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A bibliometric analysis on trends and characters of carbon emissions from transport sector

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ABSTRACT

Transport sector's substantial contribution to global greenhouse gas emissions has made it a growing area of study and concern. In order to identify trends and characteristics of carbon emissions research in the transportation sector we conducted a Bibexcel and complex network analysis for the period 1997–2016. In addition, we identify critical themes and contributions of research articles using *h-index*, PageRank and cluster analysis. We report contribution of countries, authors, institutions and journals, as well as performance of citations and keywords. Co-citing situations between different countries, authors, and institutions are also analyzed using network analysis. Between 1997 and 2016 we found a rise in publications on carbon emissions in the transportation sector and increased cooperation between countries, authors, and institutions. Authors from the USA, China and United Kingdom published the most articles and articles with the highest academic influence. Tsinghua University from China is the leading institution in carbon emissions research in the transportation sector. The most widely published author and cited author is Dr. He. We conclude our analysis by analyzing keywords and trends to suggest critical topic areas of future research. The systematic approach undertaken in this study can be extended and applied to other research topics and fields.

1. Introduction

The transportation sector accounts for 23% of global CO_2 emissions, the majority of which result from the burning of fossil fuels (Liu et al., 2015). The substantial contribution of the sector to global greenhouse gas emissions has made it a growing area of study and concern. Efforts to reduce carbon emissions will be further challenged by forecasts of 25% GDP growth in the transportation sector by the year 2030 (Liu et al., 2015; Timilsina and Shrestha, 2009).

The Kyoto protocol agreement brought political attention to reducing carbon emissions in the transportation sector as countries sought strategies to reduce their greenhouse gas emissions. In 1997, at the time of the Kyoto protocol agreement two-thirds of transportation related carbon emissions originated from the wealthiest 10% of countries (Hensher and Button, 2003). In the last 20 years, however, the distribution of emissions has changed with increasing emissions coming from developing countries with fast growing economies and rising household incomes. Carbon emissions from the transportation sector are projected to rise without

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substantial technological advancements and behavior changes. Reducing emissions from the transportation sector is critical to reach the Paris Agreement's goal of keeping global temperature rise below 2 degrees Celsius above pre-industrial levels.

Research on carbon emissions in the transportation sector have mainly focused on three key areas: trends and drivers of emissions; scenario analysis of future emissions; strategies to limit or reduce transportation related carbon emissions.

(1) Trends and drivers of carbon emissions in the transportation sector

Michaelis and Davidson reviewed greenhouse gas mitigation measures in the transportation sector, concluding that to reduce carbon emissions requires technological innovation to offset future growth. Policy changes alone, they argue, would not be adequate (Michaelis and Davidson, 1996). Chapman conducted a review of transport and climate change focusing primarily on approaches to reduce emissions from personal vehicles, road freight and aviation. The review found that adoption of energy efficient technologies requires behavior changes and policy support (Chapman, 2007). Lakshmanan and colleagues explored driving factors underlying transportation CO_2 emissions in the USA using decomposition analysis. Results of their analysis identified the three most important factors driving emissions to be growth in per capita vehicle kilometers travelled, population, and GDP (Lakshmanan and Han, 1997). Timilsina and colleagues explored rising transportation related CO_2 emissions in selected Asian countries between the years 1980 and 2005. The authors found that modal shift, increasing GDP per capita, fuel mix, and emission coefficients explained rising emission in the selected countries (Timilsina and Shrestha, 2009).

(2) Forecasting future transportation related emissions and scenario analysis

Hao and his colleagues developed a bottom-up model to simulate energy consumption and greenhouse gas emissions of China's passenger vehicle fleet under five different scenarios including constraining vehicle registration, reducing vehicle travel, strengthening fuel consumption rates, vehicle downsizing and promoting electric vehicle penetration. Implementing all five measures together, the authors found, would reduce fuel consumption by 37% by 2030 in comparison to the reference scenario (Hao et al., 2011). Karplus and his colleagues evaluated the impacts of Corporate Average Fuel Economy (CAFE) policy on transportation related carbon emissions in the USA over the period 2015 to 2030 (Karplus and Paltsev, 2012). The authors' analysis of implementing a 5% CAFE policy would reduce gasoline use by 25 billion gallons per year, reduce CO_2 emissions by 190 million metric tons per year and cost $25 billion per year relative to a no CAFE standard baseline.

(3) Strategies to limit or reduce transportation related carbon emissions

Research on strategies to reduce carbon emissions in the transportation sector have mainly focused on the adoption of alternative fuel sources with lower carbon content (Cuda et al., 2012; Kumarappan et al., 2011; Aryanpur and Shafiei, 2015) or the adoption of energy efficient technologies such as electric or fuel cell powered vehicles (Weiss et al., 2011; Pavlovic et al., 2016; Mohamed, 2016). Shiau and Michalek looked at optimal design and allocation vehicles to minimize life cycle greenhouse gas emissions (Shiau and Michalek, 2010). Krauss and his colleagues reviewed studies related with powertrain market penetration scenarios to optimize fleet composition see (Krause et al., 2030). They formulated Bayesian Belief Networks to predict how future technology and policy scenarios will influence market shares of different vehicle types. Bishop and his colleagues modelled contributions of vehicle downsizing, technology switching and changes in VKT necessary to determine an optimum UK passenger vehicle fleet composition to reduce greenhouse gas emissions (Bishop et al., 2016). Ehmke and his colleagues explored reducing the number and length of trips using personal vehicles, through changes in routing, modal shift and transport infrastructure (Ehmke et al., 2016).

The aforementioned studies highlight aspects of a rapidly growing body of research. No articles, however, have attempted to summarize scientific development based on bibliometric and network analyses to review this topic systematic in the existing literature databases. To fill this gap, we propose a systematic approach combining bibliometric and complex network analyzes to comprehensively review carbon emissions research in the transportation sector. Given the breadth of research on the topic, a systematic review will help researchers understand key developments and patterns in such a field over time, identify major contributions and contributors, and direct their research agendas. Systematic reviews differ from traditional narrative reviews by employing a replicable, scientific and transparent process that minimizes selection bias inherent in exhaustive literature searches (Vrabel, 2015). Using this unique approach, we identify trends and characteristics of carbon emissions research in the transportation sector from 1997 to 2016. Specifically, we identify thematic developments, contributions by country, institutions, authors and journals as well as cooperation between different countries, institutions, and authors. Based on the results we suggest several important areas of future research, particularly with the potential application of renewable and sustainable energy sources in the transportation sector. The rest of the paper is structured as follows: Section 2 describes data collection tools and methodological approaches; Section 3 presents results of the bibliometric and complex network analyzes; and, Section 4 summarizes key findings and highlights a research agenda forward.

2. Methodology, data collection and treatment

2.1. Methodology

We use a hybrid approach to systematically review research on carbon emissions in the transportation sector integrating

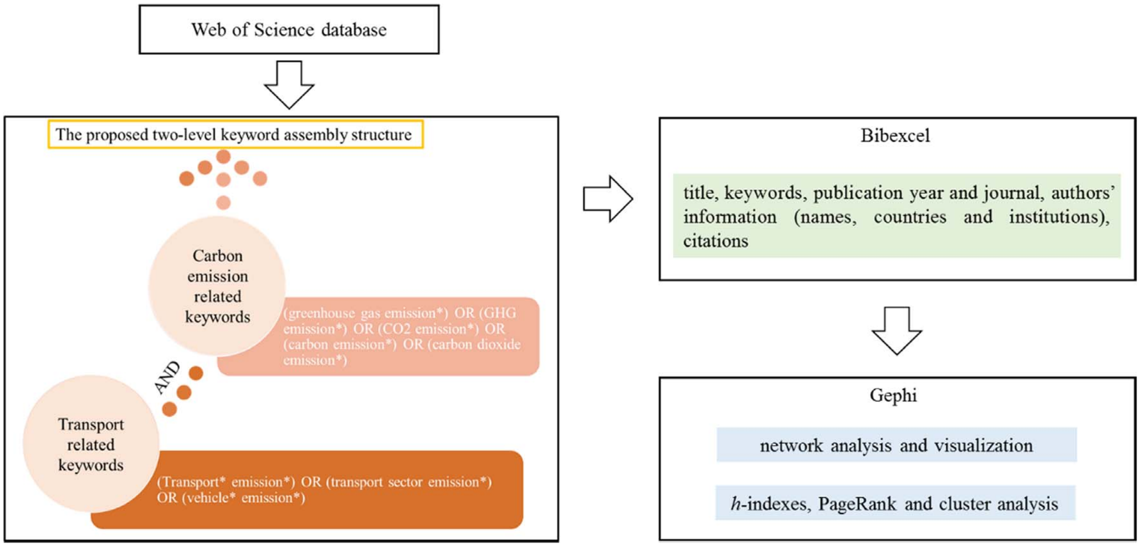

Fig. 1. The general flow chart with literature analysis (note: for keywords analysis, *presents "truncation symbol" which is used for searching vocabularies' plurality and derivate).

bibliometric, network, cluster and PageRank analyzes. A description of the research process and integration of analytical tools is shown in Fig. 1.

2.1.1. Bibliometric analysis

To carry out the bibliometric analysis we used Bibexcel. Bibexcel is a versatile bibliometric tool developed by Persson (Persson et al., 2009) and is widely regarded as a flexible data management and analytical tool (Zheng et al., 2015). Bibexcel allows users to easily import data from research databases such as Web of Science and Scopus, and links with other software tools, such as Pajek, Excel, SPSS, and Gephi (Fahimnia et al., 2015). For a detailed description of Bibexcel see Persson et al. (2009) and Šubelj et al. (2014).

2.1.2. Network analysis

Network analysis identifies patterns, linkages and relationships among interacting units (Wolfe, 1994). In literature reviews, network analysis is used to create a network of nodes that represent research papers, keywords, countries, institutions, and authors to understand contributions and relationships among nodes. This study uses the network analytical tool Gephi. Gephi is an award-winning, open-source platform well suited to visualize and manipulate large datasets (Gephi, 2014).

2.1.3. Cluster analysis

Cluster analysis is increasingly used in bibliometric studies to understand actors, relationships and ideas shaping the development of a field or research topic (Everitt and Cluster, 2011). We undertake cluster analysis to identify papers of similar topics, discern co-citation relationships, and understand collaboration patterns between authors and institutions.

2.1.4. PageRank analysis

PageRank analysis is an algorithm developed by google to rank the importance of websites based on the number and quality of links a website has (Boldi et al., 2009). PageRank has been extended to literature analysis to rank the importance of articles. An article's importance is determined based on the number of times an article is cited by other highly cited articles (Yates and Dixon, 2015).

2.2. Data collection and screening

Using the Web of Science database we employed a two-level keyword assembly structure focusing on transport related keywords and carbon emissions related keywords for the period 1997–2016. Fig. 1 presents the assembly structure where level 1 includes transport related keywords, and level 2 includes carbon emissions related keywords. The search was conducted in April 2017. One thousand five hundred and twenty-three (n = 1523) academic papers were identified in the initial search. Among these: 77.9% were journal articles, 18.8% were proceedings papers, 2.2% were review papers and 0.1% were classified as 'other'. We screened the initial selection to include English papers only (n = 1177). Further refinement by the researchers after reading abstracts and titles were used to eliminate articles which were found to be irrelevant. After refinement the final study database is comprised of 754 research publications.

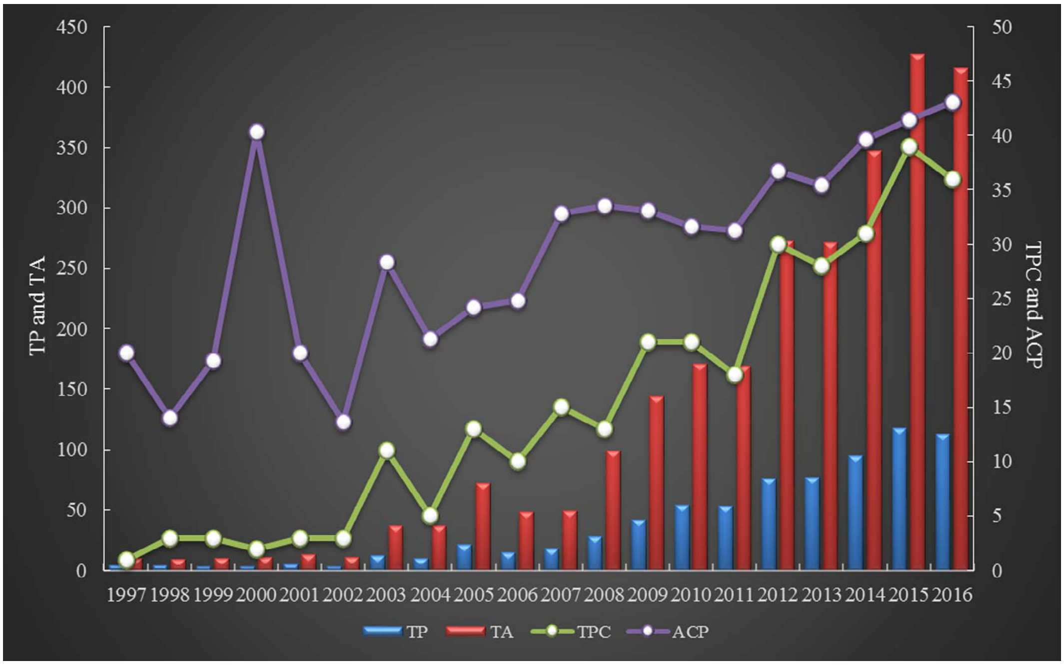

Fig. 2. General performance of selected publications from 1997 to 2016.

3. Results

3.1. General performance of selected publications

Academic interest in subjects considering carbon emissions from the transportation sector increased substantially over the study period. Fig. 2 presents results by year for total number of publications (TP), total number of authors (TA), average citations per paper (ACP) and total number of publishing countries (TPC). Total publications between the years 1997 and 2016 increased slowly per year until 2008 then much more rapidly from 2009 onward. The increase in total number of authors reveals a similar trend increasing dramatically over the study period from 10 in 1997 to 416 in 2016, an increase of over 40 times. Average citations per paper doubled between the years 1997 to 2016. Researchers from more countries worked on the topic as well. Total publishing countries increased from 1 in 1997 to 36 in 2016.

The upward trend in research parallels growing international attention to understand and reduce greenhouse gas emissions. In 1995, the Intergovernmental Panel on Climate Change (IPCC) estimated the first global account of greenhouse gas emissions identifying the transportation sector as a major contributing sector to global greenhouse gas emissions. The Kyoto Protocol subsequently labeled the sector a priority area for wealthy countries to address as part of their reduction plans (Programme, 1995).

3.2. Performance of countries, institutions and authors

Higher number of publications by a respective author, institution, or country is not necessarily equivalent to influence. To determine influence we also report *h-index* values to compare the contributions of authors, institutions and countries. *H*-index was proposed by Hirsch (year) to characterize the scientific output of a researcher as an estimate of the importance, significance, and broad impact of a scientist's cumulative research contributions (Bornmann et al., 2011; Hirsch, 2005). Fig. 3 presents *h-index* scores for author/institution/country. An author's, institution's, or country's proximity to the dashed line, distinguishes their academic contribution. The dashed line is where y = x. X represents the total number of publications and y represents *h-index*. A large gap, for example, between total number of publications and *h-index* for a country/institution/author would indicate high output but with minimal influence. Fig. 3 also displays collaboration between different countries/institutions/authors to reveal the important role of collaboration in supporting the advancement of influential research.

3.2.1. Performance of countries

Scholars from 61 different countries published research on transportation related carbon emissions between the years 1997–2016 (Fig. 3 CO). The majority of publications originated from 10 countries (n = 650, 86%). Among those, the United States accounted for a third of publications (33.7%), followed by China (15.5%), United Kingdom (9.2%), Canada (4.8%), Japan (4.6%), Germany (4.5%), Spain (4.1%), Italy (3.6%), South Korea (3.2%) and Australia (3.1%). The top three countries in terms of total publications, United States, China and United Kingdom had the highest research influence scores as well.

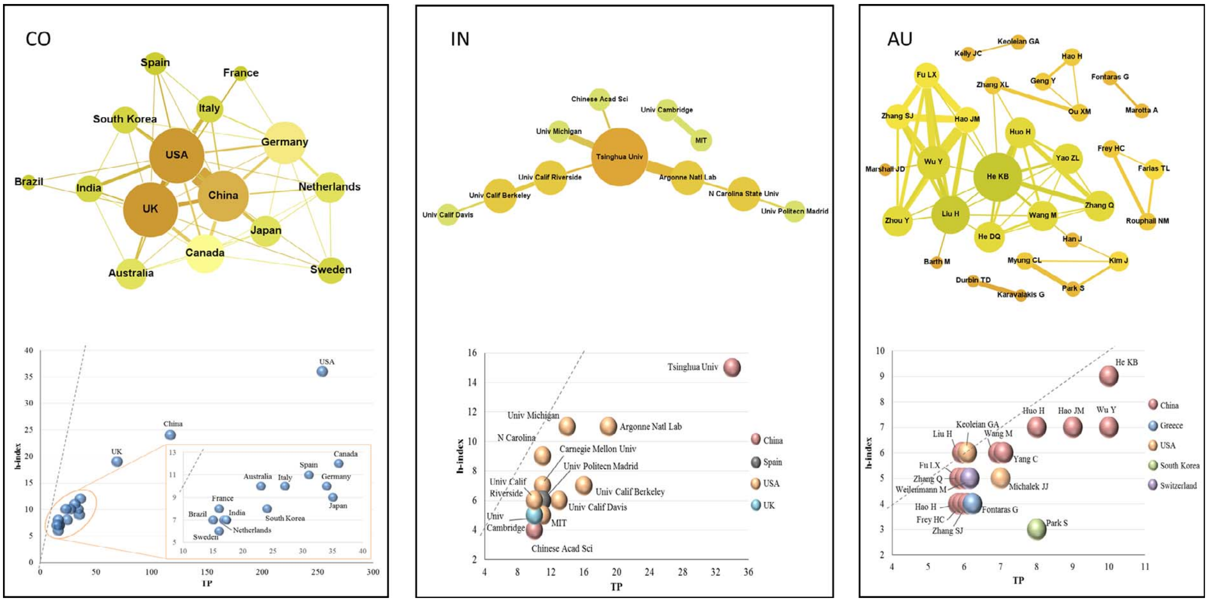

Fig. 3. Performance of countries (CO), institutions (IN) and authors (AU).

Among the top publishing countries all of them belong to OECD except China. As OECD countries generate the most transportation related greenhouse gas emissions their respective research contribution makes sense (Schipper et al., 1997). With a rapidly expanding economy and growing transportation sector, China is also challenged to identify opportunities to reduce transportation related carbon emissions. As the transportation sector depends heavily on crude oil as an energy source, countries such as China and United States rely heavily on oil imports to support domestic demand. Interestingly, research on transportation related carbon emissions from China and the United States are often framed around energy security in addition to climate change (Morrow et al., 2010; Wang et al., 2007).

In terms of academic cooperation between countries, USA researchers have the highest level of cooperation with other countries. Researchers in USA have collaborated frequently with China (29 joint papers), United Kingdom (8 joint papers) and Italy (6 joint papers). Researchers from the United Kingdom have the second highest level of cooperation with other countries, including USA (8 joint papers), China (6 joint papers) and Canada (5 joint papers). China has the third highest level of cooperation, including USA (29 joint papers, United Kingdom (8 joint papers) and Canada (5 joint papers). Cooperation between developed countries is more frequent than with developing countries. China is a notable exception as the government invests substantial funds to support joint research with developed countries to address environmental problems in China. China's emphasis on academic cooperation is considered an important approach to help advance technological development and policies to reduce carbon emissions in the transportation sector.

3.2.2. Performance of institutions

Seven hundred and seventy-six institutions conducted research on transportation related carbon emissions between the years 1997 and 2016 (Fig. 3 IN). Researchers from Tsinghua University published 34 articles, followed by Argonne National Laboratory (19 articles), University of California Berkeley (16 articles), University of Michigan (14 articles) and University of California, Davis (13 articles). Using *h-index* values as a metric of total contribution value, Tsinghua University, Argonne National Laboratory, University of Michigan, North Carolina State University and University of California Berkeley contributed research with the highest academic influence. In terms of cooperation, Tsinghua University collaborated most often with other institutions, notably, Argonne National Laboratory and University of Michigan.

3.2.3. Performance of authors

Fig. 3 (AU) presents total publications and *h-index* scores of the top 17 most productive authors (6 publications or more). He KB and Wu Y have the most publications and highest *h-index* scores. In terms of collaboration, He KB from Tsinghua University has the largest author node, co-authoring articles with Huo H and Zhang Q on the subject of fuel economy of the road transport sector. Liu H has the second largest author node co-authoring papers with Hao JM and Wu Y on control strategies for vehicle emissions.

3.3. Performance of journals, citations and keywords

Articles on transportation related carbon emissions have been published in a wide variety of journals. We examined journal titles, citations and keywords to identify topic areas, key themes and influential articles.

Table 1
Top 15 journals from 1997 to 2016.

Journal	Amount	Percentage	Impact factor
Energy Policy	69	9.15%	3.045
Transportation Research Part D-Transport and Environment	60	7.96%	1.864
Atmospheric Environment	42	5.57%	3.459
Transportation Research Record	40	5.31%	0.522
Energy	36	4.77%	4.292
Environmental Science & Technology	35	4.64%	5.393
Applied Energy	32	4.24%	5.746
Transportation Research Part A-Policy and Practice	15	1.99%	1.994
Journal of the Air & Waste Management Association	15	1.99%	1.613
Transport Policy	14	1.86%	1.522
Journal of Cleaner Production	13	1.72%	4.959
International Journal of Sustainable Transportation	11	1.46%	3.209
Energies	10	1.33%	2.077
Science of the Total Environment	8	1.06%	3.976
International Journal of Hydrogen Energy	8	1.06%	3.205

3.3.1. *Journals analysis*

The 754 articles considered in our analysis were published in 237 different journals. The top 15 journals publishing articles on the subject (listed in Table 1) account for 54% of total publications. Among these journals, *Energy Policy* has the most publications addressing transportation related carbon emissions (69 articles), followed by *Transportation Research Part D-Transport and Environment* (60 articles), *Atmospheric Environment* (42 articles) and *Transportation Research Record* (40 articles). The subject matter descriptions of the top 15 journals include energy consumption and/or carbon emissions. Several journals including *Transportation Research Part D* explicitly identify environmental impacts of transportation as a theme. *Atmospheric Environment* is not a transportation specific journal, but focusing on impacts of the changing atmospheric composition on human health, air quality, climate change, and ecosystems.

3.3.2. *Citation analysis*

The articles analyzed cited 21,694 references. The top 15 most cited references are shown in Table 2. In order to identify the relationships between co-citing references, we used cluster analysis to identify co-citing networks (Fig. 4). PageRank identifies the lead papers of each cluster and prevalent topics. As depicted in Fig. 4, there are 4 main co-citing networks. The largest cluster has 18 papers based on Yang C, 2009 (PageRank: 0.0988), focusing on life cycle assessment and scenario analysis. The second largest cluster has 13 papers based on Wang WW, 2011 (PageRank: 0.0377) focusing on driving factors, decomposition analysis and passenger transport. The third cluster includes 12 papers based on Yan X, 2009 (PageRank: 0.1199), focusing on road transport, energy consumption and vehicle emissions. The fourth cluster has 6 papers based on Vliet, 2011 (PageRank: 0.0345) focusing on electric vehicles and fuel economy.

3.3.3. *Keywords analysis*

Among the 754 selected publications, 594 included keywords. One thousand seven hundred and thirty-one different keywords were used. Some keywords with the same meaning were considered as one entry for analysis purposes. For example, “GHG emissions”, “greenhouse gas emissions” and “transportation sector”, “transport sector”, are commonly used keywords that have the similar meanings. Scrubbing for overlap in meanings, 1503 different keywords were analyzed further. Seventy-four percent (74%) of keywords appeared only once while 2% of keywords were used at least 10 times. In addition to examining keywords most commonly used, we categorized keywords by topic category, methodology, study region, and purpose. Fig. 5 presents most used keywords (ten times or more) by reference category.

For topic category, central themes focused on describing current emissions from the transportation sector, and strategies to decrease future emissions. Key sub-categories include, transportation, emissions, energy, mode and technology. Within the transportation category, road transport, was the most researched area, with electric vehicle as the most common topic. The second most frequent topic category was emissions and specifically CO_2 emissions. The energy sub-category was dominated by fuel related keywords such as natural gas and alternative fuels. Within the mode category, vehicle type choice, travel behavior, and transport mode selection were the most common sub topics. The technology topic category relates to technological and design interventions, with keywords: vehicle design, carbon capture and storage (CCS), torque control strategy being the most prevalent.

In terms of methodology, life cycle assessment was the most common method listed in keywords followed by decomposition analysis, agent-based modelling, and systems analysis. Life cycle assessment was most often used to quantify the greenhouse gas emissions and other environmental impacts of technology over its lifespan. For example, the well cited article by Samaras and Meisterling (2008) reported the life cycle GHG emissions of plug-in hybrid vehicles demonstrating that GHG emissions depend not only on the vehicle and battery characteristics but also on the GHG intensity of the electricity and liquid fuel used to power the vehicle (Samaras and Meisterling, 2008).

China is the most commonly studied region identified by keywords, followed by Europe and USA. Associated keywords include

Table 2
Top 15 most cited references from 1997 to 2016.

Year	Title	Country	Author	Journal	Citations	PageRank
2008	Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: implications for policy	USA	Samaras and Meisterling	Environmental Science & Technology	38	0.0321
2005	Oil consumption and CO_2, emissions in China's road transport: current status, future trends, and policy implications	China, USA	He et al.	Energy Policy	26	0.0380
2009	Reduction potentials of energy demand and GHG emissions in China's road transport sector	United Kingdom	Yan and Crookes	Energy Policy	24	0.0346
1997	Energy use and carbon emissions from freight in 10 industrialized countries: An analysis of trends from 1973 to 1992	USA	Schipper et al.	Transportation Research Part D Transport & Environment	17	0.0206
2009	Transport sector CO_2, emissions growth in Asia: Underlying factors and policy options	USA	Timilsina and Shrestha	Energy Policy	17	0.0248
2007	CO_2 mitigation scenarios in China's road transport sector	China	Wang et al.	Energy Conversion and Management	16	0.0272
1997	Factors underlying transportation CO_2 emissions in the USA: A decomposition analysis	USA	Lakshmanan	Transportation Research Part D: Transport and Environment	16	0.0206
2013	Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles	Norway	Hawkins et al.	Journal of Industrial Ecology	15	0.0185
2010	Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions	China	Ou et al.	Energy Policy	15	0.0282
2011	The Pollution-Routing Problem	United Kingdom, Canada	Bektas and Laporte	Transportation Research Part B: Methodological	15	0.0065
2008	Environmental and Energy Implications of Plug-In Hybrid-Electric Vehicles	USA	Stephan and Sullivan	Environmental Science & Technology	15	0.0187
1996	CO_2 emissions from passenger transport	USA	Scholl et al.	Energy Policy	14	0.0218
2007	Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect	USA	Small and Dender	The Energy Journal	14	0.0113
2011	Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet	China	Hao et al.	Energy	14	0.0216
2009	Transport Energy and CO_2: Moving towards Sustainability	France	IEA	Sourceoecd Energy	14	0.0203

Footnote: CO_2-carbon dioxide; GHG-Greenhouse gas; IEA-International Energy Agency.

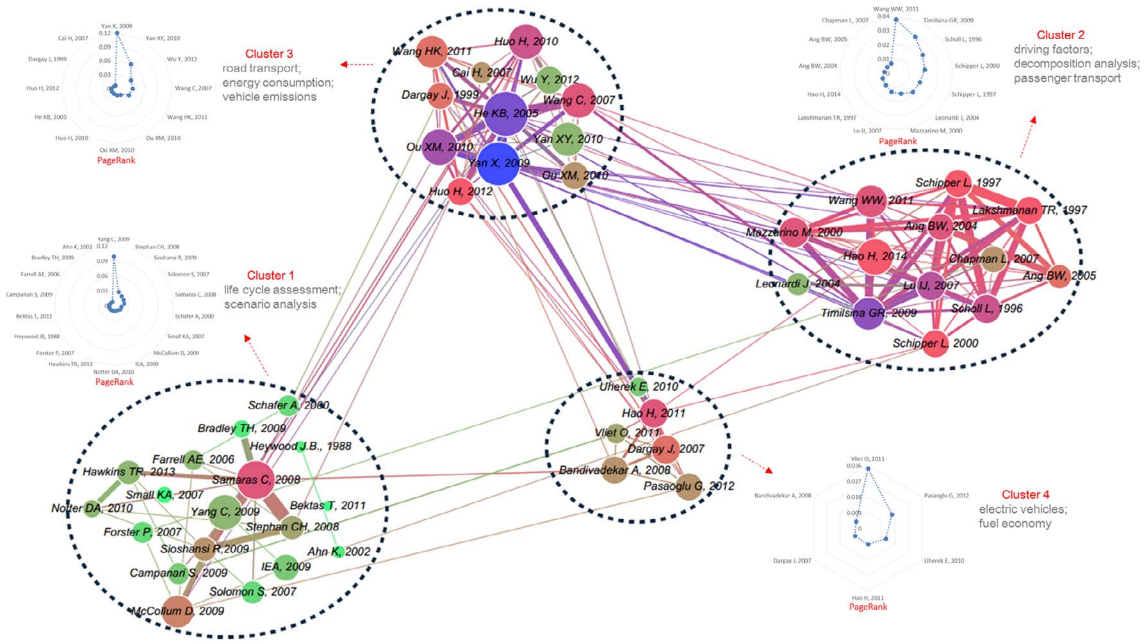

Fig. 4. The cluster structure of the given co-citing network.

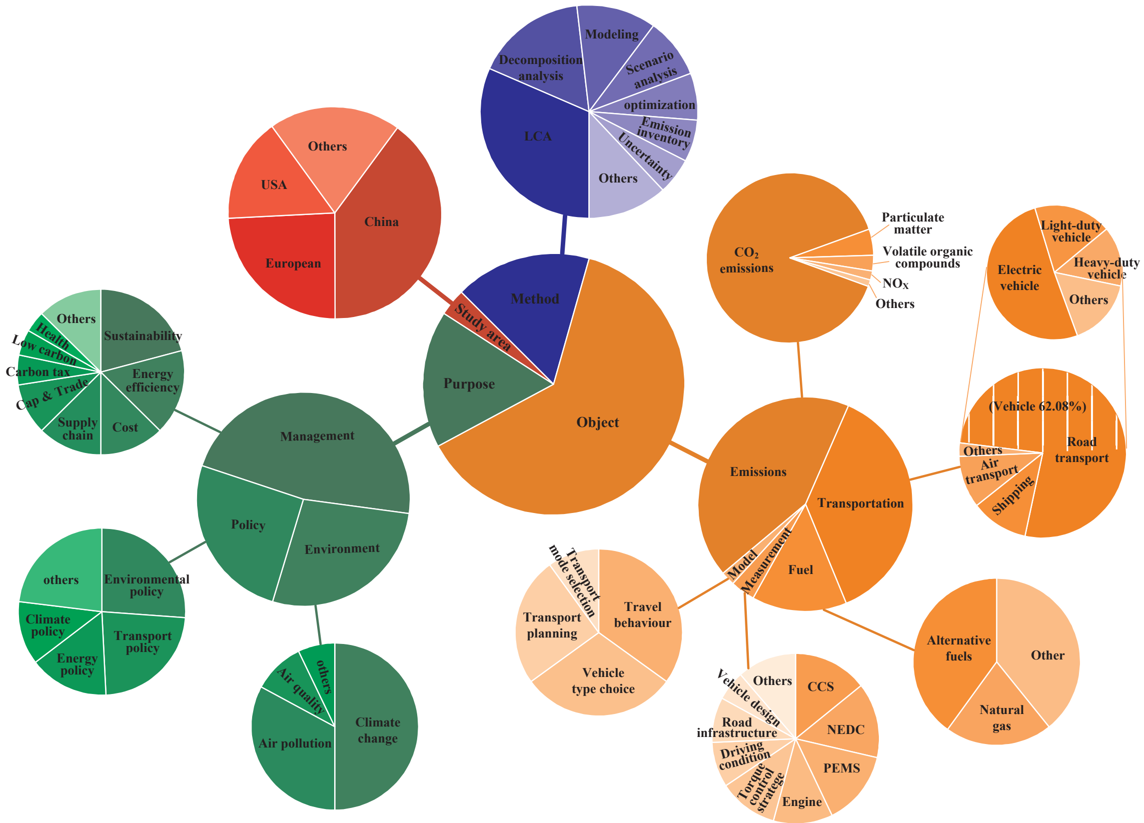

Fig. 5. Research topics from keywords.

climate change, air pollution, air quality and management of transport carbon emission. Other subtopics raised include: energy efficiency, supply chain management, and cap-and-trade. In respect to the purpose category, keyword themes included environmental, energy, transport and climate change.

4. Conclusions and directions for future research

In this study, we conducted a comprehensive review of the scientific literature on transportation related carbon emissions using qualitative and quantitative research tools. Our systematic approach combined bibliometric and complex network analyzes providing the most complete review of carbon emissions research in the transportation sector to date. Our results show that number of publications, the total number of authors, average citations per year per paper and the total numbers of countries conducting research had all increased substantially between the years 1997 and 2016. Authors from the USA, China and United Kingdom published the most articles and articles with the highest academic influence. Tsinghua University from China is the leading institution in carbon emissions research in the transportation sector and exhibited a high level of cooperation with other institutions such as Argonne National Laboratory and University of Michigan. The two most widely published authors are He KB and Wu Y from China. He KB is the most widely cited author and has published the most influential body of work. The journals *Energy Policy*, *Transportation Research Part D-Transport and Environment*, *Atmospheric Environment* and *Transportation Research Record* have published the most articles on carbon emissions in the transportation sector. Our analysis of reference citations identified 4 clusters of co-citing networks. The most remarkable cluster includes 18 papers centered on Yang C, 2009 (PageRank: 0.0988), discussing life cycle assessment and scenario analysis.

Based on our research and additional keyword analysis we have identified three key areas receiving the most research attention: alternative fuels (especially renewable and sustainable energy sources), technological advancements of transportation components, and optimizing vehicle design and transportation systems to promote behavior change. Emerging popular topics include market-based approaches to reduce carbon emissions such as a carbon tax, reduction credit trading and cap-and-trade.

Based on trends and gaps in the literature, we conclude with a list of important future research topics. We encourage more research that discusses social and economic costs and system wide impacts of a specific technology, infrastructure investment or policy change and not just potential emissions reductions. For instance, it is crucial to investigate how the application of renewable energy sources can help mitigate the overall GHG emissions from transport sector. We also encourage greater use of modeling to identify optimal pathways for reducing transportation related carbon emissions that consider impacts and relationships with other industrial sectors. In addition, we recommend that future research emphasize not only carbon emissions but also NO_X, CO, $PM_{2.5}$ given the overlap in emission sources and control strategies. Finally, we see opportunities for more research focused on changing behaviors around transportation choices and understanding the impacts of changing social practices such as online shopping on transportation supply chains.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.trd.2017.12.009.

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