

Review

Evaluation of sustainable transport research in 2000–2019

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ABSTRACT

The transport sector has extensive environmental, social and economic impacts on society and thus it is imperative for this sector to embrace the concept of sustainable development. Since 2000, a significant number of sustainable transport research outcomes have been published. The objectives of this study are to identify the hot research topics, explore knowledge gaps and recommend future directions in the domain of sustainable transport through a holistic review of the literature published in 2000–2019. A total of 882 bibliometric records of journal articles were searched from the Web of Science core collection database. Both quantitative scientometric analysis and qualitative discussion were undertaken to analyse the sustainable transport research. The analysis results showed nine hot research topics: 1) sustainable transport indicators and performance model, 2) sustainable transport policy, 3) involvement of stakeholders, 4) supply chain and logistics management, 5) environmental impact, 6) travel behaviour, 7) new fuels for vehicles, 8) transport strategic planning, and 9) bicycle and public transport. In addition, four knowledge gaps were identified relating to social sustainability of transport, use of information and communication technology, sustainability benefits, and resilient transport to deliver sustainability. Furthermore, future research directions were proposed to bridge these knowledge gaps. This review focuses on the journal articles in English only and may overlook some significant research published in other languages and conferences. Nevertheless, this study still benefits academics, industry practitioners and policy makers by providing an understanding of status quo, hot research topics, knowledge gaps and future research directions in the domain of sustainable transport.

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1. Introduction

The transport sector has extensive environmental, social and economic impacts on human society. This sector accounts for approximately 25% of the worldwide carbon dioxide emissions (Van den Berg and De Langen, 2017). In the US, this sector produced the biggest number of greenhouse gas (GHG) emissions, representing 28.9% of the national GHG emissions in 2017 (US Environmental Protection Agency, 2019). These emissions result from the combustion of petroleum-based products (e.g., gasoline) and contribute to the global climate change (Shanmugam et al., 2019a, 2019b). In addition, the transport sector also contributed 27.6% to the national energy consumption in 2018, second to the industrial sector only (US Energy Information Administration, 2019). Therefore, the transport sector should embrace the concept of sustainable development.

Sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” in The Brundtland Report (World Commission on Environment and Development, 1987). Sustainability has been widely recognised to consist of three dimensions: environmental, social and economic sustainability. Partially based on the research on sustainable development, sustainable transport or sustainable transportation has received great attention of researchers, policy makers and industry practitioners. The concept of sustainable transport stemmed from sustainable development (Hall, 2002). Sustainable transport has both a narrow definition and a broader definition. The former focuses on environmental problems and resource depletion, while the latter encompass the aforementioned as well as social and economic welfare. The latter is preferred as it allows people to take comprehensive considerations into all the impacts of the transport sector (Litman and Burwell, 2006) and encourage people to seek integrated solutions to sustainable transport (Zhou, 2012).

Since 2000, there have been an increasing number of researches on sustainable transport, covering a wide range of topics. Sustainable transport is indeed beyond transport and should also cover institutional reform, governance, policy making, interactions between the transport sector and other sectors (Zhou, 2012), which has been reflected in a wide range of research topics. Therefore, it is necessary to understand: what are the current states, hot research

topics, knowledge gaps and future directions in the domain of sustainable transport? The objectives of this study are to identify the hot research topics, explore knowledge gaps and recommend future directions in the domain of sustainable transport through a holistic review of the literature published in 2000–2019.

2. Previous review work

Literature review helps to gain an in-depth understanding of a research domain (Jin et al., 2018). Researchers have undertaken reviews in the field of sustainable transport. For example, Iftekhhar and Tapsuwan (2010) reviewed the factors influencing travel behaviour and transportation mode choice in Australia and provided implications for sustainable urban transport design; Dernir et al. (2014) reviewed research on green road freight and focused on the fuel consumption models and their roles in road transport planning; Ahmed et al. (2016), Salvi and Subramanian (2015) and Singh et al. (2015) presented a review of the recent development of hydrogen fuel and discussed the potential of using hydrogen fuel for sustainable transport; Centobelli et al. (2017) reviewed the literatures published in 1960–2014 with a focus on the environmental sustainability issues faced by transportation and logistics service providers (LSPs); and Na et al. (2019) analysed the feasibility analysis system for sustainable transport in Korea and proposed strategies to improve the system. In addition, some researchers provided reviews of sustainable transport in a region. Janic (2006) provided a review of the sustainable transport research programs undertaken in the European Union while Zhou (2012) focused on the research programs and policies regarding sustainable transport in the US, with references to Canada and the UK.

These previous review studies focused on a single aspect of sustainable transport or provides a regional summary of sustainable transport research but did not take a holistic view. Thus, it is necessary to undertake a holistic review of the global sustainable transport research. In addition, most of the existing review studies were undertaken reliant on manual reviews, which were prone to subjective opinions and lacked producibility (Hammersley, 2001). This limitation can be addressed by employing the science mapping method with a scientometric analysis (Hosseini et al., 2018b). Therefore, this study aims to undertake a holistic review of global sustainable transport research in 2000–2019.

3. Methodology

This review-focused study applies a science mapping method to analyse the journal articles published between 2000 and 2019 in the domain of sustainable transport.

3.1. Science mapping

Science mapping is recognised as a generic process of analysing and visualising scientific domains (Chen, 2017). Science mapping usually focuses on exploring the intellectual structure of a specific domain and helps researchers to discover and visualise the patterns and trends hidden in a large number of literatures and bibliographic records (Cobo et al., 2011), which have been overlooked in manual reviews (Su and Lee, 2010). In the area of construction management, science mapping has been adopted to analyse various research topics, such as building information modelling (BIM) (Li et al., 2017; Zhao, 2017), off-site construction (Hosseini et al., 2018b), construction waste management (Jin et al., 2019), green building (Darko et al., 2019; Zhao et al., 2019), etc. Therefore, science mapping was used in this study to analyse the sustainable transport research in 2000–2019. In addition, the reviews using the science mapping method have typically adopted either bibliometric analysis or scientometric analysis techniques (Hosseini et al., 2018b). The former focuses on the literature only while the latter is broader and evaluates the literature and their outputs through exploring the potential patterns and trends (Hood and Wilson, 2001). Hence, scientometric analysis techniques were applied in this study. Furthermore, Jin et al. (2019) suggested that in-depth discussion should be undertaken to summarize the mainstream research topics, explore the knowledge gaps and recommend for future research directions.

Several science mapping software tools have been developed to analyse and visualise patterns and trends in the literature of a scientific domain (Chen and Song, 2019). These tools include VOSviewer, BibExcel, CiteSpace, CoPalRed, etc (Cobo et al., 2011). Among these tools, CiteSpace was developed specifically for the purpose of visual analytic tasks in science mapping (Chen, 2017), capable of processing bibliographic data and detecting clusters and emerging trends in a specific domain through a series of network graphs (Chen, 2016). Hence, CiteSpace was employed in this study.

3.2. Bibliographic data collection

The bibliographic data were collected from the Web of Science (WoS) core collection database by Clarivate Analytics. This was because WoS database contains the most important and influential journals (Pouris and Pouris, 2011). In addition, the citation information in WoS has been used in the most recent round of Excellence in Research for Australia, which is Australia's national research evaluation framework. WoS has also been extensively applied in prior review articles (e.g., Li et al., 2017; Song et al., 2016).

The terms “sustainable transport”, “sustainable transportation”, “green transport” and “green transportation” are similar and thus used in the literature search. Preliminary analysis and comparison were conducted first. Then, the retrieval code was input into the WoS advanced search engine:

$TI=(\text{green OR sustainab*}) \text{ AND } TI=(\text{transport OR transportation})$

The character “*” represents a fuzzy search to capture relevant variations of a word. “TI” denotes the title of a publication. The time span of the search was 2000–2019 because this study focuses on the sustainable transport research published in the past two decades. The complete years between 2000 and 2019 were targeted.

In addition, only journal articles in English were used in this study because journal articles have been widely recognised as representative of the most influential and reputable research (Darko and Chan, 2016; Santos et al., 2017). Conference papers were excluded because they provided less rich information compared to journal articles (Jin et al., 2018). Several prior reviews in the area of construction management were primarily based on journal articles (Hosseini et al., 2018a; Wuni et al., 2019), demonstrating researchers' preferences on the journal articles.

A preliminary list of 1,308 bibliographic records were collected and were checked carefully. In the initial screening, the records, which did not fall within the research areas of engineering, building and construction, architecture, and sustainability, were excluded from the sample. In the second-round screening, the records not really related to sustainable transport were screened out. Finally, 882 bibliographic records were retained in the literature sample and exported from WoS to CiteSpace. Each record contains a list of authors and affiliations and country/region, title, abstract, keywords, year of publication, source journal and references. Each reference record included the first author's name, year of publication, source type (e.g., journals, proceedings, books, etc.), volume number and DOI reference.

3.3. Data analysis method

Scientometric analysis was applied for science mapping in this study. Scientometric analysis includes co-author analysis (authors, countries/regions and institutions co-occurrence), co-word analysis (keywords and subject categories co-occurrence) and co-citation analysis (authors, documents and journals co-citation). Given the objectives of this study, keyword co-occurrence analysis and document co-citation analysis were used in this study. These two analysis techniques can provide more extensive range of relevant research topics than the conventional manual review (Li et al., 2017).

Specifically, keyword co-occurrence analysis aims to explore the keywords that co-occur in two or more publications within a period. The keywords that have high frequency and centrality can indicate the critical research topics and development trend over a period of time. Document co-citation analysis aims to explore the intellectual structure of a scientific domain. Documents are linked in a network when they are jointly cited by subsequent documents. The documents with high co-citation frequencies tend to exert greater influence on the scientific domain (Chen et al., 2010). If multiple documents are frequently co-cited, they tend to be aggregated into clusters that address a similar scientific domain. Cluster analysis can be undertaken in CiteSpace to facilitate detecting the clusters. In addition, citation burst detection is undertaken in CiteSpace to identify the publications and keywords with a notable increase in citations over a short period. Each citation burst is an indicator of a most active research area over a period and considered as a milestone in the evolution of a scientific domain. Citation bursts can be identified using the algorithm developed by Kleinberg (2002). Furthermore, as recommended by Jin et al. (2019), in-depth qualitative discussion can supplement scientometric analysis and help to identify the mainstream research topics, explore the knowledge gaps and recommend future research directions.

4. Results

4.1. An overview

Fig. 1 indicates the number of the journal articles relating to sustainable transport published from 2000 to 2019 in the literature

sample. The past two decades have witnessed a general increasing trend of sustainable transport research. In the first 10 years of this period, i.e. 2000–2009, there were not many journal articles, and the annual number of articles was staggering between 9 and 19, which was relatively low. However, the number abruptly increased to 41 in 2010 and remained stable till 2014. Since 2015, sustainable transport research has attracted more attention and grown significantly. The number of articles has increased from 87 in 2015 to 138 in 2019. Hence, following this current trend, the research outputs in the area of sustainable transport are expected to continue growing in the forthcoming years.

Table 1 displays the top journal sources of sustainable transport research. In terms of number of articles, Sustainability and Transportation Research Record published 92 and 48 articles relating to sustainable transport and were thus ranked top and second, respectively. The third and fourth positions were occupied by Journal of Cleaner Production and International Journal of Sustainable Transportation that published 42 and 38 relevant articles, respectively. Citation has been seen as one of the key impact metrics of journal articles (Van Eck and Waltman, 2014). Total citations, average citations per article and average citations per year were used to measure the influence of journals on sustainable transport research. Total citations are highly associated with the number of articles while average citations per article is better able to show the average influence of the articles published in a certain journal. A journal publishing more articles does not necessarily receive more average citations per article. Energy Policy published 15 relevant articles that received 49.4 citations per article and thus occupied the top rank according to the average citations per article. Transport Policy and Transport Reviews attracted 29 and 258 citations per article, and were ranked second and third, respectively. In addition, average citations per year can correct the misinterpretation resulting from the fact that old articles tended to get more citations than new articles. Transport Policy received an average 63.7 citations per year, ranked top. Sustainability and Energy Policy were ranked second and third, respectively.

4.2. Keyword co-occurrence analysis

Keywords denote the core content of articles and describe the focused topics covered by a scientific domain (Su and Lee, 2010). A keyword network displays the structure of the knowledge body through showing the interrelationships and organisation of research topics (Van Eck and Waltman, 2014). In addition to the keywords provided by authors in the articles, there are the “keywords plus” identified by journals in the WoS database. Both

sources of keywords of the 882 records were applied to generate a keyword co-occurrence network, as shown in Fig. 2. The excessive links were removed from the network through network pruning and Pathfinder. This network consisted of 268 nodes and 1,504 links. Each node denoted a keyword from the 882 articles. Only the keywords with at least 10 co-occurrences are visible in Fig. 2. The label font size is proportional to the co-occurrence frequency of a keyword. The colour of the links in the network denotes a time slice of two years when the keyword co-occurrence appeared for the first time. The thickness of a link represents the link strength. In the keyword co-occurrence network, the strong links between keywords and the keyword circles are worth more attention. In Fig. 2, “energy consumption” and “vehicle” is connected by a red link, suggesting that sustainable transport researchers have published articles on the energy consumption of vehicles since 2010/2011. In addition, “emission”, “vehicle” and “energy efficiency” form a circle by red links, suggesting they are interrelated and that researchers have published articles on the relationship between energy efficiency of vehicles and emissions since 2010/2011.

In the follow-up keyword analysis, some general terms, such as “sustainable transport”, “sustainable transportation”, “green transport”, “green transportation”, “transport”, and “transportation” were removed because they were already used as the search terms and cannot contribute to the keyword analysis. Additionally, some terms with similar semantic meanings, such as “CO₂ emission” versus “greenhouse gas emission”, and “public transport” versus “public transportation”, were merged in the keyword analysis. The sum of keyword co-occurrence frequency was 2,697. The threshold of co-occurrence frequency for further analysis was set at 13, and thus 46 keywords met the threshold as shown in Table 2. The year column in Table 2 indicates the year when a keyword emerged in the sustainable transport articles for the first time.

The three most frequently used keyword terms were “sustainability”, “model” and “carbon emission” with co-occurrence frequencies of 135, 82 and 82, respectively. This suggested that the models used to assess the performance and sustainability, especially environmental sustainability, had been hotspots in sustainable transport research. “Policy”, “system”, “city”, “impact”, “public transport”, “travel behaviour” and “mobility” were also among the top 10 most frequently used terms.

To show the evolutionary trend of keywords, a timezone view of keyword co-occurrence is provided in Fig. 3. The keywords with at least 20 co-occurrences are shown in Fig. 3. The horizon axis shows the year when a keyword emerged in the sustainable transport articles for the first time. In 2000–2003, “sustainability”, “climate

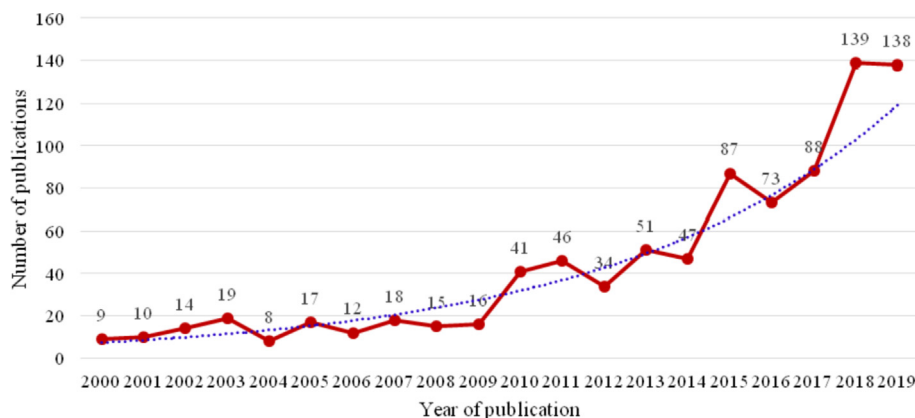


Fig. 1. The number of journal articles published in 2000–2019.

Table 1

Top journal sources publishing sustainable transport research in 2000–2019.

Rank	Journal title	No. Of articles	Total citations	Ave. citations per article	Ave. citations per year
1	Sustainability	92	396	4.3	56.6
2	Transportation Research Record	48	351	7.3	21.9
3	Journal of Cleaner Production	42	554	13.2	34.6
4	International Journal of Sustainable Transportation	38	440	11.6	31.4
5	Transport Policy	33	956	29.0	63.7
6	Transportation Research Part D-Transport and Environment	30	521	17.4	28.9
7	Transport Reviews	16	413	25.8	20.7
8	Energy Policy	15	741	49.4	41.2
9	Research in Transportation Economics	15	128	8.5	16.0
10	Journal of Transport Geography	14	352	25.1	27.1

Note: The citation statistics were from the WoS core collection database (6 January 2020).

change”, “environment” were the hot topics, suggesting that researchers focused on environmental sustainability of transport systems. In this period, “travel behaviour” also appeared, indicating that researchers began to think about how travel behaviour impacted transport sustainability. In 2004–2007, the keywords of “model”, “indicator”, and “system” emerged, indicating that STIs and models for evaluating transport sustainability attracted great attention in this period. Additionally, “city”, “emission” and “energy” were also hot topics in this period, suggesting that environmental sustainability, energy consumption and efficiency of vehicles as well as urban transport systems attracted great attention. In 2008–2009, transport policy research became a hot topic. In 2010–2011, a number of frequently cited keywords appeared, such as “impact”, “performance”, “framework”, “mobility”, etc, which indicated that the performance of sustainable transport, various sustainable transport framework, various impacts of transport systems were researched. In this period, the potentials of public transport and new-fuel vehicles in reducing emissions and improving transport sustainability began to be highlighted. In 2012–2019, only “management”, “governance” and “logistics” frequently appeared in articles. This is because more recent keywords tend to get lower frequency. In addition to these three keywords, “biofuel”, “mode choice”, “life cycle assessment”, “determinant”, and “accessibility” emerged in 2012–2013; “optimisation”, “network”, “selection”, “quality” and “consumption”

appeared in 2014–2015; and “supply chain management” and “efficiency” appeared in 2016–2017 (see Table 2).

The 46 main keywords in Table 2 can be categorised into the following six groups. These groups are correlated with each other but not standing alone because they are all under the umbrella of sustainable transport.

- 1) Sustainability and performance model: Various models have been developed to assess sustainability and performance of transport infrastructures with considerations into various indicators or criteria (Barradale and Cornet, 2018; Ekener et al., 2018; Guimaraes and Leal, 2017).
- 2) Environmental impact: The transport sector accounts for a significant amount of GHG emissions, fuel and power consumption and environmental externalities, which further lead to climate change (Demir et al., 2014; Feitelson, 2002).
- 3) New fuels for vehicles: Vehicles using clean and sustainable fuels, such as bio-ethanol, bio-diesel, biogas, compressed natural gas, hydrogen and electricity, have been researched for the purpose of reducing GHG emissions and negative environmental externalities (Al-Rousan et al., 2018; Doll and Wietschel, 2008).
- 4) Transport policy: Sustainable transport requires relevant policies regarding various aspects that include but are not limited to: land use, uptake of new fuel vehicles, public transport,

Table 2

Main keywords with co-occurrence frequency.

Rank	Frequency	Year	Keyword	Rank	Frequency	Year	Keyword
1	135	2001	Sustainability	24	25	2010	Choice
2	82	2006	Model	25	21	2003	China
3	82	2004	Carbon emission	26	20	2016	Logistics
4	78	2008	Policy	27	20	2014	Governance
5	72	2005	System	28	18	2015	Optimisation
6	62	2004	City	29	18	2015	Network
7	59	2011	Impact	30	17	2012	Attitude
8	57	2010	Public transport	31	17	2015	Infrastructure
9	55	2002	Travel behaviour	32	17	2010	Demand
10	52	2010	Mobility	33	17	2013	Accessibility
11	51	2004	Sustainable development	34	17	2016	Efficiency
12	50	2006	Indicator	35	17	2014	Consumption
13	48	2012	Management	36	17	2012	Life cycle assessment
14	45	2010	Vehicle	37	16	2014	Quality
15	45	2004	Energy	38	16	2014	Selection
16	43	2011	Urban transport	39	16	2010	Strategy
17	42	2011	Performance	40	15	2012	Determinant
18	33	2002	Climate change	41	15	2010	Growth
19	32	2016	Supply chain management	42	15	2012	Cost
20	29	2011	Framework	43	14	2012	Biofuel
21	29	2002	Environment	44	14	2008	Walking
22	28	2010	Design	45	14	2012	Mode choice
23	27	2004	Land use	46	13	2012	Perception

social engagement, transport planning and design, public attitude, as well as environmental impact (Eliasson and Proost, 2015; Gudmundsson, 2003).

- 5) Supply chain and logistics management: Transport is highly associated with supply chain and logistics, and thus sustainability of supply chain and operations of logistics service providers (LSPs) have attracted significant research attention (Dubey et al., 2017; Nilsson et al., 2017).
- 6) Travel behaviour: Travel behaviour and transport mode choice have significant influence on the sustainability of transport systems (Schneider, 2013), but the influence is mediated by various factors, such as transport policies, car ownership, household income, age (Mattioli, 2014), culture, travel distance (Cattaneo et al., 2018), and weather conditions (Kim and Macdonald, 2016).

4.3. Document co-citation analysis

4.3.1. Top cited articles

Citation is an indicator that shows the impact of an article in a research field. The research directions of frequently cited articles tend to be consistent with hot research themes. The top 20 cited articles are presented in Table 3. The citation statistics were collected from the WOS database in August 2019. As for the total citations, the top three articles by Holden and Norland (2005), Offer et al. (2010) and Jeon and Amekudzi (2005) received 220, 214 and 176 citations, respectively. Specifically, Holden and Norland (2005) undertook a survey in Oslo on the relation between characteristics of land use and energy consumption of travel and housing. Holden and Norland (2005) found that the people living in highly densified areas consumed less energy in daily travel but more energy in leisure-time travel by airplane. Offer et al. (2010) compared technological and infrastructural requirements as well as lifecycle costs among three types of new-fuel vehicles, indicating that hydrogen fuel cell plug-in hybrid vehicles and battery electric vehicles could achieve much lower lifecycle costs and that all the three types had cost sensitivity to powertrain capital cost. Jeon and Amekudzi (2005) reviewed global major initiatives to define and measure transportation sustainability and suggested their indicator systems were developed based on the cause-and-effect relations between infrastructure and environment, the influence of agencies over causal factors, as well as the influence of infrastructure on the environment, social benefits and economy.

More recent articles tend to get fewer total citations than earlier ones but may receive more citations per year. In terms of citations per year, Offer et al. (2010), O'Brien et al. (2014) and Elvik (2009) were the top three articles. O'Brien et al. (2014) analysed global bicycle sharing systems and proposed a classification approach on the basis of the spatial and variations in occupancy rates as well as

the geographical footprint. Elvik (2009) focused on the injury risk factors to cyclists and pedestrians and indicated large transfers of trips from motor vehicles to cycling or walking resulted in fewer traffic accidents. Fig. 2.

4.3.2. Document co-citation network

In the references of the 882 targeted articles, there were 32,758 documents in the references, which were not necessarily included in the 882 articles. The top 10% most cited documents in each time slice (i.e. two years) were used for document co-citation analysis and cluster analysis. A document co-citation network is shown in Fig. 4. The network contained 671 nodes and 2,258 links. Every node represents a publication with the first author's name and the publication year. The links between nodes represent co-citation relations between two documents. The node documents with at least five co-citations are made visible. The label font size is proportional to the co-citations of a document. Fig. 4 shows that a number of documents have co-citations with each other. For instance, Santos G (2010), Ewing R (2010) and another 17 articles have received co-citations from each other since 2012/2013, thus forming several circles. This suggested that these articles have similar research topics. In terms of the link colours, few are in purple and blue that are mapped to the period of 2000–2007 and most links are in yellow and orange. This indicated that a majority of the document co-citations emerged after 2010, when the number of sustainable transport articles started to soar.

The top three co-cited articles were published by Haghshenas and Vaziri (2012), Banister (2008) and Castillo and Pitfield (2010), which received 35, 27 and 21 co-citations, respectively. Haghshenas and Vaziri (2012) and Castillo and Pitfield (2010) focused on sustainable transport indicators (STIs). Haghshenas and Vaziri (2012) developed a sustainable transport composite index integrating nine STIs and compared various cities using this index, while Castillo and Pitfield (2010) proposed a method to identify and select a small subset of STIs. Banister (2008) focused on changing the existing travel paradigm with necessary policy measures.

4.3.3. Citation bursts

Citation bursts were detected in ten publications, as shown in Table 4. The strongest burst was associated with Newman and Kenworthy (1999) (burst strength = 6.65, 2003–2007), which identified a wide range of sustainability indicators, illustrated how cities around the world solved the problem of automobile dependence and explored the interactions among transport, water use, cycling, waste management and urban landscape. Another burst was related to Banister (2005) (burst strength = 3.19, 2007–2013), which analysed the global issues associated with transport, energy use, policies as well as institutional and organisational barriers to change, and examined the link between transport and sustainable urban development at the city level.

Table 3
The top 20 cited articles on sustainable transport in 2000–2019.

No.	Article	Citation	Citation per year	No.	Article	Citation	Citation per year
1	Holden and Norland (2005)	220	14.7	11	Yedla and Shrestha (2003)	112	6.6
2	Offer et al. (2010)	214	21.4	12	Awasthi and Chauhan (2011)	107	11.9
3	Jeon and Amekudzi (2005)	176	11.7	13	Sim et al. (2007)	105	8.1
4	Elvik (2009)	171	15.5	14	Haghshenas and Vaziri (2012)	100	12.5
5	Kenworthy (2006)	163	11.6	15	Black et al. (2002)	99	5.5
6	Bertolini et al. (2005)	163	10.9	16	Akerman and Hojer (2006)	95	6.8
7	Zhao (2010)	153	15.3	17	Shiftan et al. (2003)	95	5.6
8	Agrawal et al. (2007)	142	10.9	18	Gerbens-Leenes et al. (2012)	84	10.5
9	O'Brien et al. (2014)	114	19.0	19	Castillo and Pitfield (2010)	79	7.9
10	Hull (2008)	112	9.3	20	Litman (2007)	77	5.9

Note: The citation statistics were from the WoS core collection database (6 January 2020).

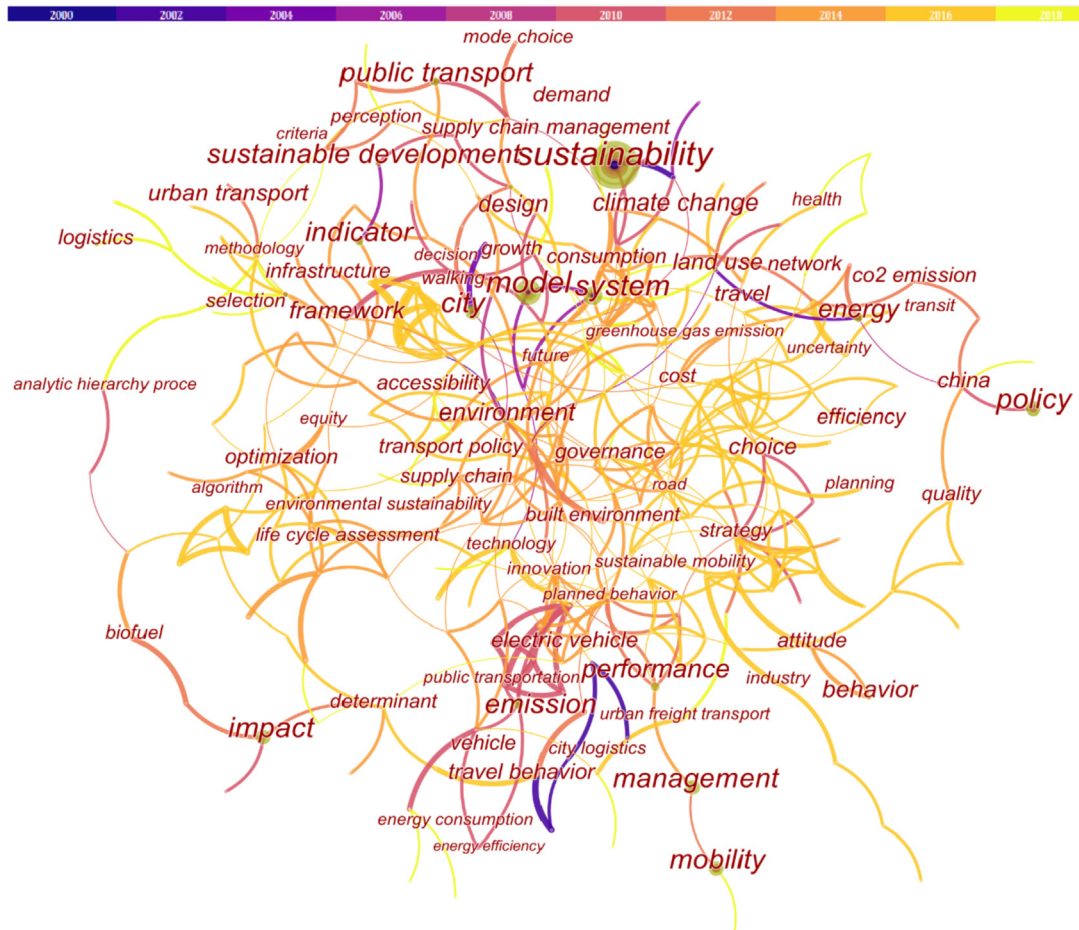


Fig. 2. Keyword co-occurrence network.

A total of four bursts started in 2010. [Jeon and Amekudzi \(2005\)](#) (burst strength = 6.09, 2010–2013) and [Richardson \(2005\)](#) (burst strength = 3.46, 2010–2013) explored the indicator systems of sustainable transport. The former article focused on the interactive relations between transport infrastructure and environment, while the latter examined the interaction between factors influencing the sustainability of passenger and freight transport.

Changes in various aspects are necessary to achieve sustainable transport in practice. [Banister \(2008\)](#) (burst strength = 5.38, 2010–2015) proposed a change in transport paradigm to achieve sustainable mobility and affirmed that the conditions necessary for the change should be assured through taking policy measures. Changes are also required in the way people think about transport problems, as suggested by [Litman and Burwell \(2006\)](#) (burst



Fig. 3. A timezone view of keyword co-occurrence in 2000–2019.

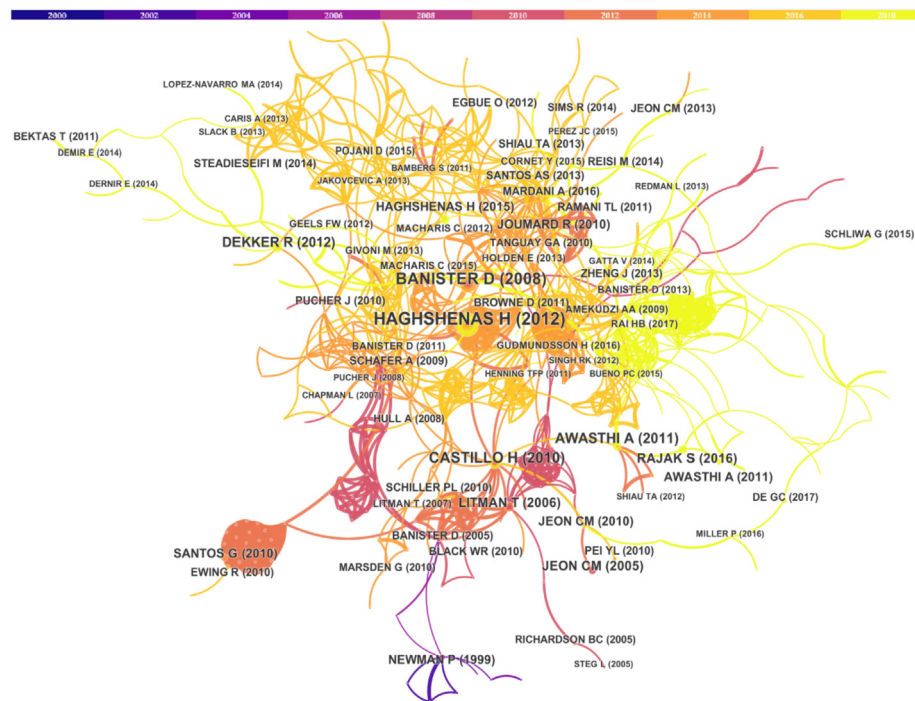


Fig. 4. Documents co-citation network

strength = 5.06, 2010–2014), which discussed the significant issues relevant to sustainable transport, including the narrow and broader definition of sustainable transport, sustainability analysis, decision making, automobile dependency, and approaches to sustainable transport.

Changes in the behaviour of companies and individuals are influenced by policy instruments. The burst led by Santos et al. (2010) (burst strength = 3.70, 2013–2015) categorised policies for sustainable road transport into three groups: physical policies (e.g., land use, public transport, walking and cycling, freight transport, etc.), soft policies (e.g., car sharing and pooling, eco-driving, advertising campaigns, teleworking and teleshopping, etc.) and knowledge policies (e.g. research and development). Individual policy instrument was not enough, and it was necessary to integrate various policies to address challenges of achieving sustainable transport.

The burst related to Litman (2007) (burst strength = 3.19, 2014–2015) addressed how to select indicators for sustainable transport planning and recommended to adopt the indicators covering environmental, economic and social objectives in a balanced manner. The most recent burst was related to Awasthi et al. (2011) (burst strength = 3.53, 2017–2019), which still focused on the decision-making process in evaluation and selection of sustainable transport systems. Another most recent burst was associated with Haghshenas et al. (2015) (burst strength = 3.40, 2017–2019), which analysed impacts of transport policies and proposed a composite index combining the selected STIs to analyse the sustainability of the transport system a historic city. Therefore, in the past two decades, the STIs and decision-making methods for assessing sustainability of transport systems have attracted consistent attention from researchers and industry practitioners. In addition, transport (Awasthi et al., 2011)policy research also

Table 4
Top ten references with the strongest citation bursts.

References	Strength	Begin	End	2000–2019
Newman, P. W. G., Kenworthy, J., 1999. Sustainability and Cities: Overcoming Automobile Dependence. Island Press, Washington, DC.	7.19	2003	2007	
Banister, D., 2005. Unsustainable Transport. Talyor & Francis, London.	3.37	2007	2013	
Jeon, C. M., Amekudzi, A., 2005. Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. Journal of Infrastructure Systems 11(1), 31–50.	6.44	2010	2013	
Banister, D., 2008. The sustainable mobility paradigm. Transport Policy 15(2), 73–80.	6.18	2010	2015	
Litman, T., Burwell, D., 2006. Issues in sustainable transportation. International Journal of Global Environmental Issues 6(4), 331–347.	5.40	2010	2014	
Richardson, B. C., 2005. Sustainable transport: analysis frameworks. Journal of Transport Geography 13(1), 29–39.	3.21	2010	2013	
Santos, G., Behrendt, H., Teytelboym, A., 2010. Part II: Policy instruments for sustainable road transport. Research in Transportation Economics 28(1), 46–91.	4.76	2013	2015	
Litman, T., 2007. Developing indicators for comprehensive and sustainable transport planning. Transportation Research Record 2017(1), 10–15.	3.25	2014	2015	
Haghshenas, H., Vaziri, M., Gholamialam, A., 2015. Evaluation of sustainable policy in urban transportation using system dynamics and world cities data: A case study in Isfahan. Cities 45, 104–115.	3.40	2017	2019	
Awasthi, A., Chauhan, S. S., Omrani, H., 2011. Application of fuzzy TOPSIS in evaluating sustainable transportation systems. Expert Systems with Applications 38(10), 12270–12280.	3.53	2017	2019	

Table 5

Top co-citation clusters of sustainable transport research 2000–2019.

Cluster ID	Size	Silhouette	Mean year	Cluster Label (LLR)	Alternative label
#0	69	0.719	2011	Indicator	Multi-criteria analysis; non-linear modelling
#1	69	0.821	2012	China	Norm activation model; adoption
#2	49	0.877	2009	Aviation	Transportation justice; transport governance
#3	46	0.765	2014	Bicycle	Sustainable freight transportation systems
#4	40	0.897	2010	Participation	Life cycle assessment
#5	32	0.903	2012	Supply chain management	Transport efficiency; intermodal transport
#6	30	0.931	2011	Urban freight transport	Transport assessment; decision support systems
#7	27	0.907	2013	Supply chain network design	Mathematical model
#8	25	0.907	2010	Strategic planning	Traffic; impact assessment
#9	24	0.996	2009	Sustainable transportation policies	Trip-based and activity-based travel demand modelling

attracted great attention hot in the periods of 2013–2015 and 2017–2019.

4.3.4. Cluster analysis

Cluster analysis, as a data mining technique, can be used to detect significant research topics and contents (Wilks, 2011) and divide a large number of publications into manageable units. A total of 18 co-citation clusters were detected. Each cluster represent a research topic in the field of sustainable transport.

The size of a cluster equals to the number of publications in a cluster. The top 10 co-citation clusters with more than 20 members are presented in Table 5. The silhouette score ranging from -1 to $+1$ was applied to check the homogeneity of members within a cluster (Rousseeuw, 1987). A high silhouette score indicates high consistency among the members. The silhouette scores of the top 10 clusters ranged from 0.996 to 0.719, showing a good homogeneity of members within each cluster.

The label of a cluster can be identified from the noun phrases in titles, keywords and abstracts of the cluster member publications through various algorithm. The loglikelihood ratio (LLR) algorithm aims to compare goodness of fit between two models, by comparing the likelihood of finding a term in a cluster with that of finding the same term in another cluster. This method was used to select labels for clusters because it assures the uniqueness of labels and homogeneity within a cluster (Chen et al., 2010) and has been widely used in researches of a similar nature (Li et al., 2017; Si et al., 2019; Song et al., 2016).

Both cluster #0 “indicator” and cluster #1 “China” had 69 members and were the largest clusters. Cluster #0 represented the research efforts to develop indicators systems for quantifying transport sustainability. Indicators are variables or criteria used to measure progress towards an objective (Haghshenas and Vaziri, 2012). STIs are the regularly updated performance measures, which help transport planners and managers to consider the environmental, social and economic impacts of their decisions (Lee et al., 2003). In this cluster, the representative publication by Haghshenas and Vaziri (2012) summarised the studies presenting urban STIs and categorised the STIs into environment, social and economic impact indicator groups. Joumard and Gudmundsson (2010) presented 10 criteria for selecting STIs and categorised them into three groups, i.e. representation, operation and policy application.

Cluster #1 was labelled “China” with alternative labels “norm activation model” and “adoption.” China is experiencing acceleration of urbanisation and consequent environmental problems resulting from motorised urban transport and increasing private car ownership. In this cluster, the representative publication by Liu et al. (2017) proposed a method to predict the intention of Chinese urban residents to reduce car use on the basis of the norm activation model and theory of planned behaviour. Liu et al. (2017) found that the perceived norm of car transport reduction, attitude

towards the reduction, and perceived behaviour control over the reduction influenced the intention to reduce car transport.

Cluster #2 “aviation” had 49 members. Aviation or air transport heavily relies on non-renewable fuels, and contributes to GHG emissions (Forsyth, 2011). Thus, Janic (2018) explored the potential of using renewable fuels, such as biomass-derived synthetic paraffinic kerosene and liquid hydrogen fuels, in air transportation to reduce direct carbon emissions in future and reported that using the liquid hydrogen fuel would almost immediately bring significant reduction of the cumulative carbon emissions.

Cluster #3 “bicycle” represented an environment-friendly and sustainable transport mode. Cycling has a high spatial penetration rate and efficiency over short distances. Bicycle sharing can address the “the last mile” travel in dense urban areas and benefit users in terms of finance and health (O'Brien et al., 2014; Shi et al., 2018). Electric bicycles are an emerging technology that transforming urban transportation. Lin et al. (2018) examined the characteristics and attitudes of electric bicycle users through a survey and reported that electric bicycles enabled mobility-dependent lifestyles but would not displace the motorised modes.

Cluster #4 “participation” represented the involvement of relevant stakeholders or the public in the process of transport planning or policy making. Integrating sustainability considerations into the process of transport set new demands for the transport appraisal process and make the relevant decision making more complex. Allowing for stakeholders' participation in the sustainable transport appraisal process can effectively support the decision making activities (Barfod, 2018; Gil et al., 2011) and has been recognised as a way to promote sustainable transport (Buehler et al., 2015; Sagaris, 2010).

Cluster #5 “supply chain management”, cluster #6 “urban freight transport” and cluster #7 “supply chain network design” were all relevant to supply chain and logistics despite different focuses. The representative publication by Bai et al. (2017) integrated economic and environmental criteria as well as vehicle performance into a sustainable transport fleet evaluation framework and developed an approach to evaluating and selecting fleet alternatives using the rough set theory and VIKOR method; Bask and Rajahonka (2017) discussed the role of intermodal transport and environmental sustainability in the selection of transport modes; and Golcic et al. (2010) revealed that companies should acknowledge the problem, build an environment-aware culture and impact supply chain practices before incorporating GHG emission reduction into their transportation in supply chain.

Cluster #8 “strategic planning” denotes the research efforts on the strategic planning of transport infrastructure. In this cluster, Lopez and Monzon (2010) developed a GIS-based multi-criteria assessment model for strategic transport planning whose criteria covered environmental, social and economic sustainability. In their model, the performance of each alternative in each criterion was measured by the value of the one of the six indicators, including

network efficiency, cross-border integration, regional cohesion, social cohesion, global warming and habitat fragmentation. Ramani et al. (2011) proposed a multi-criteria decision-making model, which evaluated 12 performance indicators and calculated sustainability index values, linked to strategic planning goals of government transport departments.

Cluster #9 “sustainable transport policies” represented research efforts on policies for sustainable transport. A number of articles have focused on transport policies, covering land use issues (Reisi et al., 2016), carbon emission reduction (Trappey et al., 2012), public transport (Tang and Lo, 2008), transport planning (Schwedes et al., 2017), uptake of new fuel vehicles (Tseng et al., 2013), etc. Positive policies have been well recognised as a driver for sustainability in transportation (Santos et al., 2010) and should be running ahead of technical capacity (Lucas et al., 2007).

5. Discussion

5.1. Research topics

The similar topics in the above 10 co-citation clusters and six keyword groups were merged, producing a refined list of hot research topics in sustainable transport: 1) sustainable transport indicators and performance model, 2) sustainable transport policy, 3) involvement of stakeholders, 4) supply chain and logistics management, 5) environmental impact, 6) travel behaviour, 7) new fuels for vehicles, 8) transport strategic planning, as well as 9) bicycle and public transport. It merits attention that these topics do not stand alone but are intercorrelated with each other.

5.1.1. Sustainable transport indicators and performance model

Researchers have developed various models to assess sustainability and performance of transport infrastructures. Some researches focused on selection of STIs in terms of environmental, economic and social sustainability, whilst others developed models for transport appraisal and planning, life-cycle assessment (LCA), and selection of sustainable transport alternatives. Various multi-criteria decision-making techniques have been extensively applied in this topic. For example, Ekener et al. (2018) adopted multi-criteria decision analysis to develop a LCA model, which incorporated the results from social and environmental LCA as well as life-cycle costing; Buyukozkan et al. (2018) developed an aggregation method on the basis of intuitionistic fuzzy Choquet integral and group decision-making techniques to select sustainable transport alternatives; Barradale and Cornet (2018) proposed a framework that enabled customisation of assessment criteria in sustainable transport appraisal and identified 28 criteria that encompassed direct project impacts, indirect social impacts, and environmental impacts using this framework; and Jeon et al. (2013) presented a sustainability assessment model for transport planning through aggregating several performance measures into system effectiveness, environmental, economic, and social impacts.

5.1.2. Sustainable transport policy

A large number of articles have focused on a wide range of transport policies. Sustainable transport requires supportive policies, with considerations into public responses. Without considerations into market and public responses, the effectiveness of sustainable transport policies may be exaggerated (Eliasson and Proost, 2015). With a global perspective, if only a small number of countries take measures to reduce fuel consumption in the transport sector, spatial leakage effects and intertemporal leakage effects will become more significant (Eliasson and Proost, 2015). In addition, the role of STIs in policy making has also been investigated. Gudmundsson (2003) discussed if and how the indicator systems

contributed to achieving sustainable mobility in practice and concluded that more efforts should be made in integrating sustainability and policy targets, linking indicator systems and policy making, including causal factors, as well as managing environmental comprehensiveness. Some STIs were indeed used in the policy-making process but did not actually influence policies. Indicators tended to play symbolic, conceptual and process roles but seldom played a direct instrumental role (Gudmundsson and Sorensen, 2013). As for sustainable passenger transport policies, Holden and Linnerud (2011) indicated that the policies facilitated more use of public transport and reduced trip distances in everyday life, but unintentionally increased leisure travel, because these policies are towards an intermediate objective focused on everyday transport rather than reducing carbon emissions from all travel.

5.1.3. Involvement of stakeholders

It is necessary to undertake key stakeholder consultation or involve stakeholders in the policy making process (Cavoli et al., 2015) and the transport planning and appraisal process (Barfod, 2018; Gil et al., 2011). One stakeholder group's actions can lead to barriers for other groups (Byrne and Polonsky, 2001). Policy makers should consider opinions of different stakeholders and how a policy influences various stakeholders. Stakeholder engagement can reduce resistance to or misunderstandings of sustainable transport and contributes to self-motivated changes in travel behaviour towards sustainability. Buehler et al. (2015) indicated that citizen or stakeholder participation was one of the common strategies to promote sustainable transport in the USA and Germany. Sagaris (2014) argued that stakeholders or citizens can be recognised as planners, but not only as participants in the transport planning process, which can further innovate transport systems. In addition, personality traits of the individuals in stakeholder groups can influence their acceptance to sustainable transport policies. Kim et al. (2014) focused on the role of personality traits and found that personality traits (e.g., extraversion, agreeableness, and conscientiousness) were related to the acceptability of transport policies, providing implications for marketing transport policies.

5.1.4. Supply chain and logistics management

Transportation is a crucial factor for logistics whilst logistics is regarded as a key component of supply chain management. Sustainable supply chain, recognised as a supply chain focusing on environmental, social and economic stability for long-term sustainable growth, has become a hot topic (Dubey et al., 2017). There is indeed an overlap between sustainable transport and sustainable supply chain researches. Nilsson et al. (2017) investigated the control over carbon emissions from transport operations of European LSPs and found that the environmental policies of different LSPs appeared similar but differed in practice. Sanchez-Rodrigues et al. (2010) examined the impacts of logistics uncertainty on sustainable transport operations and recognised delays, poor information, delivery constraints and insufficient supply chain integration as impactful factors for sustainable transport operations. In addition, supply chain and logistics research tend to relate to operations research. Operations research can minimise the costs of existing processes, bring about less fuel consumption with less GHG emissions, and explore the trade-offs between environmental impact and costs (Dekker et al., 2012). Operations research played a critical role in green road freight transportation or green logistics research. Demir et al. (2014) provided a summary of the available models, including macroscopic and microscopic models, which were used to estimate fuel consumption and carbon emissions in road freight transportation, and examined routing problems in terms of fuel consumption. Lin et al. (2013) presented a review of green vehicle routing problems (VRPs) and discussed how the

traditional VRPs variants interacted with green VRPs.

5.1.5. Environmental impact

The environmental impact of transport systems has been well researched. The specific themes include but were not limited to carbon and GHG emissions, environmental impact assessment, ecological footprint, air pollutants, air pollution and climate change. For example, [Ho et al. \(2015\)](#) explored the potential of eco-driving in Singapore and found that it reduced carbon emissions by 12% in road transport and produced fuel savings of 16%; [Song et al. \(2017\)](#) attempted to assess the expected environmental costs of accessibility; [Colville et al. \(2004\)](#) attempted to evaluate the road transport sustainability regarding the exposure to air pollution from traffic through modelling the movement of air, vehicles and exhaust emissions; and [Salehi et al. \(2017\)](#) developed a method to minimise total carbon emissions with the considerations into speed control.

5.1.6. Travel behaviour

The sustainability of transport systems is significantly affected by people's travel behaviour and transport mode choice ([Schneider, 2013](#)). The sustainability can be enhanced by shifting car-driving travel to walking and bicycling ([Schneider, 2013](#)) or public transport ([Paulsson, 2018](#)). The environmental benefits of these modes relies on their substitution for car driving travel. [Piatkowski et al. \(2015\)](#) attempted to measure the substitution effect, implying that substitutive walking behaviour was highly associated with age and that bicycle substitution was predicted by weekly car trips and helmet use. In addition, the studies on travel behaviours and attitudes of the people with various socio-demographic situations tend to have great implications for sustainable transport policies. For instance, [Mattioli \(2014\)](#) found that the effects of car dependence on travel behaviour of British carless households could be either direct, or indirect, mediated by the changing composition of the carless households across various areas. The carless households in rural or peripheral areas, usually corresponding to a marginal socio-demographic situation, tended to depend on car lifts or travel less. However, in urban areas, the difference in mobility between carless and car-owning households was insignificant ([Mattioli, 2014](#)). In addition, weather conditions also influenced transport mode choice. [Kim and Macdonald \(2016\)](#) examined how wind discouraged people from walking, cycling and using public transport in San Francisco.

5.1.7. New fuels for vehicles

To meet the increasing fuel requirement and reduce environmental impacts of transport, various researches have been undertaken to explore alternative fuels of vehicles. Clean and sustainable fuels, such as biofuels converted from biomass ([Hong et al., 2019](#)), compressed natural gas, hydrogen and electricity, have attracted great attentions of researchers. For instance, [Macharis et al. \(2007\)](#) analysed the feasibility of using hybrid or electric vehicles for the transportation of containers in the pre- and post-haulage operation; [Rakshit \(2010\)](#) focused on the critical hindrances to using lignocellulosics for the production of bioethanol for transport; [Fallde and Eklund \(2015\)](#) investigated the socio-technical transitions towards sustainability through using biogas in transport; and [Al-Rousan et al. \(2018\)](#) found that injecting oxy-hydrogen gas directly into a single cylinder diesel engine enhanced the combustion efficiency and increased the brake thermal efficiency by around 17%. In addition, some researches undertook comparative analysis of various types of new-fuel vehicles in terms of fuel consumption, environmental impact, and cost ([De Souza et al., 2018](#); [Offer et al., 2010](#); [Shafiei et al., 2015](#)).

5.1.8. Transport strategic planning

Incorporating sustainability considerations into transport planning shifted transport planning objectives towards strategic policy goals, such as cohesion, network efficiency and environmental issues ([Bigotte and Antunes, 2007](#); [Journard and Nicolas, 2010](#)). Some relevant studies focused on the indicators and decision-making techniques used in the planning process. For example, [Hatefi \(2018\)](#) adopted the fuzzy complex proportional assessment method to evaluate strategic plan options of an Iranian urban transport system. In addition, strengths and weaknesses of various transport modes is also worth research as they are associated with strategic planning decisions. [Sagaris and Arora \(2016\)](#) investigate how hybrid bike-bus systems strategically contribute to sustainable transport systems. Furthermore, some studies adopted case studies to illustrate the strategic planning approach to promoting sustainable transport systems. For example, [Robèrt et al. \(2017\)](#) and [Borén et al. \(2017\)](#) focused on the Swedish project GreenCharge Southeast that aimed to achieve a fossil-free transport roadmap by 2030 highlighting the use of electric vehicles and proposed a strategic planning model for sustainable community development.

5.1.9. Bicycle and public transport

Bicycle, as a sustainable mode, has a high spatial penetration rate and efficiency over short distances. Prior studies on bicycles were diverse, covering the public attitudes towards the use of bicycle ([Acheampong, 2017](#)) and electric bicycles ([Lin et al., 2017, 2018](#)), bicycle lane planning ([Nita et al., 2018](#)), bicycle sharing systems ([O'Brien et al., 2014](#)), etc. As for public transport, studies were also diverse and covered public transport planning ([Paulsson, 2018](#)), public transport policy ([Tang and Lo, 2008](#)), financially sustainable strategies for public transport ([Xue et al., 2017](#)), etc. Public transport is expected to move large groups of commuters over medium and long distances but lacked efficiency over short distances. Thus, [Sagaris and Arora \(2016\)](#) advocated intermodality, particularly complementarity of bicycle and public transport.

5.2. Knowledge gaps and future research

5.2.1. Social sustainability

The first knowledge gap relates to the social sustainability of transport. A narrow concept of social sustainability is related to social equity, freedom, community liveability, safety, health, values, beliefs, dignity, and perceptions about society ([Griessler and Littig, 2005](#); [Litman and Burwell, 2006](#)) while a broader concept can extend to social safeguarding, social capital, social protection, social value, social cohesion, as well as social inclusion and exclusion ([Dempsey et al., 2011](#)). In the sustainable transport research published in 2000–2019, a high proportion of the articles have focused on and GHG emissions and environmental sustainability of transport. Although some studies attempted to integrate social sustainability indicators in the performance assessment model ([Ekener et al., 2018](#); [Haghshenas et al., 2015](#); [Jeon et al., 2013](#)), few researches have really focused on social sustainability of transport. [Lucas et al. \(2007\)](#) attempted to explore the direct interactions between transport interventions and social progress and identified five social indicators including poverty, accessibility, housing, safety and quality of life, which were presented to key stakeholders to solicit feedbacks. However, with the passage of time, a more comprehensive set of social sustainability indicators is still lacking.

Corporate social responsibility (CSR), as a critical aspect of social sustainability ([Zuo et al., 2012](#)), is defined as “companies’ integration of social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis” ([European Commission, 2001](#)). In the building and

construction sector, Zhao et al. (2012) presented a framework to evaluate CSR performance of construction companies while Xia et al. (2018) analysed the nexus between CSR and sustainable development with regards to environmental, social and economic dimensions. However, few researches have attempted to investigate the role of CSR in sustainable transport systems.

In addition, without careful consideration into social sustainability, adopting sustainable transport would also incur social risks. Yuan et al. (2018) highlighted the role of social risk management in securing social sustainability of transport infrastructure projects. The concept of Social License to Operate (SLO) can be introduced to the transport sector. SLO is defined as “outside of the government or legally-granted right to operate a business” (Wilburn and Wilburn, 2011). SLO is used to describe a specific aspect of company-community relationships in the mining sector. Gaining a SLO indicates that the activities of a company are accepted by the local community or society and helps to avoid conflict and social risk exposure (Prno and Slocombe, 2012). In the mining sector, adopting CSR strategies is an effective market-oriented method to gain a SLO (Mayes, 2015; Prno and Slocombe, 2012), which provides implications for the transport sector.

Therefore, to fill the knowledge gap, future research of sustainable transport would develop a comprehensive list of social sustainability indicators for transport systems, explore the CSR in the business operations within the transport sector and adopt the concept of SLO in the transport sector to proactively manage the potential social risks.

5.2.2. Use of ICT for sustainable transport

The second knowledge gap relates to using information and communication technology (ICT) for sustainable transport. The advancement of ICT allows transport systems to be more sustainable; thus, the ICT for sustainable transport is still worth more attention.

In metropolitans, traffic data are usually collected through monitoring equipment, such as roadside sensors and cameras and wireless sensor networks. Traffic data fit big data's key characteristics in terms of velocity, volume, variety, veracity, and value (Neilson et al., 2019). The traffic data can be processed and analysed. The key traffic information can be shared in a real-time manner and helps drivers to find the best routes, reducing traffic congestion, fuel consumption, carbon emissions and commute time. Hsu et al. (2015) developed a cloud-based system to collect real-time traffic conditions and driving behaviour through telematics and digital tachygraphy and roadside cameras, which incorporated a novel algorithm to diagnose misguided driving behaviour, significantly reducing fuel and power consumption in transport. In addition, big data relating to urban transport can support urban sustainable transport planning by predicting the future dynamic temporal and spatial changes (Wey and Huang, 2018) and facilitate optimising the design transport noise devices (Oltean-Dumbrava et al., 2016).

Hence, future research would develop more efficient and accurate big data analytical approaches to make better use of the massive amount of traffic data and adopt decision support systems to optimise traffic routes, guide eco-driving behaviour, reduce noise and fuel consumption. New digital platforms, data and technologies will provide transport agencies with the ability to modify their provision of services in ways more aligned with how commuters experience the transport system. An ICT-assisted and more integrated transport system would also help shape and understand the future mobility to ensure it works for the individual commuters and broader communities.

5.2.3. Understanding sustainability benefits

The third knowledge gap relates to understanding and capturing

broader sustainability benefits. Tupper et al. (2012) highlighted the need for transport agencies to evaluate the life-cycle benefits of all the potential sustainable strategy options. It is then important for transport agencies to improve their understandings and knowledge of the full economic, social and environmental benefits of transport investments and programmes, which include police-making benefits, broader economic benefits, and distributional impacts (Newman, 2015).

In addition to the government agencies, Xia et al. (2017) verified the importance of making the public aware of the perceived benefits of sustainable transport. Engaging with customers, communities and businesses will no doubt support sound strategic planning decisions for sustainable futures. A good example can be found in the study of Glazebrook (2011) that illustrated an independent public inquiry into the long-term plan for the public transport of Sydney, which aimed to raise public awareness of potential solutions and transport options.

However, given the long term and complex nature of sustainability benefits, it is difficult to predict and assess direct/indirect and tangible/intangible benefits created by transport projects. Such difficulties are currently impairing the quality of decision making and strategic planning. It is hence imperative to investigate how to predict, capture, assess, quantify and showcase different types of sustainability benefits, which can help engage with end-users and communities.

5.2.4. Resilient transport to deliver sustainability

The fourth knowledge gap relates to resilient transport to deliver sustainability. Resilience is defined as the ability of a system returning to the normal state from disadvantaged environment (Walker and Salt, 2012; Xue et al., 2018), demonstrating the adaptability and survivability of a system (McDaniels et al., 2008). Resilience is closely linked to four attributes: robustness, rapidity, resourcefulness and redundancy (Bruneau et al., 2003). Calvert and Snelder (2018) added another two attributes: reliability and vulnerability.

A variety of unexpected events such as extreme bad weather, accidents, transit outages and cyber-attacks can disrupt the operation and serviceability of transport. Resilience of transport denotes the capacity of transport infrastructures to continue operating through minor disturbances and recover quickly from major disturbance events (Kelly et al., 2015). Sustainability and resilience are compatible yet different concepts that together can achieve better outcomes in transport systems (Mejia-Giraldo et al., 2012). The transport systems that are not resilient will not deliver sustained performance. However, such integration of resilience and sustainability requires a long and thorough process with a multidisciplinary team including various stakeholders (Achour et al., 2015). Both policies and relevant incentives would be adopted to support this integration process. Therefore, a well-observed gap of knowledge exists in the design of incentives and policies, as well as the cooperation between multidisciplinary stakeholders in order to integrate resilience and sustainability in transport. Future research would further investigate the integration of resilience and sustainability of transport and consider inclusion of resilience assessment indicators in the sustainability assessment models.

6. Conclusions

The transport sector plays a key role in the human society but also greatly contributes to the global GHG emissions and fuel consumption. Sustainable transport, as a way of the transport sector to embrace the concept of sustainable development, has attracted wide attention of academics, industry practitioners and governments. Since 2000, there have been a great number of

researches undertaken in the domain of sustainable transport. However, there have been few efforts to holistically review these researches. This study aims to present a holistic review of the global sustainable transport research in 2000–2019. A total of 882 bibliographic records collected from the WoS core collection database were used in the scientometric analysis.

With considerations into citations and co-citations, the impactful researches were identified. The most cited articles (e.g., Holden and Norland, 2005; Jeon and Amekudzi, 2005; Offer et al., 2010), the articles with most annual average citations (e.g., Elvik, 2009; O'Brien et al., 2014), and the most co-cited articles (e.g., Banister, 2008; Castillo and Pitfield, 2010; Haghshenas and Vaziri, 2012) represent the most impactful research in the domain of sustainable transport.

The citation bursts in the document co-citation analysis can show the evolution of the research focuses. The early citation bursts before 2010 usually focused on the link between transport and sustainable development and link between sustainable transport and cities. Since 2010, research focuses have become diverse, including changes in transport paradigm, policy instruments for sustainable transport, decision making, sustainability analysis, and indicators for sustainable transport planning.

Regarding the keyword co-occurrence, “sustainability”, “model”, “carbon emission”, “system”, and “policy” were the top five most frequently used terms in 2000–2019. The 51 keywords were categorised into six groups, each of which represent a potential research topics of sustainable transport research, whilst 10 largest co-citation clusters were detected based on the keywords of the reviewed publications. On the basis of the six keyword groups and 10 co-citation clusters, nine hot research topics were identified: 1) sustainable transport indicators and performance model, 2) sustainable transport policy, 3) involvement of stakeholders, 4) supply chain and logistics management, 5) environmental impact, 6) travel behaviour, 7) new fuels for vehicles, 8) transport strategic planning, and 9) bicycle and public transport.

Through a qualitative analysis of the sustainable transport research, four knowledge gaps were identified regarding social sustainability of transport, use of ICT for sustainable transport, understanding of sustainability benefits and resilient transport to deliver sustainability. Therefore, future research directions would include:

- 1) Propose a comprehensive list of social sustainability indicators with considerations into the concepts of CSR and SLO. This would requires investigating the role of CSR and the nexus between CSR and social sustainability indicators for transport systems. In addition, how to secure SLO for transport projects and avoid social risks is worth further research attention as SLO is still new to the transport sector.
- 2) Develop more advanced big data analytical methods and digital platforms for sustainable transport. More traffic monitoring equipment, such as sensors and cameras, should be used to collect traffic data in a more efficient and effective way. The massive amount data should be analysed in a real-time way through more advanced analytical methods and stored in a database, in order to support decision-making process in sustainable transport planning, facilitate eco-driving behaviour, enhance experiences of commuters, drivers and communities, as well as reduce noise and fuel consumption.
- 3) Investigate how to showcase benefits of sustainable transport. This involves predicting, assessing and/or quantifying various benefits, including direct/indirect, tangible/intangible, long/short-term benefits produced by a more sustainable transport system, and identifying who will benefit from such a system. Further research would also find out how these benefits influence the public awareness of sustainable development, travel behaviour and mode choice.
- 4) Explore how to integrate resilience and sustainability in transport systems. This involves including resilience assessment indicators into the STI systems and making relevant policies regarding resilience and sustainable development. This requires attention paid to the specific demand for resilience in a specific region/country and specific weather conditions. In addition, the theoretical rationale behind integrating resilience into sustainability would also be further investigated, which may expand the theoretical framework of sustainable development.

It merits attention that this review ignored some research efforts that were not published in journals in English. Hence, only English-written journal articles included in the WoS core collection database were targeted. This is a limitation because it may exclude the most recent sustainable transport research published in other languages and conferences.

Nevertheless, this study still expands the knowledge body by presenting a holistic perspective of the global sustainable transport research published from 2000 to 2018. Using both scientometric analysis and in-depth discussion, the review method is more effective and overcomes the shortcomings cause as a result of merely relying on either subjective opinions or scientometric analysis results. This study benefits academics, industry practitioners and policy makers through providing an understanding of status quo, hot research topics, knowledge gaps and potential research directions in the domain of sustainable transport.

Declaration of competing interest

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

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