleration cycles (Ma et al., 2014). Route optimization is another way of managing traffic (Guo et al., 2018) and plays its role not only in emission reduction studies but policy-making, as well (Grote et al., 2016a). Looking at the impacts at a bigger spatial domain, mesoscopic models suggest green logistics and operations that combine different modes of transport for efficient eco-friendly routes especially for long-distance freight transport (Kirschstein and Meisel, 2015). Overall, the model spread can be seen below in Fig. 11.

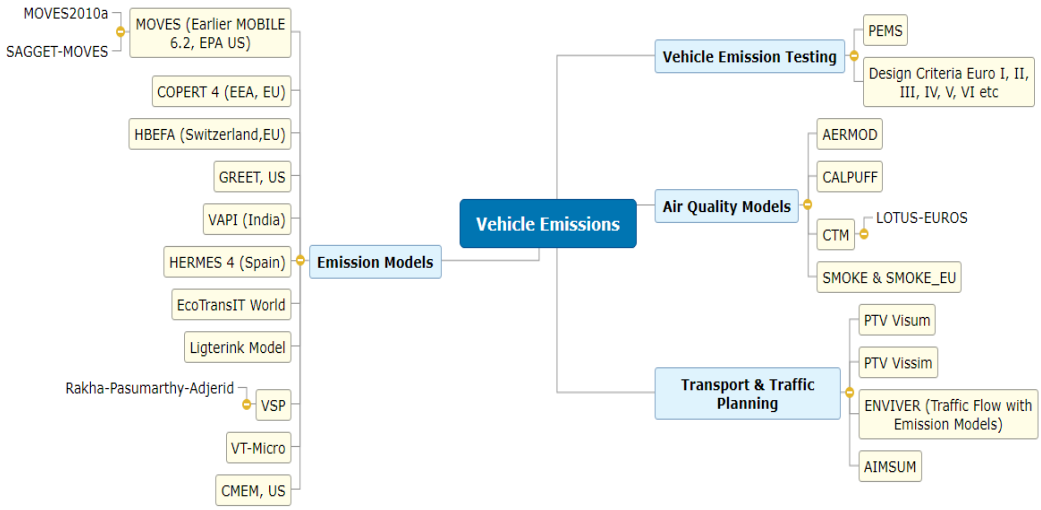



**Fig. 11.** Models used during the studies (2011-2020)

## 6.2. B: Analysis of Emission Models evolving trends in last five years (2016-2020)

Year-wise 232 papers were analyzed for content from the last five years and the relevant areas are narrowed down to areas like Atmospheric Pollutant mainly GHG, traffic optimization, prediction technique, road transports, integrated emission models, urban hot spots etc. The areas not considered are railroad, air and sea transport as well as air pollutants other than Greenhouse Gases, etc. From the year 2016, 12 out of 44 papers are

analyzed for their content lying in the review areas mentioned above while 7 papers were picked from the 39 papers of 2017. 10 and 12 papers respectively are analyzed for content from the 46 and 41 papers of the year 2018 and 2019. The year 2020 saw a boom of research publications in this area however only 8 papers fitted the category that we marked initially for review so altogether from the last five years it is the review of content from 49 papers that the research areas are categorized in multiple domains as below:

### 6.2.1. Emission Models in Use and their refinements:

The year by year analysis show extensive use of established models like MOVES, COPERT, VISIIM, HBEFA, etc in research calculations worldwide, even in 2020 COPERT is still used in Japan to calculate emission on congested roads (Abdull et al., 2020) and VISSIM in Portugal is used to study emission reduction after autonomous vehicle is introduced in traffic (Rafael et al., 2020). Forecasting is also done using HBEFA & COPERT model by researchers in Belgium to analyze Electric Vehicles' impact for replacing petrol and diesel cars (Hooftman et al., 2016) though HBEFA tends to underestimate the emission figures at times (Elkafoury et al., 2015). MOVES model is used in a gridding bottom-up methodology to generate spatial regression optimization models for trucks in the US (Perugu et al., 2017) while positive matrix factorization technique used SUMO and VT-micro models in Netherland for overall traffic flow (Jamshidnejad et al., 2017). In another study mesoscopic Cell Transmission Model (CTM) is used to simplify emission calculations (Kan et al., 2020) while, mesoscopic traffic emission models were used for different traffic conditions like idling, cruising, and acceleration in both free flow and over-saturated traffic conditions. Cluster-based Validation Emission Re-calculation (CLEVER) offers a hybrid approach to calculate emission factors for varying conditions and reduces computational burden (Tu et al., 2018). In Toronto, the CLEVER algorithm is applied to generate accurate GHG emission estimates for varied traffic conditions instead of average speed (Tu et al., 2019). Previously developed models are being tested and verified regularly as in 2019 EF generated through MOVES was found to be higher than actual (Xu et al., 2019) and advancement of MOVES model is done as MOVES-Matrix (Liu et al., 2019) for development of simulated emission models.

### 6.2.2. Novel Concepts:

Several novice models and concepts have been introduced in the year 2016 using GPS trajectory data for taxi service in Singapore, data is acquired on instantaneous velocity and acceleration to find hot emission spots in the cities (Nyhan et al., 2016). The same researchers Nyhane et. al, further conducted studies on different driving cycles namely acceleration, deceleration, and cruising speed to build up a comparative data analysis on emissions in each cycle (Weng et al., 2017). GPS-based modelling practice was further tried in 2018 as well in a study done in Portugal where microsimulation traffic model, VISSIM, mesoscopic model Transport Emission Model (TREM), and Air Quality Model (URBAIR) determined emission inventories (Dias et al., 2018). Models were also built using Dijkstra's algorithm that utilizes vehicle group trajectories to reconstruct expected maximization algorithms to find the most optimal routes with minimal consumption (Bernhardt et al., 2016).

At the National Research Council of Italy, new analytical research is seen on the mechanical design of 4-stroke motorcycles in which a three-way catalyst categorized in the Euro-3 category is used for better emission standards (Iodice and Senatore, 2016) and the benefits of a 4-stroke engine over the 2 stroke engine were studied (Mahesh et al., 2019) in India due to the widespread use of these motorbikes. Similarly, realistic vehicle trajectory distribution is also generated using Car-Following-Model that utilizes Vehicle Specific Power through a newly developed model, Rakha-Pasumarthy-Adjerid for emission analysis after vehicle fuel consumption. This model, however, requires further validation & testing (Wang et al., 2017). In Brazil, another model detecting PM from diesel-operated freight transportation in urban areas; Panis was introduced that was integrated with EnViver, AIMSUN, and VISSIM to give better results (Bertoncini et al., 2017). Emission model calculations have uncertainties in their estimation and to address these uncertainties a combined Variable Speed Limit (VSL) and Cell Transmission Model (CTM-VSL) approach is applied (Sayegh et al., 2018) besides research in emission modelling also started using Artificial Neural Network for better predictability (Wang et al., 2018).

### 6.2.3. Integrated Model:

The emission model studied in combination with input variables like ambient weather conditions, vehicles age, and HC estimation was studied in Montreal for GHG emissions (Sider et al., 2015), while NOx is calculated after integrating emission with atmospheric dispersion models (Shekarrizfard et al., 2016). Computer programming in emission monitoring is conducted using Python Tool Kit SAGGET for small area emission (Wohlstadter et al., 2016). Linking transport dynamics to emission forecasting generates long-term emission estimates (Guzman and Orjuela, 2017) and to manage clean cities, macroscopic traffic models are combined with macroscopic emission models using geographic information systems to observe the impacts of green drivers on traffic emissions (Perez-prada et al., 2017). Likewise, air quality modelling has also become part of urban mobility, where the movement of the particulate matter and NOx were analyzed incorporating the VSP model and VADIS models (Vicente et al., 2018). A novel index named Energy Consumption Index is established for energy-efficient driving behavior evolved using Generalized Regression Neural Network, VSP, and CMEM models (Xu et al., 2018). Further models are also seen being integrated like VISUM, TREM, and GIS for the generation of high spatial-temporal resolution emission inventories (Li et al., 2019).

### 6.2.4. Transport Management

Taxis and bus services offer insight into hot areas for emission though even at the terminals, different emission levels were detected at disembarkment, loading, and transit locations particularly for PM (Qiu et al., 2016). Emissions, in an analytical study done in Madrid, compared different existing model's emission results (López-Martínez et al., 2017) on the bus service in Madrid and related fleet. Trucks use diesel that releases more $CO_2$ and NOx while gasoline emits more CO (Prakash and Habib, 2018), if the fuel is changed to Compressed Natural Gas $CO_2$ emissions are further reduced by 17-23% and 31-42% for near and long terms, respectively (Lajevardi et al., 2018). Weaving road segments generates more emissions due to complex vehicle manoeuvrings, such as greater acceleration and

harder braking. Urban traffic management and planning this year again remains the pillar of global research as vehicles remain the major cause of pollution in urban areas. Roundabouts are observed to be generating more exhaust gases (Jaworski, 2019) due to specific traffic conditions like braking, accelerating, etc, so are the curves of road designs as it releases enhanced emissions (Zhang et al., 2019), and one-way traffic management is also environmentally friendly (Fan et al., 2019). Even the signalized intersection roles in $CO_2$ emission need to be understood as enhanced signal timings, arrival rate, and multiple traffic interference are bound to increase emissions (Zhao et al., 2019)(Conditions, 2019). Therefore, the impact of greenhouse gas reduction has forced researchers and planners to focus not only on the technological elements of IC Engine design or fuel type but on the generation of an Intelligent Traffic Management System (Bento et al., 2019) that evaluate the spatiotemporal releases due to traffic and road design parameters as well. Likewise, the location of bus stops can be shifted after parks, cinemas, malls or pedestrian areas as the trajectory of emissions show lower emission levels as buses decelerate or stop and increase at the time of acceleration after the stop (Xing et al., 2019). A bottom-up approach in macro perspective is analyzed in China to reveal that commuters living in an outer periphery of cities tend to cause greater emissions than the one living in the city centers (Wang and Zeng, 2019). We mostly calculate emissions based on VKT, however, emissions are released both during operations and during idling and this concept is discussed in the form of disaggregate emission models when emissions from bus services are analyzed that should consider both the running emissions and the time of transit when these are idling, emissions are however dependant on the number of passengers and vehicle load (Waraich et al., 2020). People commute in nowadays dynamics and whether it is a bus terminal or daily commute the multimodal choices let people go through using different vehicles even for one singular journey and here a person trip must account for all the modal choices and their emissions in the journey. Similar research is being carried out through Vehicle Specific Power and Emission Measurement System (Chen et al., 2020). In the USA dampening effect on traffic waves by autonomous driving, behaviour is studied and it was observed that integration of even a single-vehicle generates results after some time

### 6.2.5. Policy & Planning integration

Local government bodies do utilize emission model data in planning for urban traffic controls, road networks, and traffic management to avoid congestion (Grote et al., 2016b)(Elkafoury et al., 2015). A modelling platform is being designed to provide support to environmental decision-making management systems called OLYMPUS that are expected to introduce refinement in traffic modelling (Etuman et al., 2018). Traffic Planning, road network planning involving the design of the roads for vehicle flow like intersections, roundabouts, weaving roads, slopes, etc are designed not only to reduce anthropogens but noise pollution as well though noise is not in our scope of study yet a part of transport management and design system (Estévez-mauriz and Forssén, 2018). In 2020, the focus of research revolves around environmental planning relating to the design of cities and enhancing the road planning that could lead to lesser fuel emission of vehicles from different aspects like longitudinal slope designs for roads as quantified models show different emission patterns on the uphill, downhill and flat roads for passenger cars in

Canada (Xu et al., 2020). Similar research on longitudinal slopes is conducted in China for diesel trucks for low carbon operations (Dong et al., 2020). The urban concept of polycentrism, mass transit scheme, and alternate fuel vehicle is discussed in a commuting model that can bring significant GHG emission reduction in metropolitan cities (Yang et al., 2020). Overall evolving trends can be seen in Fig. 12 below:

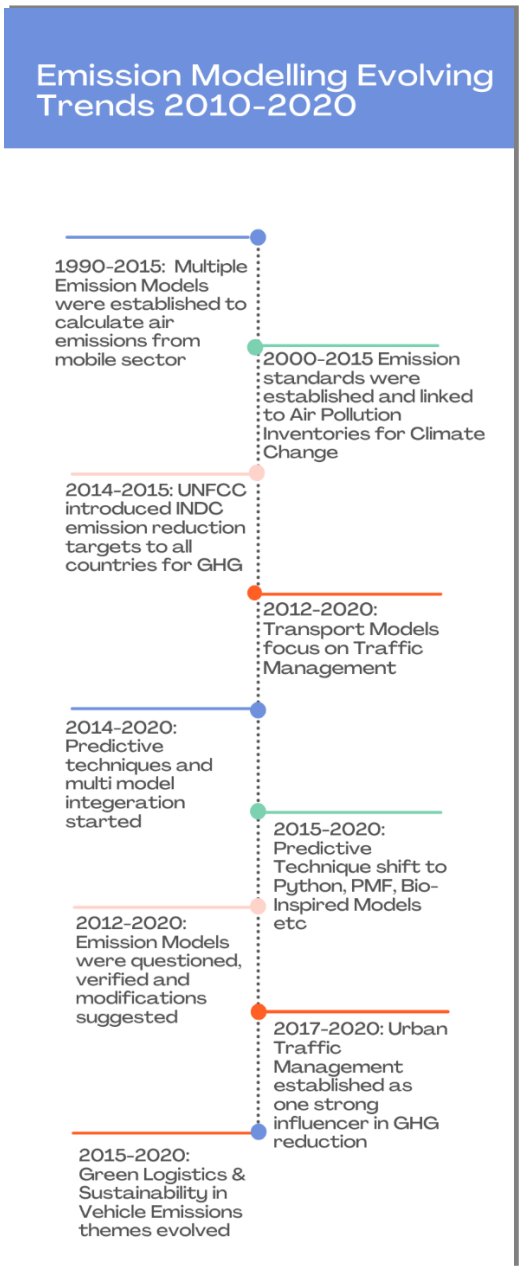



**Fig. 12.** Research Themes (2016-2020)

## 7. CONCLUSION:

We have performed descriptive analysis along with Bibliometric and content analysis to map the previous literature on transport emission models. For Bibliometric and descriptive analysis all published research from the past 20 years was taken into consideration however for content analysis we wanted an in-depth review of the literature and performed analysis on the top-cited publications (past 10 years), as well as the most recent literature (past 5

years). The reason for doing so is we wanted to analyze the top-cited work, but we also wanted to provide researchers with an opportunity to get an idea of the recent trends and provide a comparative analysis.

We have identified that there has been tremendous growth in the number of research publications over the past few years in the transport emission models area. Hatzopoulou, M. was discovered to be the most productive author, with ten papers published in the said area. The most productive institution is National Oceanic and Atmospheric Administration is with 20 total publications. The top three journals in the discipline with the most publications are 'Atmospheric Environment,' 'Transportation Research Part D Transport And Environment,' and 'Atmospheric Chemistry And Physics.'

It's worth noting that the United States, the United Kingdom, and Germany are the top three countries in terms of collaboration. China published more research articles than Germany, but their collaborative research is significantly less. Algeria, Oman, Ukraine, Vietnam, New Zealand, Singapore, Malaysia, Argentina, Iran, Mexico, Pakistan, Slovenia, and Tunisia are among the countries with the least number of publications showing these countries have paid less attention towards transport emission models. Through co-occurrence of keywords analysis, we determine that the most prominent keywords are Emission Models, Traffic Emissions, and Modelling showing that most of the research is surrounded by these 3 main streams keywords. We also identified some of the least studied keywords that have fewer occurrences and are recently studied by the researchers making them the hot topics for future researchers.

From Content Analysis of the last ten years, it is learnt that standard emission models like COPERT, HBEFA, MOVES, etc are used by most countries, however, adaptations according to specific needs of a country can also be made like VAPI in India or HERMES in Spain, etc. New variables like vehicle class, vehicle velocity, payload, driving behaviour, tractive power etc were introduced leading to new emission models in static and dynamic conditions for multiple fossil fuels namely GREET, SMOKE, LOTUS-EUROS etc. This opens the door for future researchers to develop simplified techniques, better predict variables from multidisciplinary fields. Few results are deceptive like per capita emission rate of modal urban transport for the bus would indicate least per capita emission, but environmental deterioration caused by freight and buses are far higher than the benefits sought. It is also the takeaway of this review that emissions can significantly be achieved by better traffic planning and management skills.

From the last five years analysis of related work independent of citation shows the enhanced usage of innovative techniques, AI, smarter algorithms, integrated models projecting multi-dimensional environmental impacts. Evolving models cover more of the spatial and temporal depth by focussing on emissions not only from fuel but add on causes as well from the basic design to system usage. This would enable future researchers to work on emission impacts of the road network, traffic dynamics, traffic management, driving patterns, traffic calming, resulting in efficient policies and organized traffics especially of urban hotspots.

## 8. LIMITATIONS

Since this study is the first of its kind, we didn't put limitations on the duration and took studies from the past 10 years to provide a comprehensive review of the literature. Future studies could take a shorter span and provide an in-depth analysis of the recent literature. This research is focussed on Carbon Emissions, road transport and air pollutants future research can be on other pollutants like Ammonia, Particulate Matter etc, likewise rail, air or sea can be selected as a mode of transport soil or water can be the contaminated element other than air. The number of published articles selected as a part of the study is taken from just one database i.e., the Scopus database. Future research could incorporate findings from various databases, such as Web of Science and Google Scholar, or conduct a review combining data from multiple databases.

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# 9. APPENDIX

## 9.1. APPENDIX A: QUERY STRING

603 documents found in Scopus using the following query string

TITLE-ABS-KEY ("emission models" AND "transport") AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012) OR LIMIT-TO (PUBYEAR, 2011) OR LIMIT-TO (PUBYEAR, 2010) OR LIMIT-TO (PUBYEAR, 2009) OR LIMIT-TO (PUBYEAR, 2008) OR LIMIT-TO (PUBYEAR, 2007) OR LIMIT-TO (PUBYEAR, 2006) OR LIMIT-TO (PUBYEAR, 2005) OR LIMIT-TO (PUBYEAR, 2004) OR LIMIT-TO (PUBYEAR, 2003) OR LIMIT-TO (PUBYEAR, 2002) OR LIMIT-TO (PUBYEAR, 2001) OR LIMIT-TO (PUBYEAR, 2000) OR LIMIT-TO (PUBYEAR, 1999) OR LIMIT-TO (PUBYEAR, 1998) OR LIMIT-TO (PUBYEAR, 1997) OR LIMIT-TO (PUBYEAR, 1996) OR LIMIT-TO (PUBYEAR, 1995) OR LIMIT-TO (PUBYEAR, 1994) OR LIMIT-TO (PUBYEAR, 1993) OR LIMIT-TO (PUBYEAR, 1992) OR LIMIT-TO (PUBYEAR, 1991))

## 9.2. APPENDIX B

**Table 1.** Top 20 well explored keywords in the previous literature (based on their TLS)

| Keywords | Links | Total link strength | Occurrences | Avg. pub. year |
|---|---|---|---|---|
| Emission Models | 40 | 77 | 51 | 2012.4 |
| Emissions | 37 | 60 | 39 | 2011.3 |
| Modelling | 31 | 49 | 25 | 2009.6 |
| Air Quality | 30 | 41 | 18 | 2013.5 |
| Emission Inventory | 26 | 37 | 15 | 2013.6 |
| Greenhouse Gas (Ghg) Emissions | 19 | 33 | 17 | 2015.1 |

| Keywords | Links | Total link strength | Occurrences | Avg. pub. year |
|---|---|---|---|---|
| Road Traffic Model | 18 | 33 | 12 | 2012.6 |
| Air Pollution | 20 | 27 | 20 | 2014.3 |
| Carbon Dioxide | 17 | 23 | 8 | 2010.2 |
| Moves | 12 | 20 | 8 | 2015.8 |
| Nox Emissions | 12 | 19 | 8 | 2012.8 |
| Vehicle Emissions | 16 | 18 | 16 | 2013.8 |
| Emission Factors | 13 | 16 | 10 | 2016.2 |
| Methane | 9 | 16 | 8 | 2011.5 |
| Congestion | 11 | 15 | 5 | 2013.6 |
| Traffic Emissions | 10 | 13 | 8 | 2011.5 |
| Dust Emission | 10 | 13 | 8 | 2010.6 |
| Climate Change | 10 | 13 | 6 | 2010.1 |
| Road Transport Emissions | 10 | 12 | 4 | 2014.5 |
| Dispersion Modelling | 11 | 12 | 6 | 2012.1 |

**Table 2.** Top 20 emerging hot topics (based on average publication year)

| Keywords | Links | Total link strength | Occurrences | Avg. pub. year |
|---|---|---|---|---|
| Autonomous Vehicles | 4 | 4 | 2 | 2019.5 |
| PM 2.5 | 4 | 4 | 2 | 2019.5 |
| Bus Stops | 1 | 1 | 2 | 2018.5 |
| Nitrogen Dioxide | 2 | 2 | 2 | 2018.5 |
| Sediment Transport | 2 | 2 | 2 | 2018.5 |
| Vehicle Specific Power | 2 | 2 | 2 | 2018.5 |
| COPERT | 3 | 3 | 2 | 2018 |
| Environment | 3 | 4 | 2 | 2018 |
| Emission Rate | 2 | 2 | 2 | 2017.5 |
| Diesel | 5 | 5 | 2 | 2017 |
| Road Transport | 1 | 2 | 2 | 2017 |
| Urban | 7 | 7 | 2 | 2017 |
| Driving Pattern | 5 | 8 | 7 | 2016.7 |
| Electric Vehicle | 5 | 5 | 8 | 2016.6 |
| Local Government | 5 | 9 | 2 | 2016.5 |
| Numerical Modelling | 6 | 7 | 4 | 2016.5 |
| Emission Factors | 13 | 16 | 10 | 2016.2 |
| HBEFA | 2 | 2 | 2 | 2016 |
| Life Cycle Assessment | 3 | 3 | 2 | 2016 |
| Transit Bus Emissions | 5 | 10 | 3 | 2016 |

**Table 3.** Top 10 countries based on the number of published documents.

| Country | Documents | Citations | Total Link Strength |
|---|---|---|---|
| United States | 181 | 7437 | 118 |
| China | 101 | 1302 | 38 |
| United Kingdom | 58 | 2810 | 66 |
| Germany | 40 | 1670 | 54 |
| France | 37 | 1390 | 56 |
| Canada | 34 | 1343 | 24 |
| Japan | 30 | 1569 | 31 |
| Italy | 27 | 1068 | 36 |
| India | 26 | 716 | 6 |
| South Korea | 26 | 678 | 23 |
| Spain | 22 | 542 | 8 |
| Sweden | 21 | 603 | 17 |

| Country | Documents | Citations | Total Link Strength |
|---|---|---|---|
| Netherlands | 17 | 495 | 18 |
| Brazil | 16 | 613 | 20 |
| Australia | 15 | 286 | 17 |
| Portugal | 15 | 329 | 8 |
| Belgium | 14 | 976 | 17 |
| Austria | 13 | 313 | 15 |
| Greece | 13 | 264 | 13 |
| Taiwan | 12 | 341 | 3 |